UNITED STATES PATENT AND TRADEMARK OFFICE

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BEFORE THE PATENT TRIAL AND APPEAL BOARD

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INTEL CORPORATION,

Petitioner,

v.

AX Wireless LLC,

Patent Owner.

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**DECLARATION OF JAMES L. LANSFORD, PH.D.**

I, James L. Lansford, do hereby declare the following:

1. I submit this Declaration at the request of Intel Corporation for consideration by the Patent Trial and Appeal Board in *inter partes* review proceedings.

2. I reside in Florissant, Colorado.

3. I am over eighteen years of age, and I would otherwise be competent to testify as to the matters set forth herein if I am called upon to do so.

4. I am being compensated for my time at my standard consulting rate. I am also being reimbursed for expenses that I incur during the course of this work. My compensation is not contingent upon the results of my study and analysis, the substance of my testimony, or the outcome of any proceeding involving the challenged patent or patents. I have no financial interest in the outcome of this matter or in any litigation involving the challenged patent or patents.

5. I have held numerous leadership positions in IEEE 802 over the last 25 years, including:

A. Founding Chair, IEEE 802.19 Coexistence Working Group. In this role, I was a member of the Sponsor Executive Committee (SEC), the leadership team for all of IEEE 802 (including 802.11, 802.3, and 802.15, among others).

B. Vice-chair, IEEE 802.15.2 Wi-Fi Bluetooth Coexistence Technical Group.

C. Chair, IEEE 802.11 DSRC Coexistence Tiger Team.

D. Chair, IEEE 802.11 Wireless Next Generation Standing Committee.

6. I was employed as Chief Technical Officer and Vice President of Business Development by Mobilian Corporation in Hillsboro, Oregon from February 2000 to November 2003. During my tenure at Mobilian, I was responsible for, among other things, strategy and tactics with respect to standard-setting bodies, including the IEEE, the Bluetooth special interest group, the European Telecommunication Standards Institute's Broadband Radio Access Network group (ETSI/BRAN), the Software Defined Radio forum, and the Wi-Fi Alliance (formerly known as WECA). While I was at Mobilian, I regularly attended meetings of the IEEE 802.11 and 802.15 Working Groups and was an active contributor, having posted and presented several documents to both the 802.11 and 802.15 Working Groups. I regularly accessed and reviewed documents that were submitted by members of both the 802.11 and 802.15 working groups, including through the IEEE's 802wirelessworld website discussed below. In addition, during this period, I was the founding Chair of the IEEE 802.19 Coexistence Working Group, which gave me automatic membership in the IEEE 802 Sponsor Executive Committee (SEC), the group that oversees all working group activities in IEEE 802. During this period, the

IEEE 802.11, 802.15, 802.18, and 802.19 Working Groups collaborated closely, including by holding meetings on the same dates and in the same venue, where attendees of any Working Group could and often did attend meetings of other Working Groups, by sharing the 802wirelessworld document server and website discussed below, and by awarding cross credit across Working Groups, for attending sessions of any of the Working Groups, for purposes of gaining or maintaining voting privileges.

7. I was employed as Chief Technology Officer of Alereon, Inc. in Austin, Texas from November 2003 to February 2010. During my tenure at Alereon, I was responsible for, among other things, defining and executing on the company's standards and regulatory strategy. During that time, I was also the co-chair of the IEEE 802.15.3a Task Group, chair of the WiMedia Technical Steering Committee, co-chair of the WiMedia 60GHz Study Group, chair of the WiMedia Mobile Applications Study Group, Vice-Chair of the WiMedia Video Study Group, and a member of various other related boards and working groups. During this period, the meetings of the 802.11 and 802.15 Working Groups continued to be held at the same times and places, the 802.11 and 802.15 Working Groups continued sharing document servers and websites (including initially the 802wirelessworld server and website and later the Mentor server and website discussed below), and the Working Groups continued allowing cross credit for attendance. The IEEE 802.11 and 802.15

Working Groups were also formally coordinated via a liaison.[1] Because of my role as an 802.15 co-chair, I attended every such meeting from 2004 through early 2006. During my tenure at Alereon and as co-chair of the IEEE 802.15.3a Task Group, I also continued to regularly submit documents and to access and review documents that were submitted by other members of the 802.11 and 802.15 working groups, including through the IEEE's 802wirelessworld server and through the IEEE's successor (and current) server called Mentor.

8. I was employed by CSR, plc from February 2010 to September 2015. After Qualcomm acquired CSR in September 2015, I continued working for Qualcomm through May of 2023. While I was at CSR, among other work, I was the head of CSR's Wi-Fi Alliance and IEEE 802.11 Standards teams. During that period, I was Chair of the 802.11 Wireless Next Generation Standing Committee, in addition to being an active participant, contributor, and voting member of the IEEE 802.11 Working Group. After transitioning to Qualcomm, I became a director of technical standards, where I continued as an active member of the 802.11 Working Group and also continued as chair of the IEEE 802.11 Wireless Next Generation Standing Committee, among other work.

[1] For example, see https://mentor.ieee.org/802.15/dcn/05/15-05-0473-00-0000-tgn-liaison-report-jul05.ppt which was the TGn – 802.15 liaison report for July 2005.

9. Since 2010 I have been a lecturer at the University of Colorado, Boulder, in the department of Computer Science. I have taught the Wireless Local Area Networks class in the graduate school since 2011, which is exclusively focused on IEEE 802.11 technology. Among other topics, I teach my students about the IEEE's standard setting processes, including the processes by which 802.11 Working Group participants submit and retrieve documents in order to discuss various proposals in periodic Working Group meetings. As part of those lectures, I show my students how to use the IEEE's Mentor website to find and download Working Group submissions, and we frequently review current proposals to evaluate their technical content. Students are able to browse and download submissions on Mentor without any need for a username, password or any other restrictions on access to documents.

10. I have been a member of the Institute of Electrical and Electronics Engineers ("IEEE") since 1985 (38 years) and am currently a Life Senior Member. I have participated in the activities of the IEEE Standards Association ("IEEE-SA") continuously since 2010, and before that with some breaks in voting membership. I have participated in the IEEE 802.11 Wireless Local Area Networks ("WLAN") Working Group since 1999, also with some breaks in voting membership.

11. The IEEE-SA generates standards using processes that are recognized by the International Organization for Standardization (ISO) as meeting typical standards development processes. IEEE-SA members can

participate in what used to be called Sponsor Ballots (now called SA Ballots) which is the review process for draft standards that have passed from the Task Group to the Working Group to the Sponsor Executive Committee. I have participated in several Sponsor/SA ballots over the last 13 years as an IEEE-SA member.

12. The 802.11 Working Group operates indirectly under the IEEE-SA (with the IEEE 802 SEC providing overall oversight of all 802 Working Groups), and includes several Task Groups, each of which is typically responsible for generating a single amendment which will ultimately become part of the baseline IEEE standard. The Task Groups generate draft amendments for approval by the Working Group, which the Working Group presents (indirectly) for approval by IEEE-SA using the Sponsor/SA Ballot process after approval by the IEEE 802 SEC. Task Group n (TGn), which was formed in September 2003, was one task group that operated under the 802.11 Working Group.

13. During the 2004 to 2005 timeframe, I was active as co-chair of the IEEE 802.15.3a Task Group, and attended every 802 meeting (which included meetings of the IEEE 802.11, 802.15, 802.18, and 802.19 Working Groups), posting, downloading, and reviewing submissions to the 802wirelessworld server as an active chair of an IEEE 802 Task Group.

14. During the 2004 to 2005 timeframe, the 802.11 Working Group would hold regular meetings throughout the calendar year; these meetings were

(and continue to be) held every two months, so there are a total of six meetings per year. These meetings were open to the public. The only requirement for attending these meetings was that the attendee had to pay a registration fee.[2] Generally, attendees of the 802.11 Working Group meetings were engineers, researchers, and business persons interested in networking technologies, including wireless local area networking (WLAN) technologies.

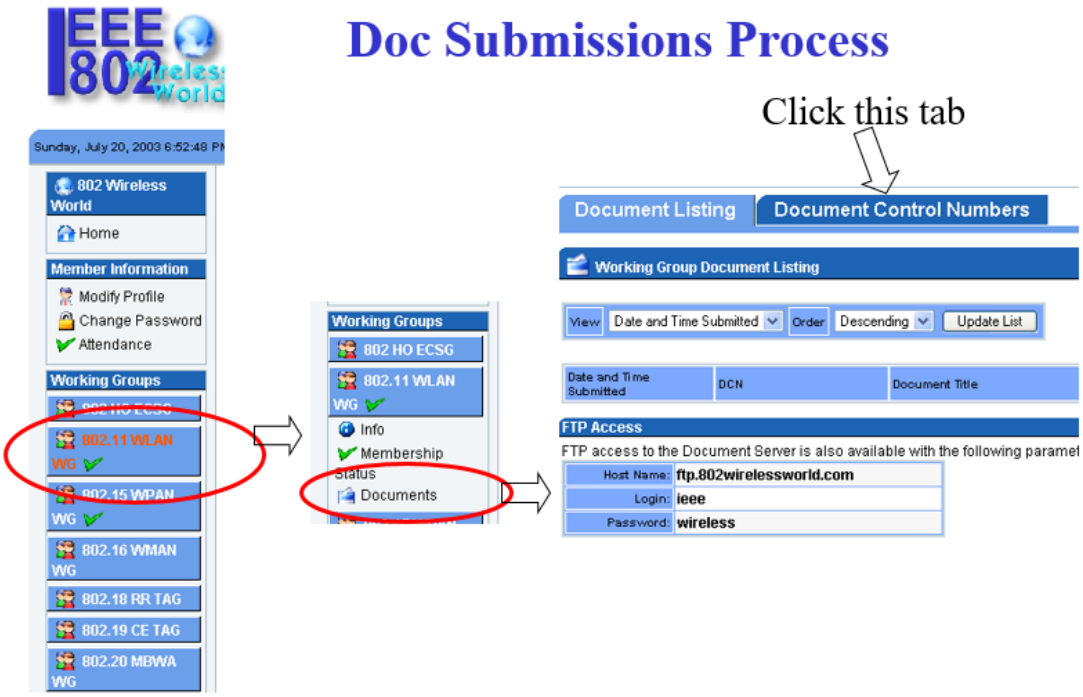
15. During the 2004 to 2005 timeframe, 802.11 Working Group members could provide submissions to the group for consideration. These submissions were presented at 802.11 Working Group meetings and were available to all participants. Submissions typically contained technical material that the group would discuss and consider whether to include in a standard.

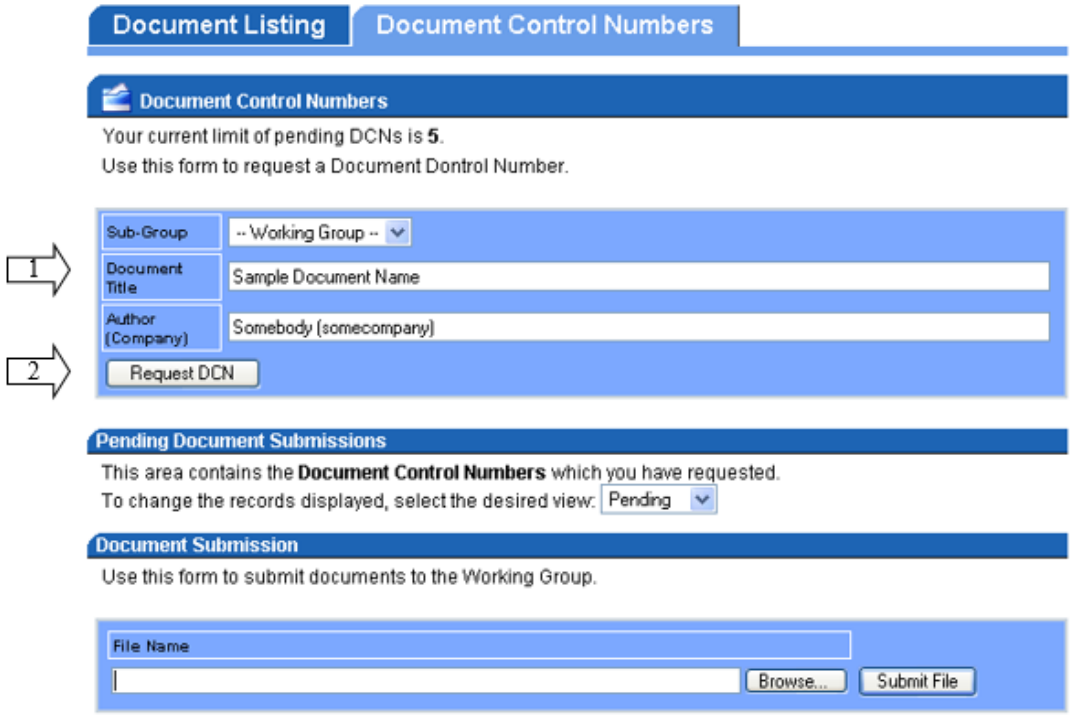
16. During this timeframe, members could make these submissions through the IEEE 802wirelessworld website.[3] The attached "New Participant Orientation" slides, which were presented at the July 2004 meeting, explain how documents were submitted via the 802wirelessworld website. New Participant Orientation Slides[4] (Appendix A); July 2004 Meeting Minutes,[5] p. 5 (Appendix B). As shown below, to submit a document, a member clicked the "Document Control Numbers" tab, entered some information about the

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[2] The registration fee can be waived for attendance by visitors.
[3] http://www.802wirelessworld.com.
[4] Available at https://mentor.ieee.org/802.11/dcn/04/11-04-0422-04-0000-new-participant-orientation.ppt.
[5] Available at http://grouper.ieee.org/groups/802/11/Minutes/Cons_Minutes_July-2004.pdf.

document, clicked the “Request DCN” button to request a document control number, and uploaded the document to the server. New Participant Orientation Slides, slides 35-37 (Appendix A). A member could submit revisions to a document using the same process. New Participant Orientation Slides, slides 35-37 (Appendix A).






17. A submission's Document Control Number provides some descriptive information about the submission. Slide 10 of the New Participant Orientation Slides (Appendix A) explains the meaning of the Document Control Numbers. Submissions were assigned a filename in the format gg-yy-sss[1]r(n)-G-HumanName.ext. The "gg" is the group (for example, "11" for 802.11), "yy" is the year the original document was submitted (for example, "04" for 2004), "sss" is a unique number sequentially assigned to each document, "l" is an optional letter for companion documents, "r" and "n" indicate the revision number (for example, "r0" indicates an original document and "r2" indicates a second revision), and "G" indicates the group to which a document is assigned. New Participant Orientation Slides, slide 10 (Appendix A). Note that slide 10 refers to the "old" document submission process that was in operation before the 802wirelessworld website was used. For documents submitted via the

802wirelessworld website, Document Control Numbers were assigned automatically by the website. New Participant Orientation Slides, slides 36-37 (Appendix A).

18. In addition to being presented at the public Working Group meetings, submissions to the Working Group were accessible to any member of the public after free registration through the 802wirelessworld website during the 2004 to 2005 timeframe. To access Working Group submissions via the website, an interested member of the public could visit the 802wirelessworld website, click the "become a member" link, enter some required contact information, and create a password. New Participant Orientation Slides, slides 25-30 (Appendix A). After creating an account, such a person could view the "Working Group Document Listing" and download any submissions that had been uploaded. New Participant Orientation Slides, slide 35 (Appendix A).

19. In addition, submissions to the Working Group were also publicly available via FTP at ftp.wirelessworld.com. After creating a free account on the 802wirelessworld website, a new user would be given the FTP server's address and instructed to use the "ieee" login with a password of "wireless." New Participant Orientation Slides, slide 35 (Appendix A). The FTP server's address and login credentials were also publicly available elsewhere. For example, U.S. Patent No. 7,415,074, which was filed on December 21, 2004 and published on July 28, 2005, refers to IEEE submission number 802.11-03/714r0 and states that it is available at "ftp://ieee:wireless@ftp.802wirelessworld.com/." U.S.

Patent No. 7,415,074, col. 1, ll. 32-39 (Appendix C). In the forgoing URL, "ieee" is the username, "wireless" is the password, and ftp.802wirelessworld.com is the domain name. My colleague Adrian Stephens also wrote a paper which was published in April 2005 in Volume 35, Issue 2 of the ACM SIGCOMM Computer Communication Review that states that "WG working group documents are available (after free registration) from: http://802wirelessworld.com." (Appendix D).

20. The IEEE now maintains a website at the address https://mentor.ieee.org/802.11/documents ("Mentor") where any member of the public can download documents submitted to the 802.11 Working Groups. The Mentor website provides a variety of bibliographic information about each document. This bibliographic information includes the document number, title, authors, and the date a document was uploaded to the IEEE's database (and made available to the public) as discussed above.

21. The IEEE's current Mentor website was established in mid-2007 to replace the 802wirelessworld website. All documents thereafter uploaded by members were available on the Mentor website. Member submissions that had been uploaded to the 802wirelessworld server prior to establishing the Mentor website were copied over to the Mentor website shortly after the Mentor website was created. I personally used the Mentor website between 2007 and 2009, including to download documents that were previously submitted using the 802wirelessworld website. These documents retained their original titles,

authors, and document number. These documents also retained their original upload dates. From the time it was first available in 2007 to the present, the Mentor website and all of the documents that it contains, have been freely available to members of the public.

22. The entries in the Mentor website can be searched and extracted by year, task group, title, or other parameters. Examples of such extractions are shown in Appendices E, H, K, M and Q. In the normal course of business of the 802.11 Working Group, these database entries and the corresponding documents would have been available to any member of the public as of the indicated upload date, through either the 802wirelessworld or Mentor websites, and the documents that were previously submitted via the 802wirelessworld website would have been available via the Mentor website in 2007, shortly after the Mentor website was put into service.

23. Appendix E shows an extract of all documents for Task Group N (TGn) with Document Control Number (DCN) 149. The last entry (bottom row) in Appendix E indicates that revision 0 of document 149 submitted to Task Group N was entitled "WWiSE Proposal: High throughput extension to the 802.11 Standard" by C. Kose (Conexant) and B. Edwards (Broadcom), and was originally uploaded to the database on March 4, 2005, at which time it would have been publicly available. This entry corresponds to the document attached as Appendix F, which I personally downloaded from the Mentor website on

June 27, 2023. Appendix F is a true and correct copy of the document I downloaded from the Mentor website.

24. The first entry (top row) in Appendix E indicates that revision 5 of document 149 submitted to Task Group N was entitled "WWiSE Proposal: High throughput extension to the 802.11 Standard" by Cenk Kose (Conexant), Matthew Fischer (Broadcom) and was originally uploaded to the database on July 9, 2005, at which time it would have been publicly available. This entry corresponds to the document attached as Appendix G, which I personally downloaded from the Mentor website on June 27, 2023. Appendix G is a true and correct copy of the document I downloaded from the Mentor website. Appendix G is a revised version of the document attached as Appendix F. I am informed that Appendix G is being submitted as Exhibit 1006 to the petition being filed by Intel.

25. Appendix H shows an extract of all documents for Task Group N in 2004 with document control number 886. The last entry in Appendix H indicates that revision 0 of document 886 submitted to Task Group N was entitled "WWiSE Proposal: High throughput extension to the 802.11 Standard" by Manoneet Singh (Texas Instruments), and was originally uploaded to the database on August 15, 2004, at which time it would have been publicly available. This entry corresponds to the document attached as Appendix I, which I personally downloaded from the Mentor website on June 28, 2023.

Appendix I is a true and correct copy of the document I downloaded from the Mentor website.

26. The first entry in Appendix H indicates that revision 6 of document 886 submitted to Task Group N was entitled "WWiSE Proposal: High throughput extension to the 802.11 Standard" by Manoneet Singh (Texas Instruments) and was originally uploaded to the database on January 6, 2005, at which time it would have been publicly available. This entry corresponds to the document attached as Appendix J, which I personally downloaded from the Mentor website on June 28, 2023. Appendix J is a true and correct copy of the document I downloaded from the Mentor website. Appendix J is a revised version of the document attached as Appendix I and an earlier version of the documents attached as Appendices F and G. I am informed that Appendix J is being submitted as Exhibit 1013 to the petition being filed by Intel.

27. Appendix K shows an extract of all documents for Task Group N containing "WWiSE" in the search field. The fifth entry in Appendix K identifies the same revision 5 of document 149 referenced above and attached as Appendix G. The second entry in Appendix K indicates that revision 1 of document 737 submitted to Task Group N was entitled "WWiSE Complete Proposal Presentation July 2005" by Sean Coffey (Realtek) and was uploaded on July 19, 2005, at which time it would have been publicly available. This entry corresponds to the document attached as Appendix L, which I personally downloaded from the Mentor website on June 27, 2023. Appendix L is a true

and correct copy of the document I downloaded from the Mentor website. Appendix L is a set of presentation slides for a presentation that was given to Task Group N by promoters of the WWiSE proposal attached as Appendix G.

28. Appendix M shows an extract of all documents for Task Group N for year 2005 containing "July" in the search field. The last entry in Appendix M indicates that revision 0 of document 557 submitted to Task Group N was entitled "Tgn July 05 Opening Report" by Bruce Kraemer (Conexant) and was uploaded on July 18, 2005, at which time it would have been publicly available. This entry corresponds to the document attached at Appendix N, which I personally downloaded from the Mentor website on June 27, 2023. Appendix N is a true and correct copy of the document I downloaded from the Mentor website. Appendix N is a set of presentation slides opening the Task Group N meetings that took place between July 18, 2005 and July 22, 2005, at the Hyatt Regency hotel in San Francisco, California. I was personally present at this IEEE event.[6]

29. The second entry on Exhibit M indicates that revision 0 of document 760 Submitted to Task Group N was entitled "Tgn July Closing Report" by Bruce Kraemer (Conexant) and was uploaded on July 22, 2005, at which time it would have been publicly available. This entry corresponds to the

[6] See IEEE P802.15-05/0427r1 dated July 18, 2005 which states "co-Chairs Gregg Rasor and Jim Lansford called the TG3a meeting to order." These were the minutes from the 802.15.3a session, which was held concurrently with the 802.11 sessions at the Hyatt Regency Hotel in San Francisco from July 18-22, 2005.

document attached as Appendix O, which I personally downloaded from the Mentor website on June 27, 2023. Appendix O is a true and correct copy of the document I downloaded from the Mentor website. Appendix O is a set of presentation slides closing Task Group N meetings that took place between July 18, 2005 and July 22, 2005, at the Hyatt Regency hotel in San Francisco, California.

30. The first entry on Exhibit M indicates that revision 0 of document 665 submitted to Task Group N was entitled "Tgn Minutes July 2005 Meeting" by Garth Hillman (AMD) and was uploaded on July 27, 2005, at which time it would have been publicly available. This entry corresponds to the document attached as Appendix P, which I personally downloaded from the Mentor website on June 27, 2023. Appendix P is a true and correct copy of the document I downloaded from the Mentor website. Appendix P is a set of meeting minutes for Task Group N meetings that took place between July 18, 2005 and July 22, 2005 at the Hyatt Regency hotel in San Francisco, California.

31. Appendix Q shows an extract of all documents from the year 2004 for Task Group N (TGn) with Document Control Number (DCN) 889. The fifth entry in Appendix Q indicates that revision 3 of document 889 submitted to Task Group N was entitled "TGnSync Proposal Technical Specification" by Aon Mujtaba (Agere Systems), and was originally uploaded to the database on January 20, 2005, at which time it would have been publicly available. This entry corresponds to the document attached as Appendix R, which I personally

downloaded from the Mentor website on June 27, 2023. Appendix R is a true and correct copy of the document I downloaded from the Mentor website. I am informed that Appendix R is being submitted as Exhibit 1012 to the petition being filed by Intel.

32. The first entry in Appendix Q indicates that revision 7 of document 0889 submitted to Task Group N was entitled "TGnSync Proposal Technical Specification" by Syed Aon Mujtaba (Agere Systems Inc.), and was originally uploaded to the database on July 8, 2005, at which time it would have been publicly available. This entry corresponds to the document attached as Appendix S, which I personally downloaded from the Mentor website on June 27, 2023. Appendix S is a true and correct copy of the document that I downloaded from the Mentor website.

33. After IEEE-SA approved a final standard for publication (after the draft passed Sponsor/SA Ballot), the standard would be copy-edited by the IEEE-SA editorial department. The purpose of this process is to catch editorial (e.g., stylistic, grammatical, linguistic and syntactic) errors not caught by the balloting participants. During this process, the copy editor engages with the Task Group editor to ensure that no changes have any technical impact.

34. After publication, IEEE standards are made available to members of the IEEE and for purchase by any member of the public. An example of one such standard is the IEEE 802.11a-1999 standard which I understand is being submitted as Exhibit 1015 to the petition being filed by Intel.

I hereby declare that all the statements made in this Declaration are of my own knowledge and true; that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. § 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

I declare under penalty of perjury under the laws of the United States of America that the foregoing is true and correct.

Executed on June 30, 2023 in Timisoara, Romania

James L. Lansford, Ph.D.

# APPENDIX A

# New Participant Orientation

IEEE 802.11 Vice-Chair

**Al Petrick**

IEEE 802.15 Vice-Chair

**Jim Allen**

IEEE 802.18 Chair

**Carl Stevenson**

IEEE 802.19 Chair

**Steve Shellhammer**

IEEE 802.20 Chair

**Jerry Upton**

IEEE 802.21 Chair

**Ajay Rajkumar**

# IEEE 802.11 Officers…Primary Roles Wireless LANs

- Stuart J. Kerry, Chairman
- Al Petrick, Vice-Chair…Attendance record and Treasury
- Harry Worstell, Vice-Chair….Documentation, Voter Database
- Tim Godfrey, Secretary ...Working Group Minutes and Wireless Network Lead.

# IEEE 802.15 Officers…Primary Roles Wireless PANs

- Bob Heile, Chairman, Documentation
- Jim Allen, Vice-Chair…
- Pat Kinney, Secretary ...Working Group Minutes
- Mike McInnis, Asst Secretary
- James Gilb, Parliamentarian
- Rick Alfvin, Webmaster/Docmaster/Attendance
- John Barr, Treasury

# IEEE 802.18 Officers…Primary Roles Radio Regulatory TAG

- Carl Stevenson, Chairman, Documentation
- Denis Kuwahara,Vice-Chair/Secretary
  - WG minutes
  - Attendance

# IEEE 802.20 Officers…Primary Roles

## Mobile Broadband Wireless Access

- **Jerry Upton, Chairman, Documentation, Voting Rights**
- **Gang Wu, Vice-Chair, Voting Tokens**
- **Rao Yalla Pragada, Secretary ...Working Group Minutes, Attendance**

# IEEE 802.21 Officers…Primary Roles

## Media Independent Handover Services

- **Ajay Rajkumar Chairman, Documentation, Voting Rights, Voting Tokens**
- **Vice-Chair, OPEN**
- **WG Secretary, OPEN**

# *IEEE-SA Standards Board Bylaws* on Patents in Standards

**6. Patents**

IEEE standards may include the known use of patent(s), including patent applications, provided the IEEE receives assurance from the patent holder or applicant with respect to patents essential for compliance with both mandatory and optional portions of the standard. This assurance shall be provided without coercion and prior to approval of the standard (or reaffirmation when a patent becomes known after initial approval of the standard). This assurance shall be a letter that is in the form of either

a) A general disclaimer to the effect that the patentee will not enforce any of its present or future patent(s) whose use would be required to implement the proposed IEEE standard against any person or entity using the patent(s) to comply with the standard or

b) A statement that a license will be made available without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination

This assurance shall apply, at a minimum, from the date of the standard's approval to the date of the standard's withdrawal and is irrevocable during that period.

Approved by IEEE-SA Standards Board – March 2003, May 2004

# Inappropriate Topics for IEEE WG Meetings

- Don't discuss licensing terms or conditions
- Don't discuss product pricing, territorial restrictions or market share
- Don't discuss ongoing litigation or threatened litigation
- Don't be silent if inappropriate topics are discussed… do formally object.

**If you have questions,**
**contact the IEEE Patent Committee Administrator**
**at patcom@ieee.org**

Approved by IEEE-SA Standards Board – December 2002

# General Information

- Meetings governed by Roberts Rules of Order. latest edition
- Meetings operated under published IEEE 802 and IEEE 802.11/.20 Policies and Procedures
  - IEEE 802.11 Policies and Procedures
    - document: IEEE 802.11-00/331r7 (on the 802.11 Website)
  - IEEE 802.15 Policies and Procedures
    - document: 99001r6P802-15_Policies and Procedures
  - IEEE 802.20 Policies and Procedures
    - document: 802.20 – PD -05
  - Participation and Representation
  - Individual representation and voting…. Not by company!!!!
  - Open participation with conference fee
  - www.IEEE802.org/11 802.11 working group web page
  - www.IEEE802.org/15 802.15 working group web page
  - www.IEEE802.org/18 802.18 working group web page
  - www.IEEE802.org/19 802.19 working group web page
  - www.IEEE802.org/20 802.20 working group web page
  - www.IEEE802.org/21 802.21 working group web page
- Photography not permitted unless approved by WG Chair
- Audio taping of IEEE 802.11/.15 meetings is NOT allowed
- Media – Press and Analyst briefings
  - Only the 802.11/.21 Chair and Vice-Chairs are allowed to give verbal statements/interviews to the media on behalf of IEEE 802.11/.21 WG

# Old Document – Submissions for 802.11

- The file name starts with:
- File names and document format: gg-yy-sss[l]r(n)-G-HumanName.ext
- where
  - "gg" is the 802 group
  - "yy" is the last digit of the year
  - "sss" is the sequence number of the document
  - "l" is an optional letter "A" added to the document number
  - (for companion documents as a Power Point Presentation on
  - a Word document submission
  - "r" is the letter r
  - "n" is the revision number
  - "G" is the group to which the document assigned to (see above
  - in the document list)
- The human name should be as short as possible.
- (please use either a dash or underscore for the coupling letter)
- Try to avoid adding the TG in the name.
- **Example:**

  **11-01-462r8-W-New-Participant-Orientation.ppt**

See Harry Worstell – Vice Chair for document – submission numbers

# Document – Submissions for 802.15

- File names and document format: yysssrnP802-15_TGx-title.ext
- where
  - "yy" is the last digit of the year
  - "sss" is the sequence number of the document provided by the Chair
  - "r" is the letter r
  - "n" is the revision number
  - "x" is the group to which the document assigned to (see above
  - in the document list, e.g.TG3,SG3a or WG)
- The title should be as short as possible with dashes between all words.
- Try to avoid adding the TG in the name.
- **Example:**
  **01273r0P802-15_TG3-sample-document.doc**
- **Boiler Plate is available, copyright statement MUST be on all submissions.**

# Document – Submissions for 802.18

- The file name starts with:
- File names and document format: gg-yy-sss[l]r(n)-G-HumanName.ext
- where
  - "gg" is the 802 group
  - "yy" is the last digit of the year
  - "sss" is the sequence number of the document
  - "l" is an optional letter "A" added to the document number
  - (for companion documents as a Power Point Presentation on
  - a Word document submission
  - "r" is the letter r
  - "n" is the revision number
  - "G" is the group to which the document assigned to (see above
  - in the document list)
- The human name should be as short as possible.
- (please use either a dash or underscore for the coupling letter)
- Try to avoid adding the TG in the name.
- **Example:**

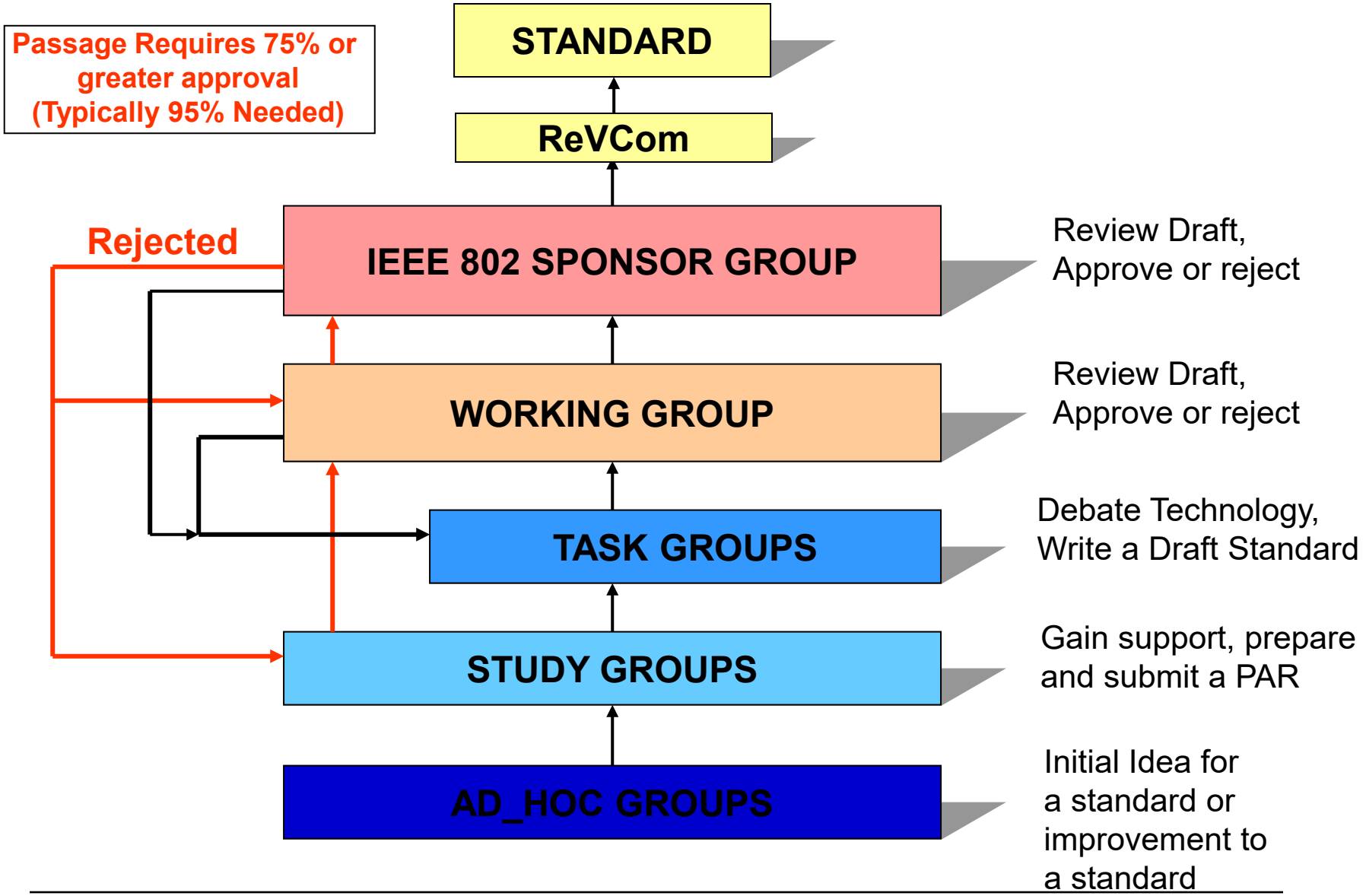
  **18-01-462r5-W-New-Participant-Orientation.ppt**

See Carl Stevenson – Chair for document – submission numbers

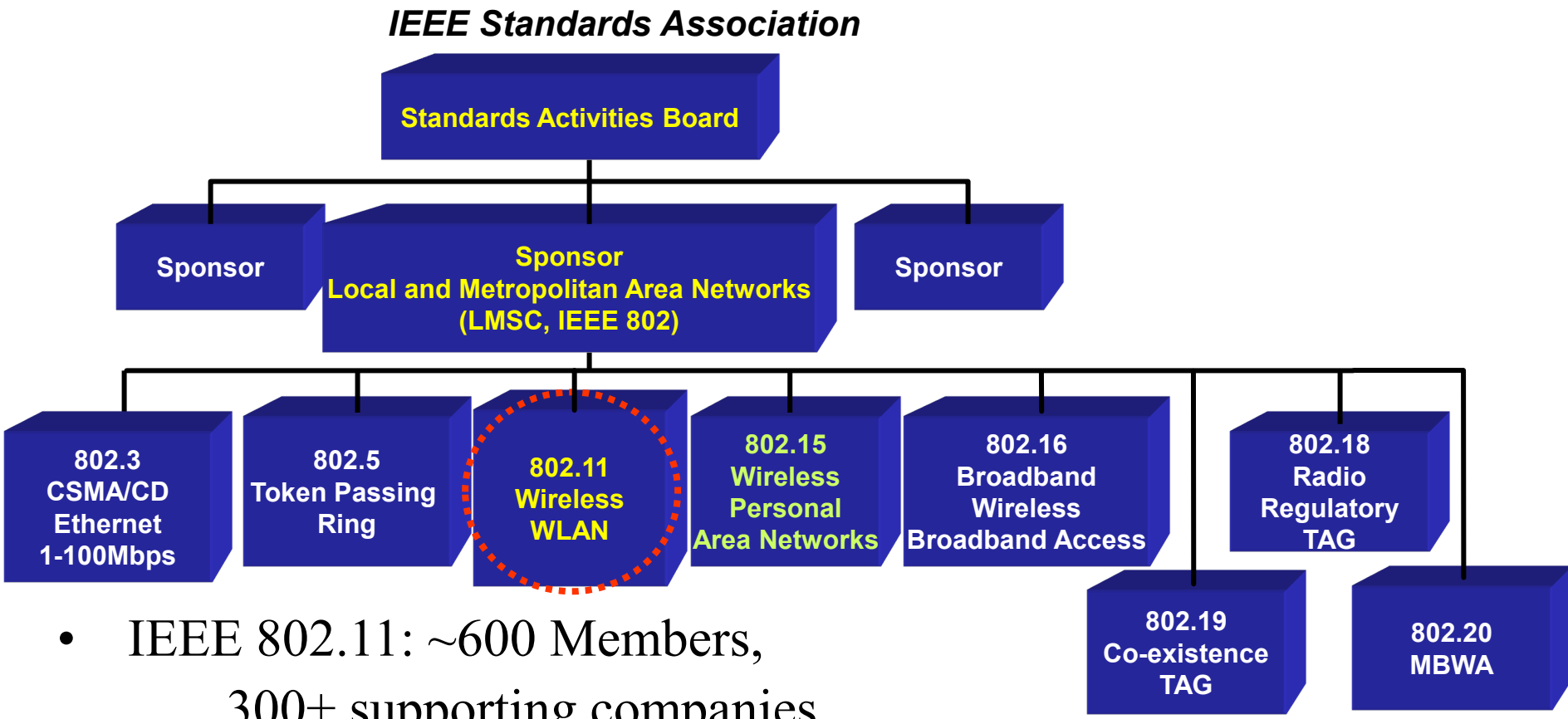
# Voting Rights

- Earned by attending and participating in meetings for each session in progress.
- Two (2) types of meeting sessions
  - Plenary:….3 sessions per calendar year (March, July, November)
    - Organized by IEEE 802
  - Interim: .. Currently 3 sessions per calendar year (January, May, September)
    - Organized by working group IEEE 802.11/.20 and sponsored by a host
- Voting rights can be earned by participation in 2 plenary sessions within 4 consecutive plenary sessions
  - One (1) Interim session may be substituted for a plenary
  - Definition of participation…..
    - Must be present in at least 75% of ALL meetings in a session
- 802.11 and 802.15 voters **attending 802.18** will receive voting credit for maintaining voting rights in 802.11 and 802.15

# IEEE 802: Standardization Process

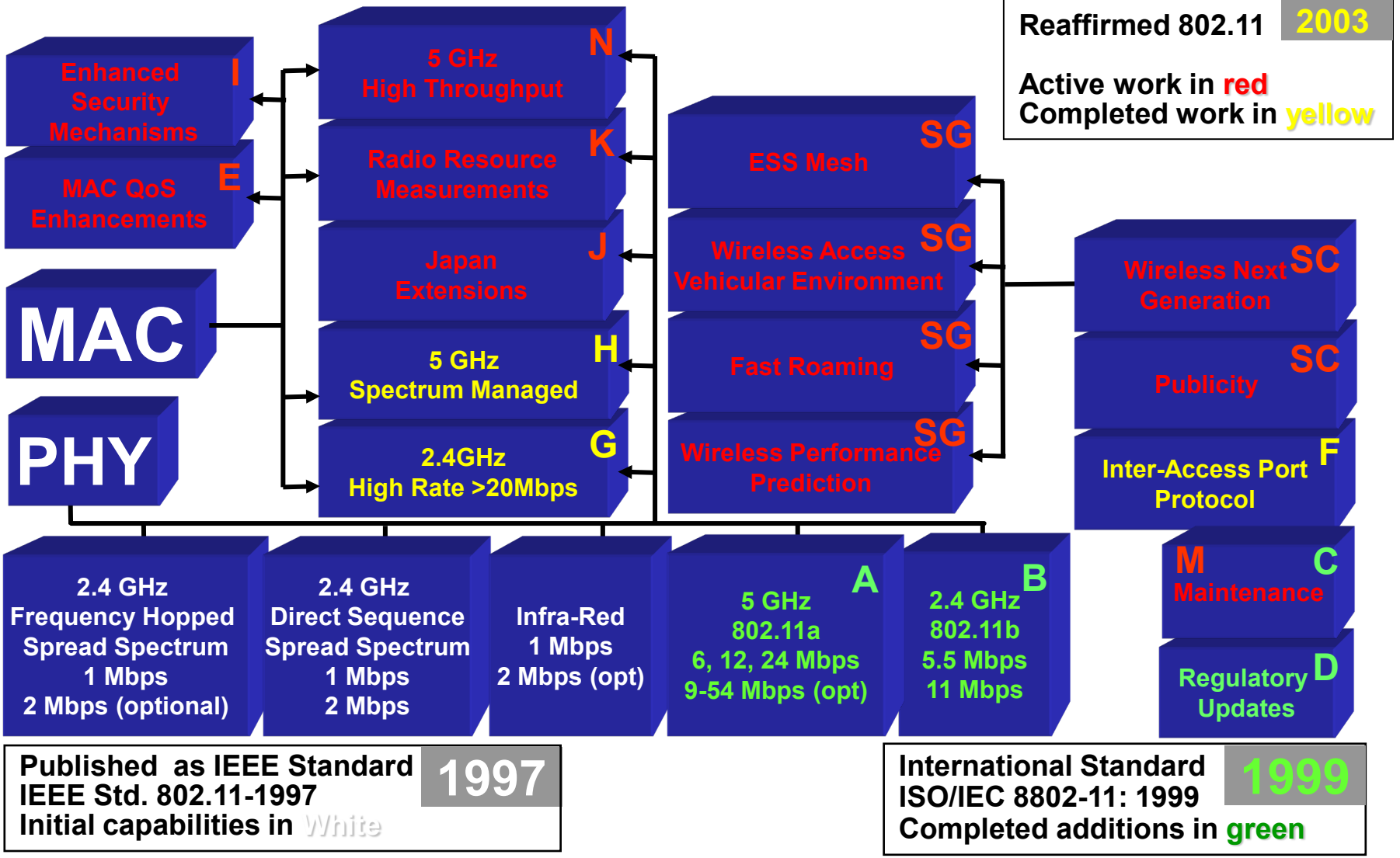


# 802.11: Standards Organization in IEEE

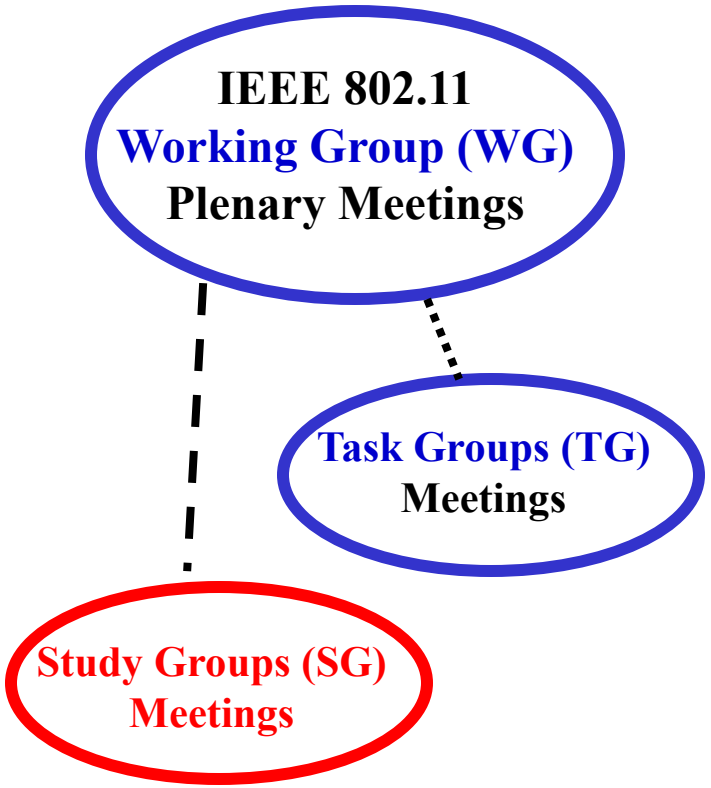



- IEEE 802.11: ~600 Members,
  300+ supporting companies
- www.ieee802.org/11

# IEEE 802.11 Architecture



# Voting Rights (cont.)

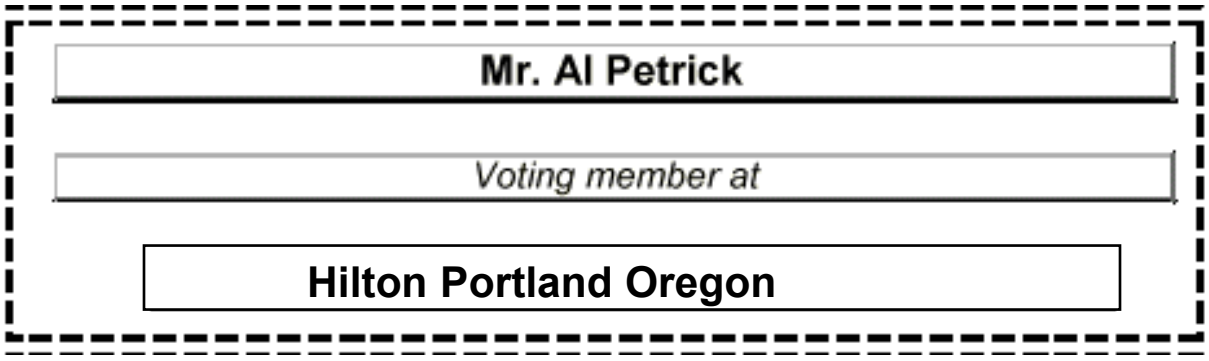



- Must be present at a session to VOTE
- Participation in debates, Motion(s) moved, seconded is only permitted by VOTING members in ALL 802.11,.15,18,19,20 meetings
- However WG & TG Chairs may permit observers/attendees to participate in debates and discussions….
- In Study Groups ALL attendees and have VOTING rights

# Voting Tokens

- Once you become a Voter, a Voting "token" will be printed for each session and can be obtained at the opening of a session, providing you have paid your attendance fee!
- Display session Badge at ALL times
- If you loose your Voting token during a session please see Al Petrick, Harry Worstell or Stuart J. Kerry for a replacement in 802.11.
  - See Rick Alfvin for 802.15 voting tokens
  - See Carl Stevenson for 802.18 voting tokens
  - See Steve Shellhammer for 802.19 voting tokens
  - See Gang Wu for 802.20 voting tokens
- Voters are required to use this "token" when a vote in progress on a Motion.

Acrobat Document

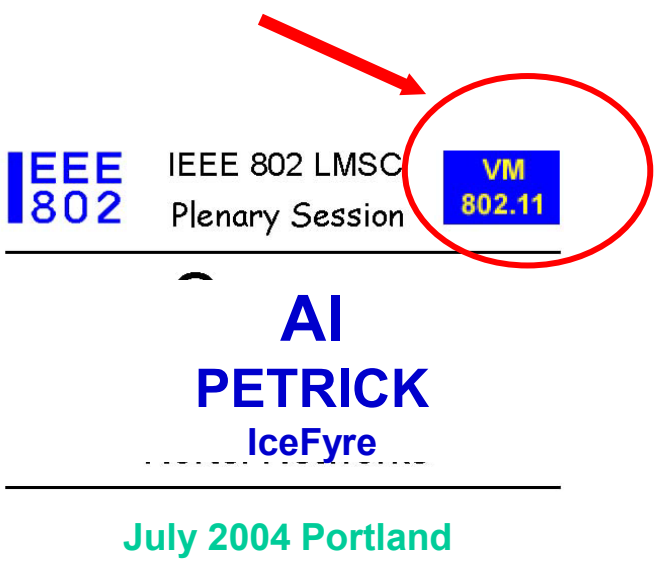


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  - See Jerry Upton for 802.20 voting tokens
- Voters are required to use this "token" when a vote in progress on a Motion.

Acrobat Document

**Registration badges are Voting Tokens for 802.11**



# Becoming a Voter

- Pay conference fee
- Provide contact/email information

→ New Participant

1st (Plenary) Meeting

→ Aspirant

2nd Meeting

•"Participate" in 75% of ALL meetings of 1st session

- Get added to the IEEE 802.11 email reflectors

→ Nearly Member

3rd Meeting

- Must attend 75% of ALL meetings of a session
- "Participate" in 2 out of 4 consecutive Plenary sessions
- However you can substitute (1) Interim for a Plenary session
- Get access to "Members Only" IEEE 802.11/.15 WG

→ Voter

- If present, at this session, you become a Voting member
- Participate in Working Group Letter Ballots
- Open to Nomination for Officers, & Chair

# Access to the Website

- When you become an "Aspirant"
  - Your email address is added to the technical reflector
    - Stds-802-11
- When you become a "Nearly Voter"
  - You get access to the "Members Only" private section of the website
    - Member ID and Password
    - Includes documents of draft standards for the "task groups

# Achieving Voting Rights

If you start on a "Interim"

| 2004 | 2004 | 2004 | 2004 |
|---|---|---|---|
| May Interim | July Plenary | Sept Interim | Nov Plenary |
| B- New Part.<br>E- Aspirant | B- Aspirant<br>E- Nearly Voter | B- Nearly Voter<br>E- Nearly Voter | B- Voter |

**B = Beginning**
**E = End**

Substitute an **"Interim"** for a Plenary
Must participate in 2 out of 4 Plenary Sessions

Note: 802.11/20 voter rights begin at the "**start**" of the plenary.

# Achieving Voting Rights

If you start on a "Plenary"

| 2004 | 2004 | 2004 |
|---|---|---|
| July Plenary | Sept Interim | Nov Plenary |
| B- New Part.<br>E- Aspirant | B- Aspirant<br>E- Nearly Voter | B- Voter |

**B = Beginning**
**E = End**

Substitute an **"Interim"** for a Plenary
Must participate in 2 out of 4 Plenary Sessions

Note: 802.11/20 voter rights begin at the "**start**" of the plenary.

# Maintaining Voting Rights

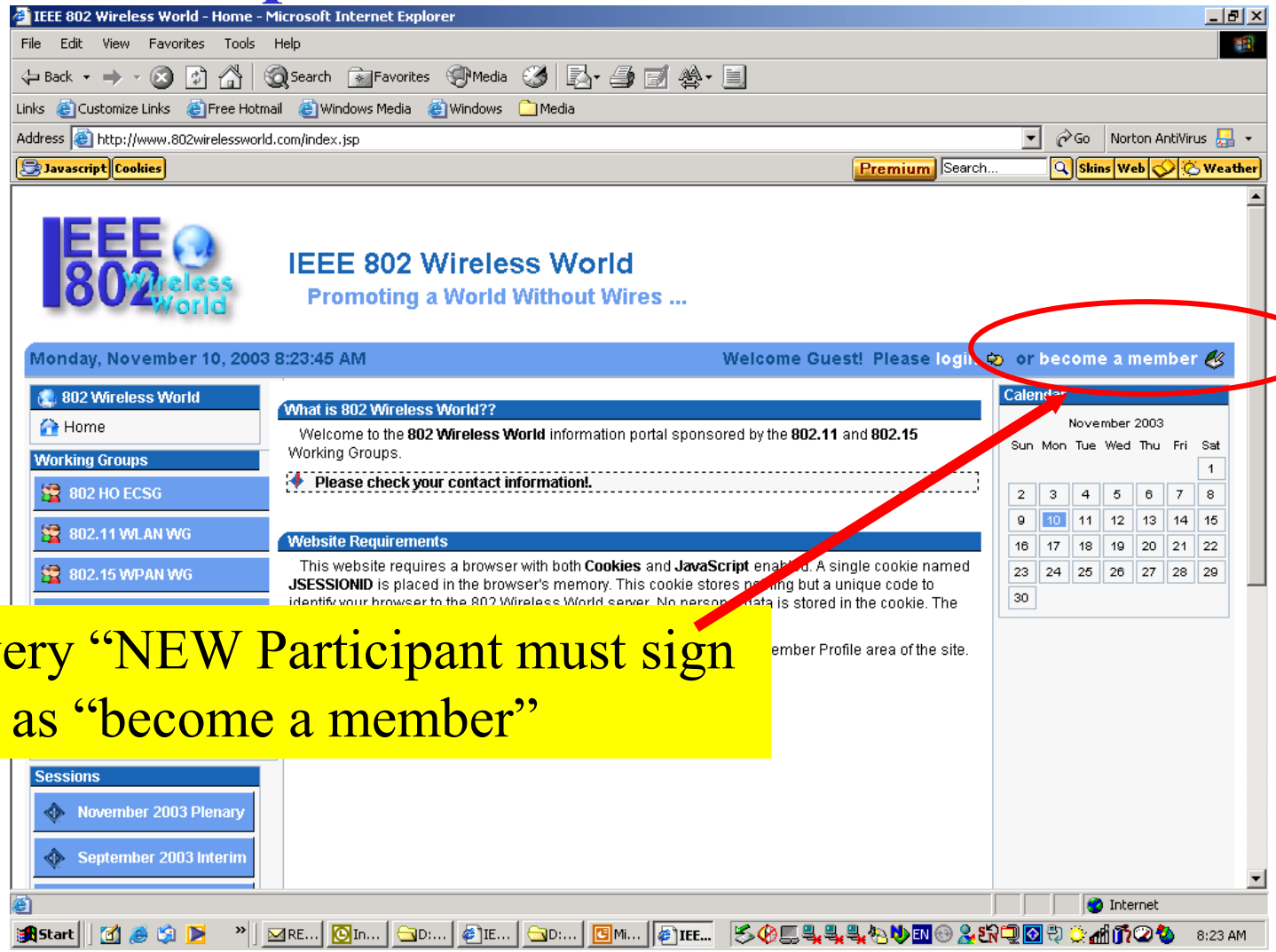
- Every voter is responsible for keeping track of their voting status as recorded on the electronic attendance server www.802wirelessworld.com
- In the Event of Discrepancies…bring it the attention of Al Petrick - 802.11, Rick Alfvin for 802.15, Carl Stevenson – 802.18, Jerry Upton - 802.20
- How to loose voting rights……

**Voter** →

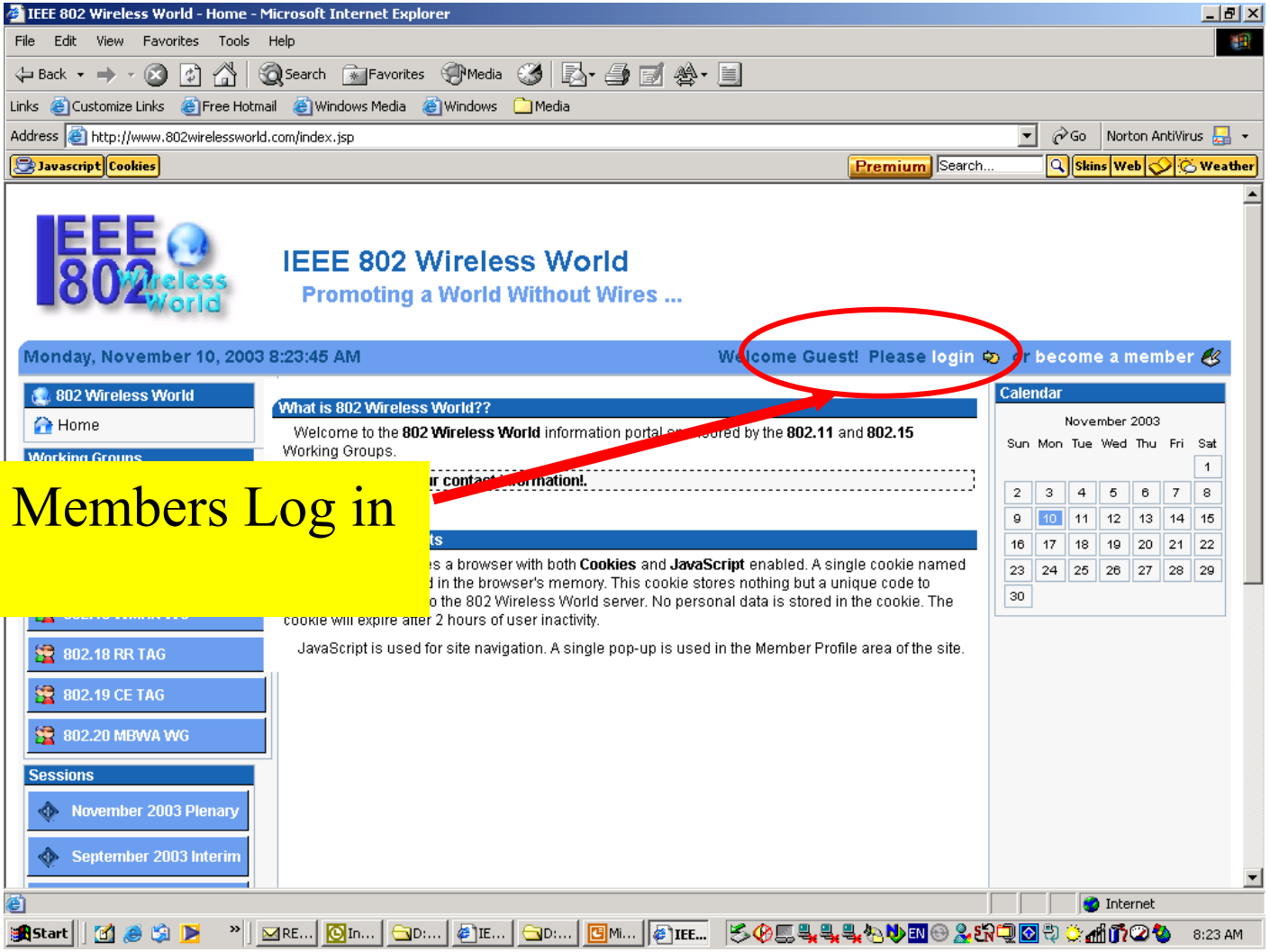
- Fail to "Participate" at least 2 out of 4 consecutive Plenary sessions
  - Participation is to attend 75% of ALL meetings within a 802.11 session
  - May substitute (1) Interim session for Plenary
- Fail to respond and vote on 2 out of 3 mandatory working group letter ballots
- Fail to pay either Interim or Plenary conference fees

← **Non-Voter**

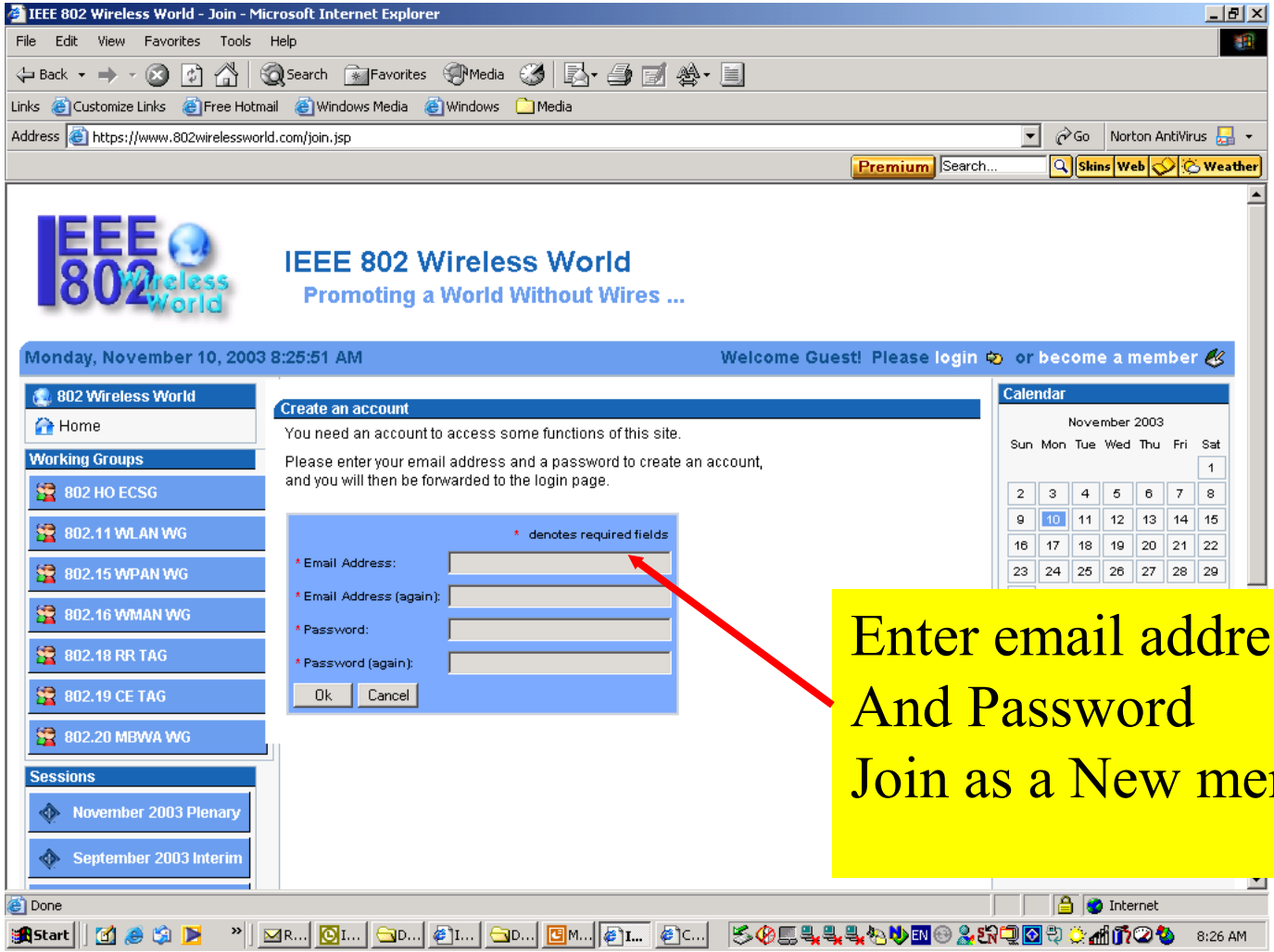
# http://www.802wirelessworld.com



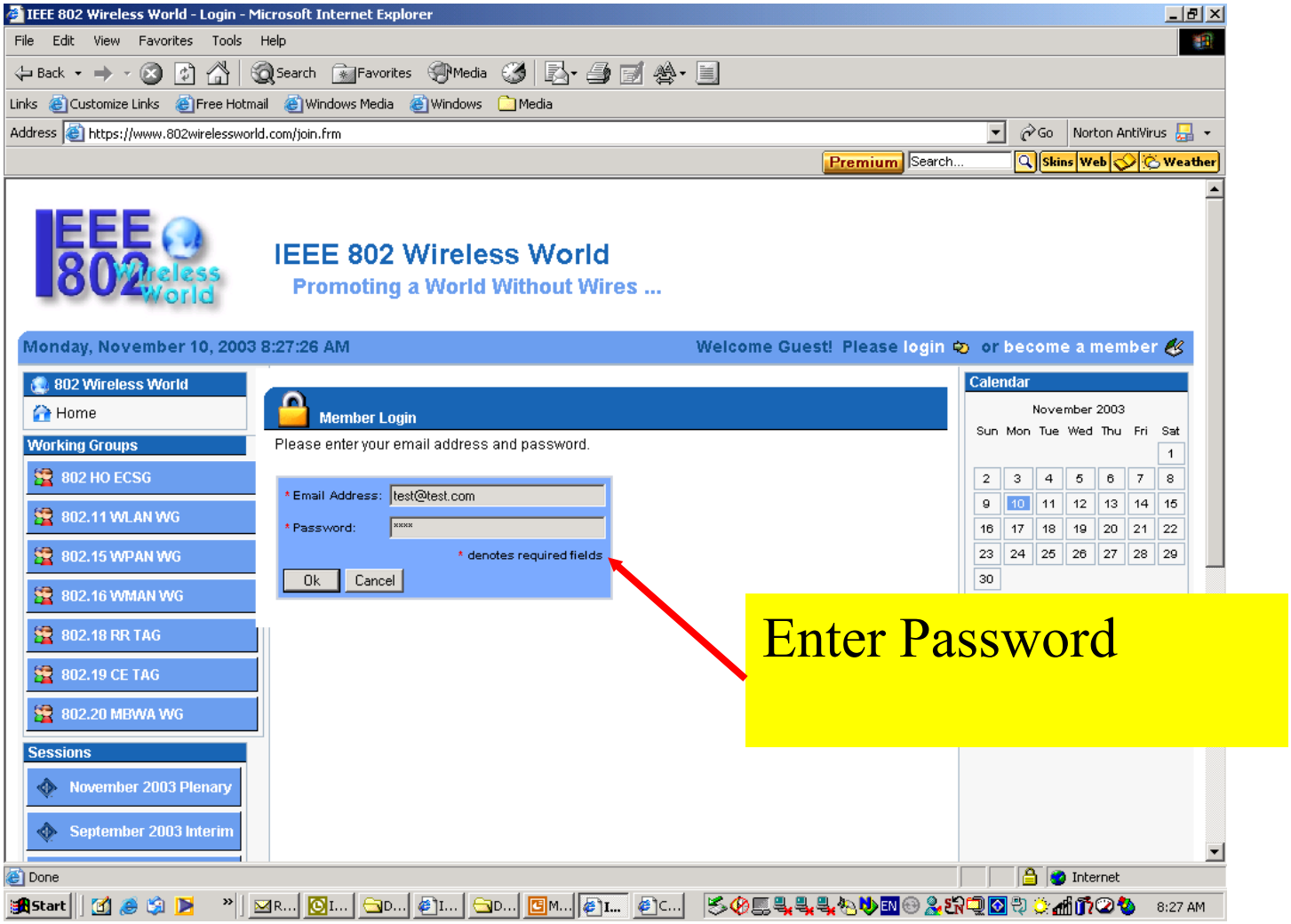
# http://www.802wirelessworld.com



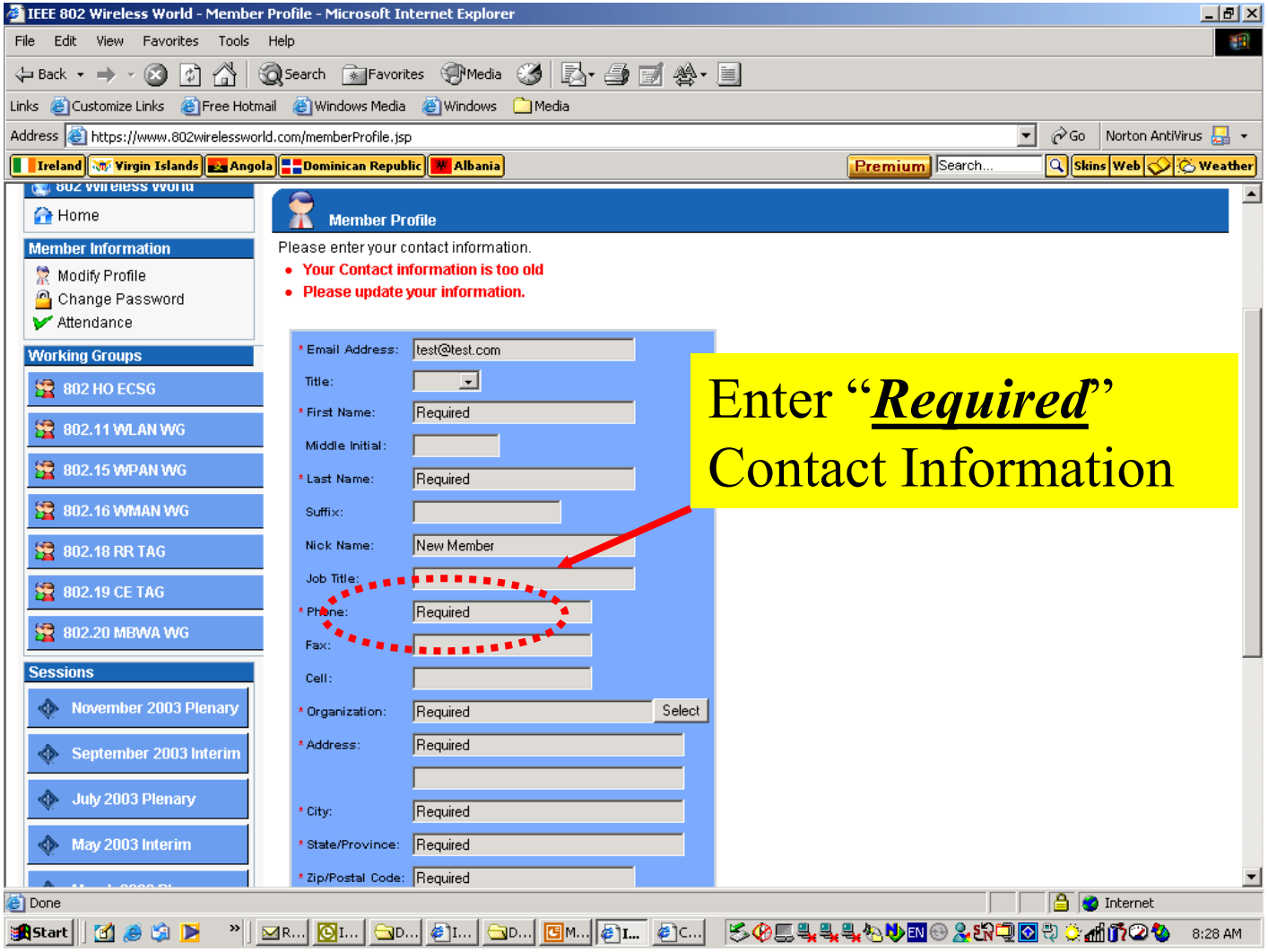
# http://www.802wirelessworld.com



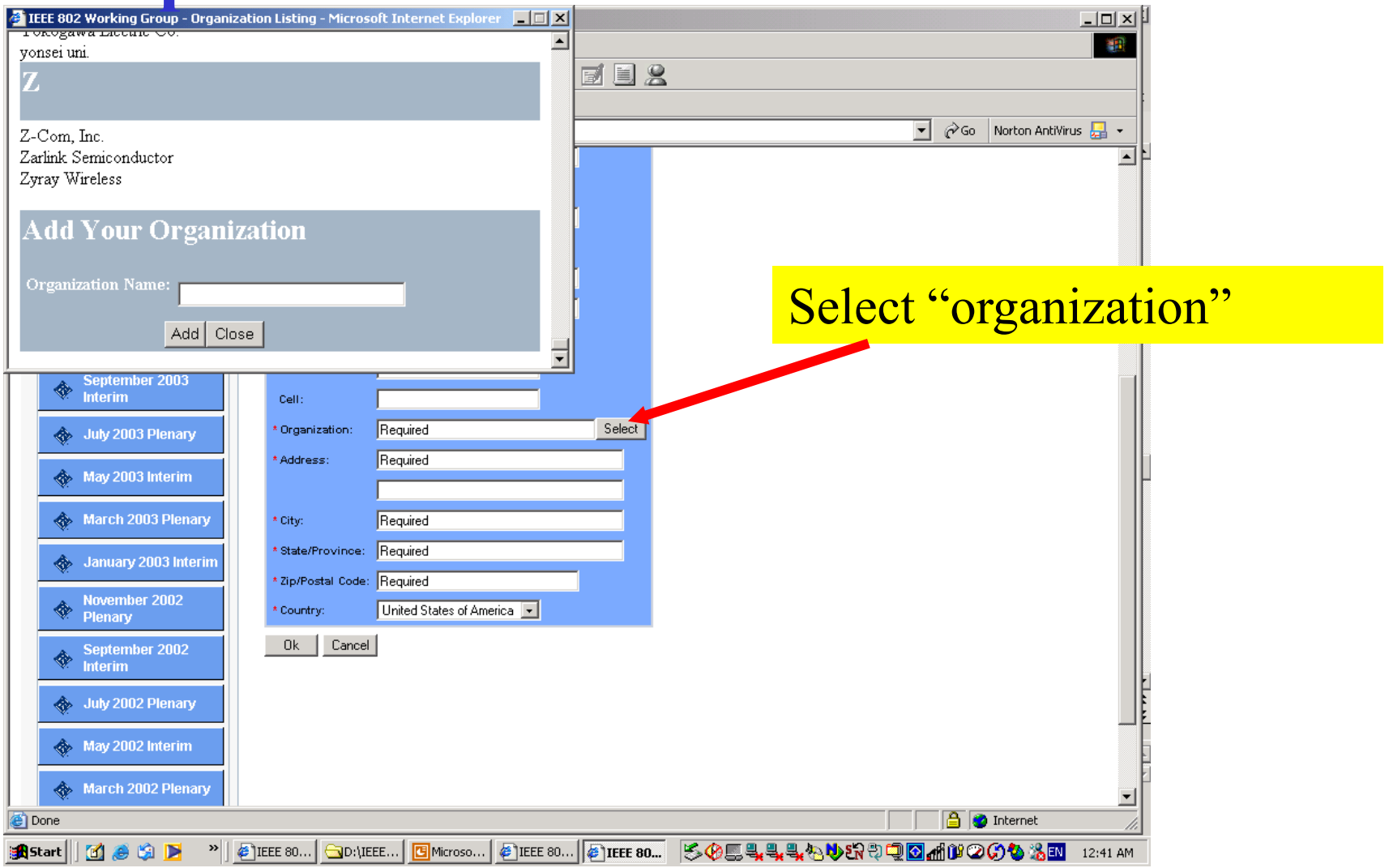
# http://www.802wirelessworld.com



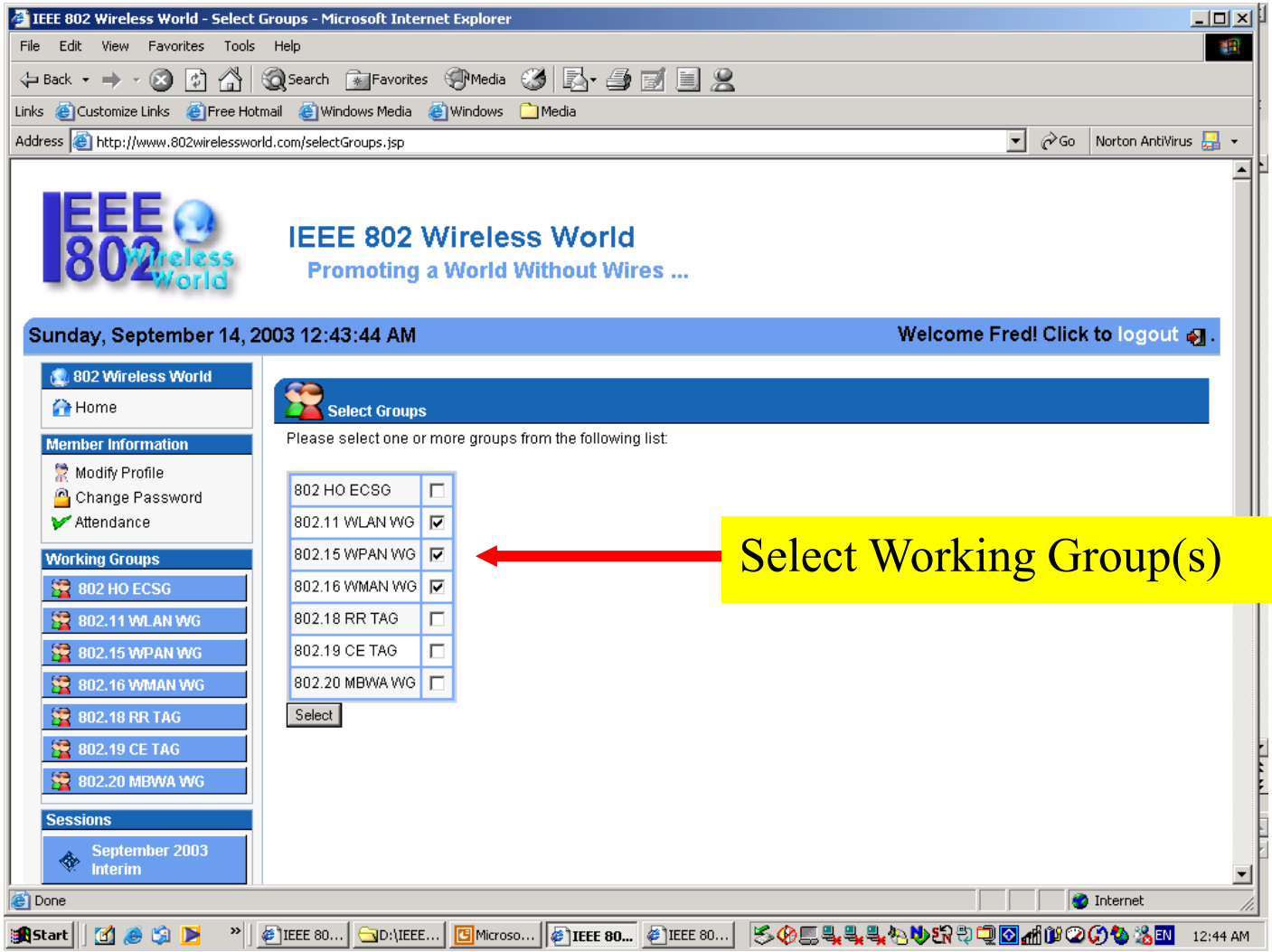
# http://www.802wirelessworld.com



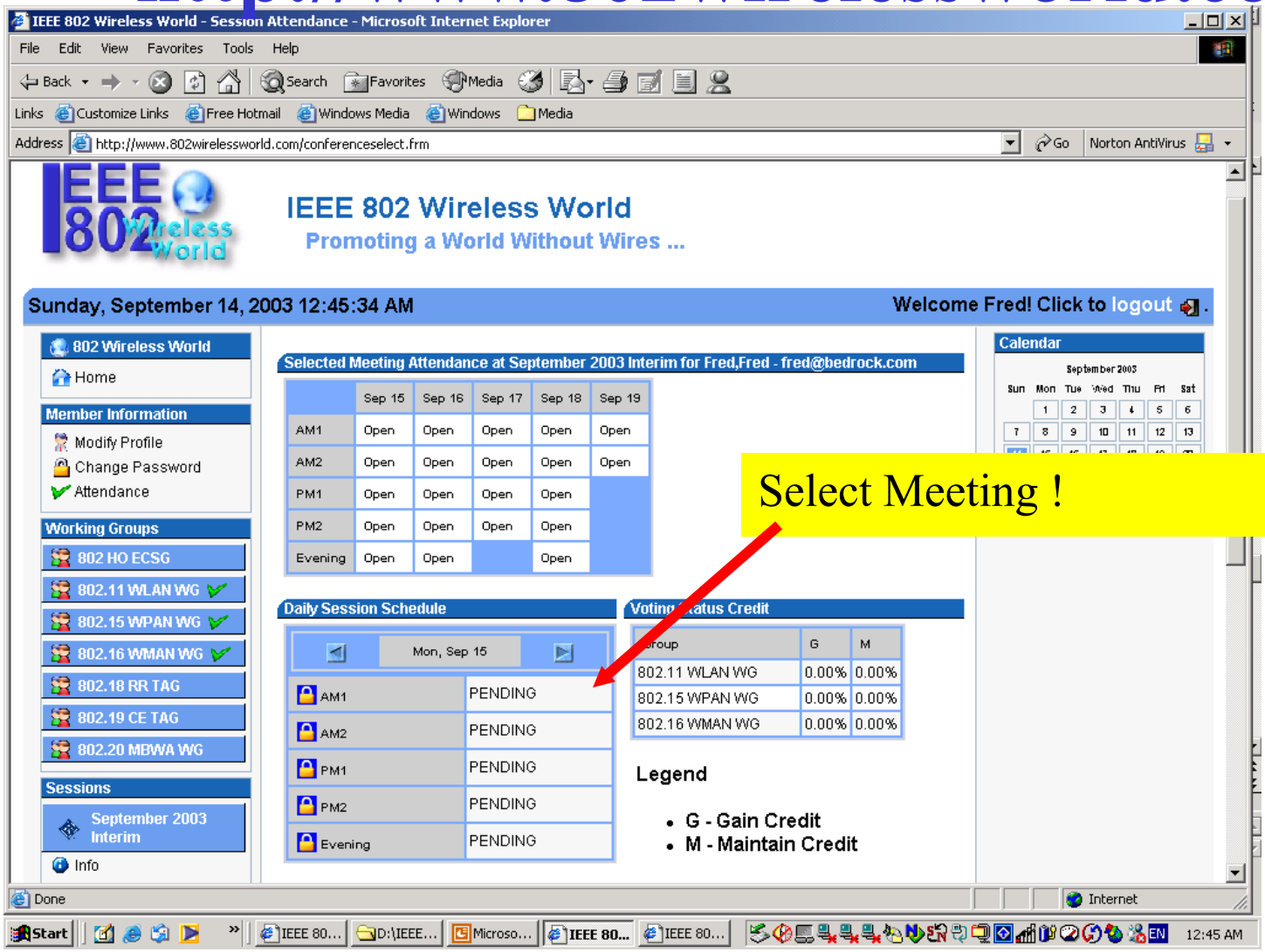
# http://www.802wirelessworld.com



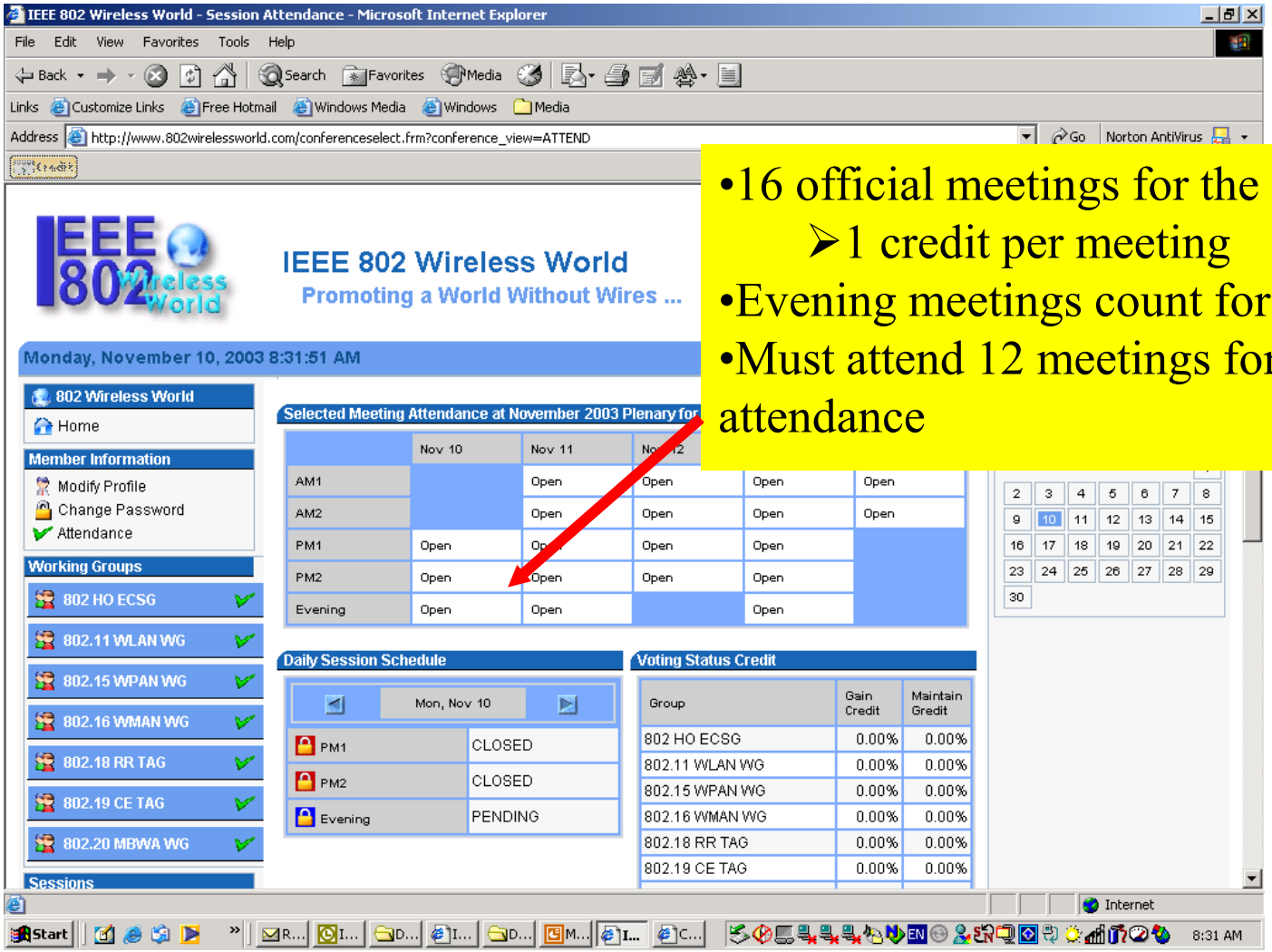
# http://www.802wirelessworld.com



# http://www.802wirelessworld.com

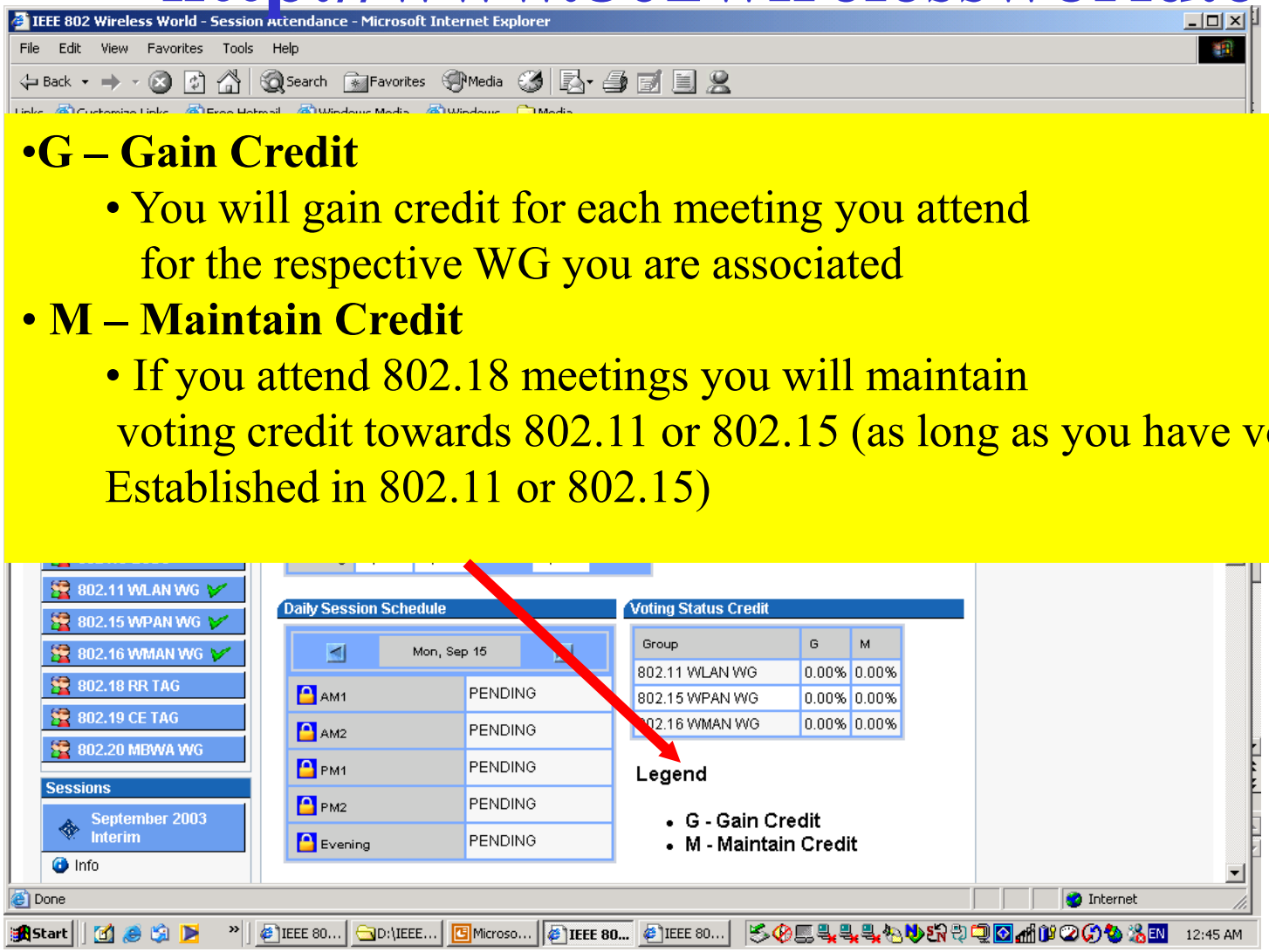


# http://www.802wirelessworld.com



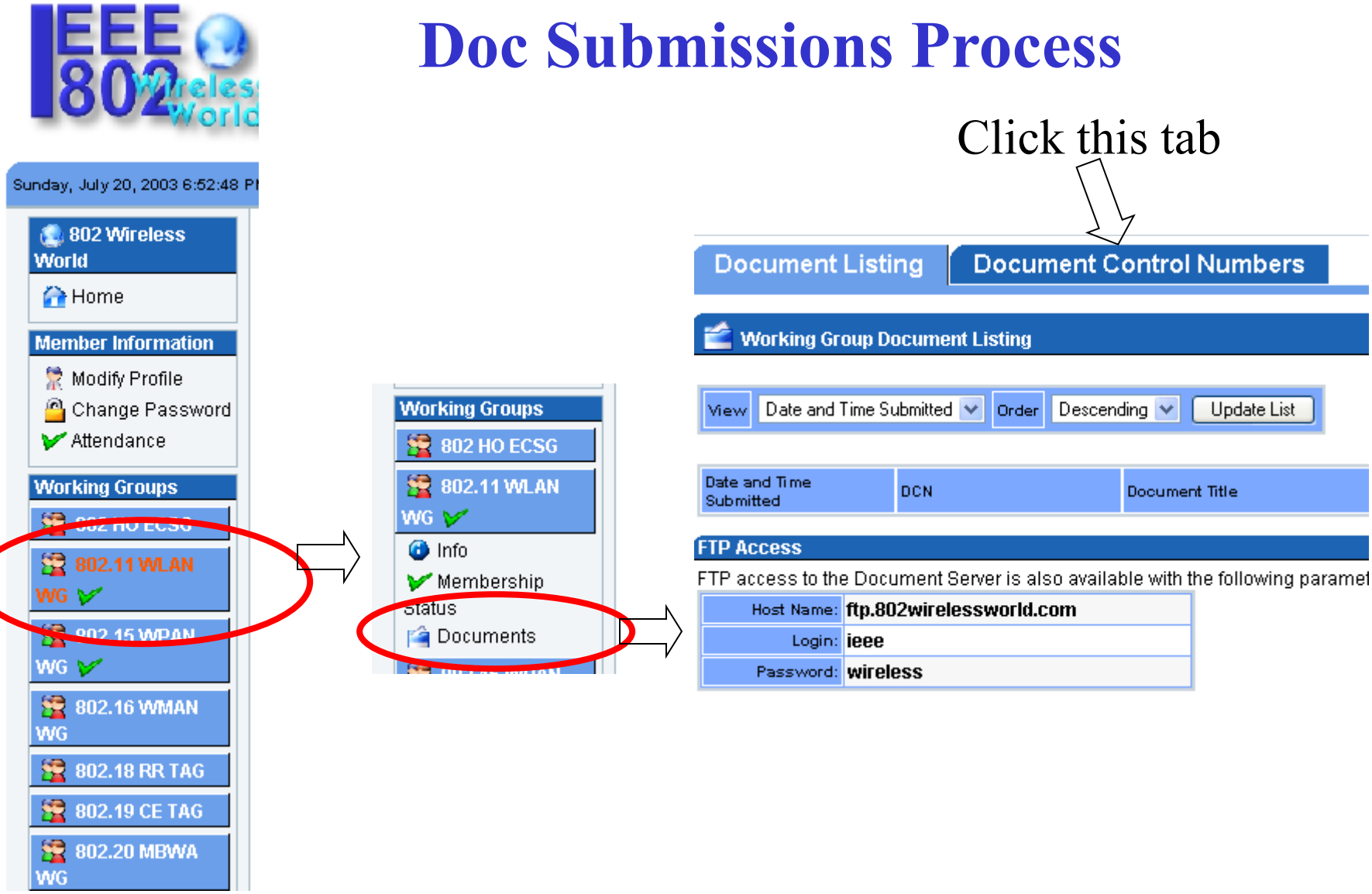

- 16 official meetings for the session
  - 1 credit per meeting
- Evening meetings count for 1 credit
- Must attend 12 meetings for 75% attendance

# http://www.802wirelessworld.com

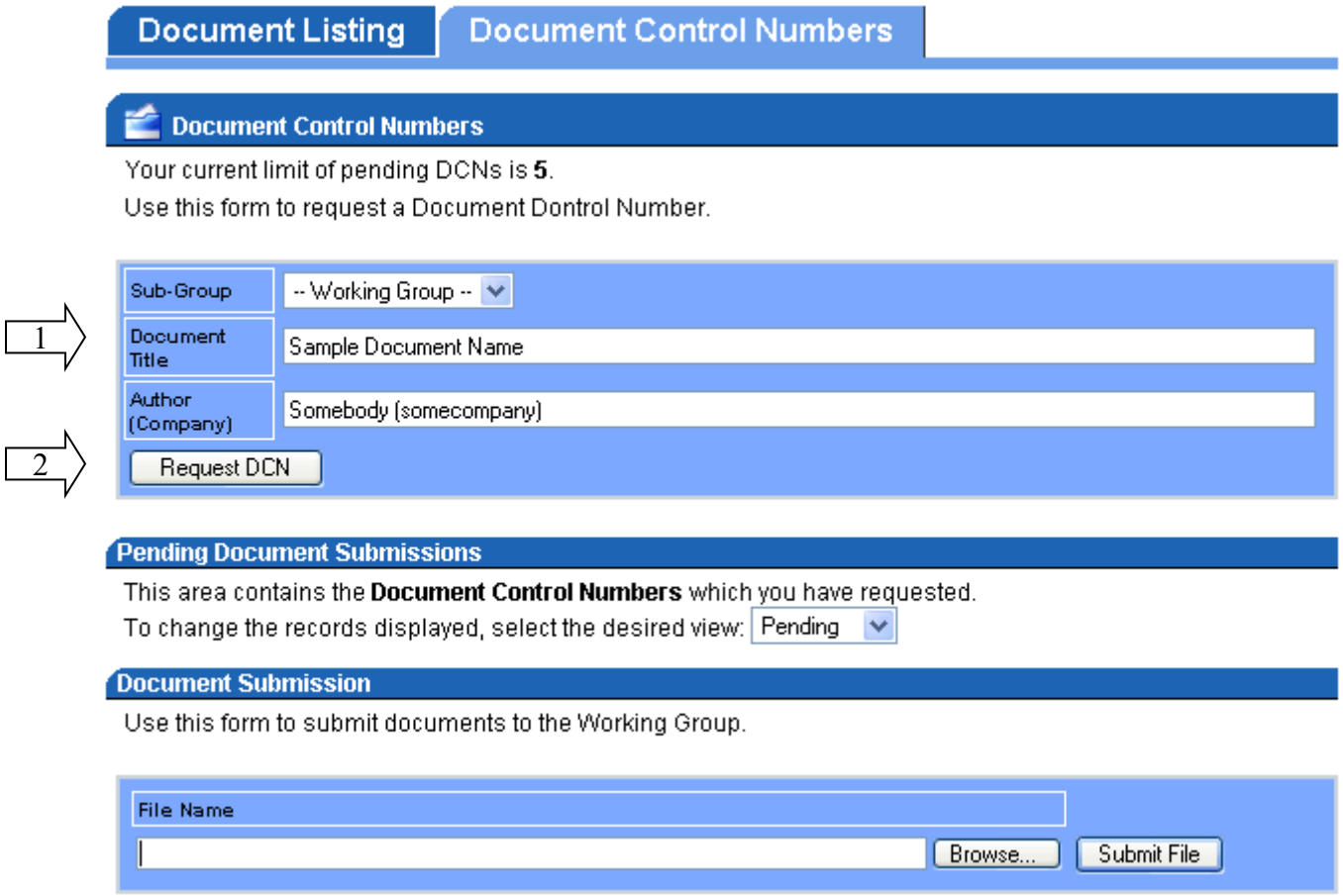



- **G – Gain Credit**
  - You will gain credit for each meeting you attend for the respective WG you are associated
- **M – Maintain Credit**
  - If you attend 802.18 meetings you will maintain voting credit towards 802.11 or 802.15 (as long as you have voting rights Established in 802.11 or 802.15)

# Doc Submissions Process

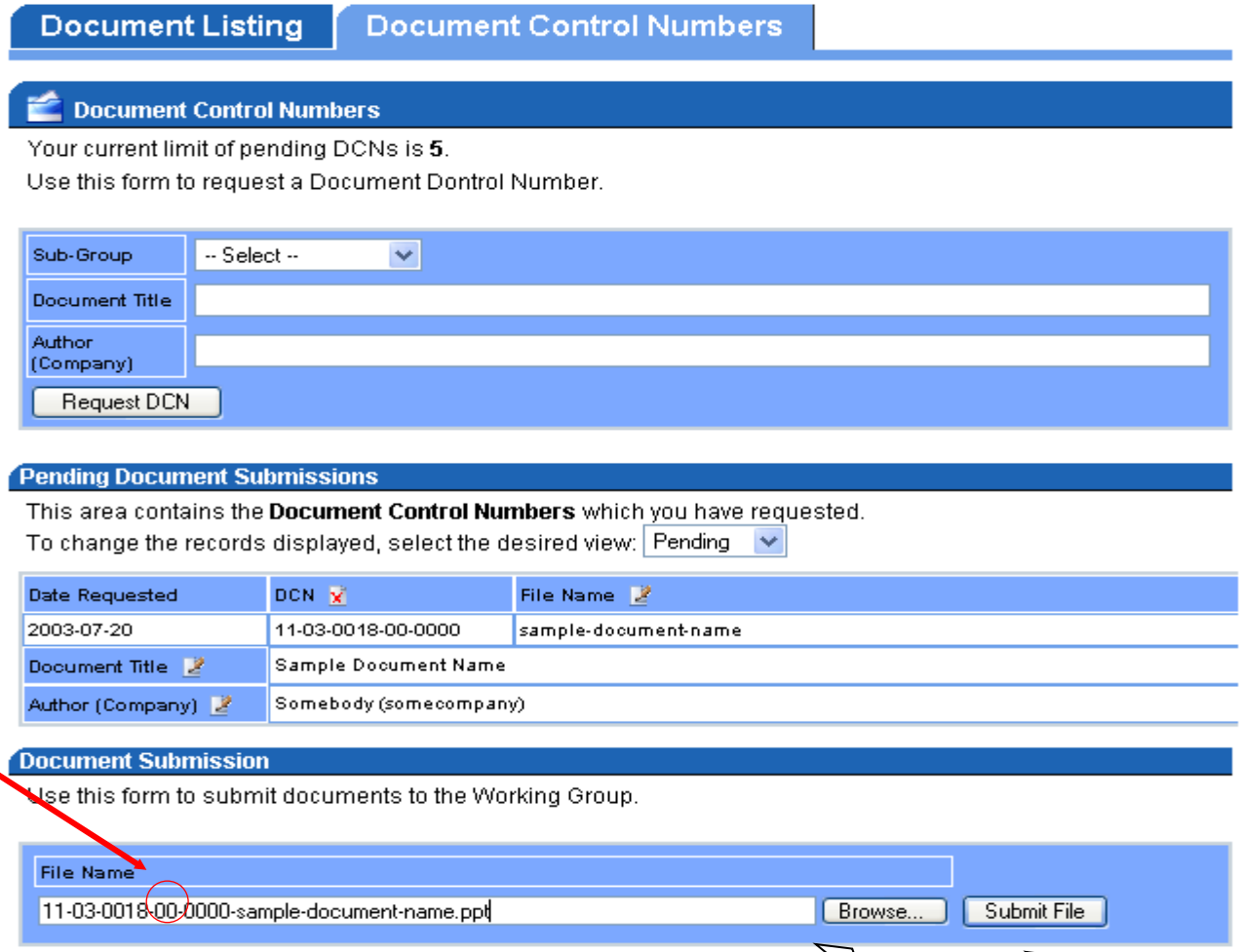


# Doc Submissions Process



# Doc Submissions Process

**To submite a revised Document Change revision Number in the File name**

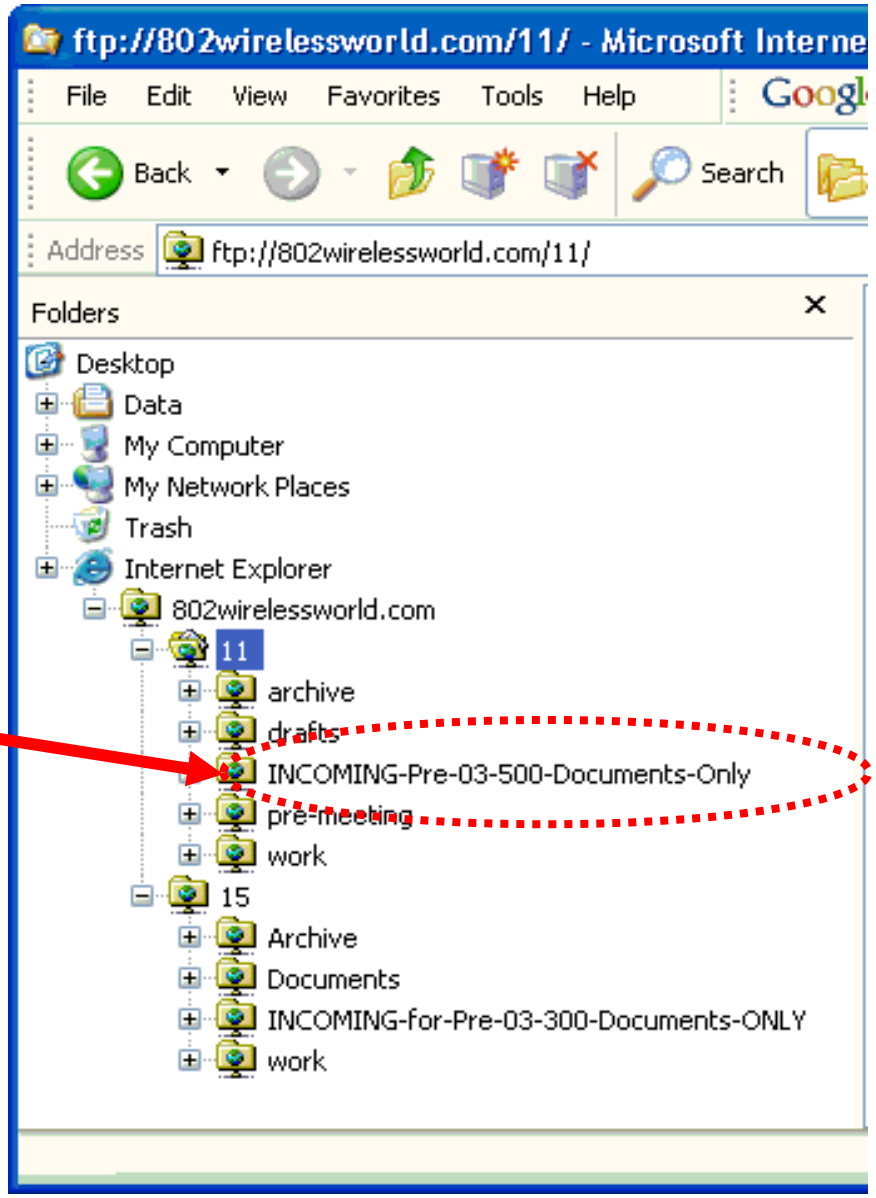



**Enter filename (as it is on your computer)**

**……or….. just browse to the file on your computer, finally**

# Revised Doc Submission

- Revisions to documents should be transferred by FTP to the working area(s) on Pluto.
- **ftp://802wirelessworld.com/11**



# Wireless Network Information

- Only 802.11b networks are available
- SSID (case sensitive)
  - IEEE
- Enable DHCP in the Netcard's TCP/IP properties
  - "Obtain IP Address Automatically"
- No WEP is being used. Be sure your WEP is disabled.
- Outgoing SMTP Server is 10.0.1.1 mail.802wirelessworld.com

# Attendance Server

- Electronic Attendance and Document Number Server: 802WirelessWorld
  - Access in web browser as: **http://www.802wirelessworld.com/**
    - Static IP of local server is 10.0.1.3
  - This site will continue to be available on the Internet between meetings.

# File Server information (new)

- Meeting File Server (802.11 and 802.15)
  - PLUTO 10.0.1.3 (AKA 802wirelessworld)
    - Meeting Document Access (only via FTP)
      - FTP Login - **user: IEEE password: wireless**
      - ftp://pluto or ftp://www.802wirelessworld.com
        - Contains multiple Working Group directories
    - Document Submissions
      - Via web site at www.802wirelessworld.com
        - Documents link under your working group link
        - Note – some Working Groups may not use this for document submissions yet. Currently, 802.11, 802.15, and 802 Handoff SG are using this method. Other servers are still on-line for other Working Groups. Check with your WG for status.

# Other WG server information

- 802.15: MARS
  - Replaced by ftp.802wirelessworld.com
- 802.18, 19, and 20: 802-18-19 10.0.1.18
  - 802.18 Radio Regulatory \\802-18-19\RadioReg
  - 802.19 Coexistence \\802-18-19\Coexistence
  - 802.20 MBWA \\802-18-19\MBWA
  - 802.20 MBWA \\802-18-19\MBWA-Subm

# Troubleshooting

- Make sure your wireless association is to **SSID: IEEE**
  - There are several other wireless networks in the area
- Make sure you have an IP address
  - Run IPCONFIG and be sure your IP address is 10.0.x.x
- If you can't access or find a particular server
  - Ping it – is the address being pinged in some other range than our local network 10.0.x.x? Is the name being pinged something like pluto.yourcompany.com? That means you have some other host with the same name on your home network.
  - To solve, run: IPCONFIG /flushdns from a command prompt to flush your DNS cache.

# Network and Electronic Assistance

- Help desk
  - Outside of the Ballroom
    - During regular IEEE 802 registration hours
      - 8AM til 5PM
  - See Doug Hock or Tony Awtrey
    - IDEAL Corporation

# IP and Virus Protect!

- Enable DHCP and Do NOT configure your wireless card with a static IP address!
- Do NOT enter the wireless network without having the most current
  - Virus Protection installed,
  - Firewall installed
  - Microsoft security updates

and turned on !

# *Enjoy IEEE 802 at the Hilton Towers Portland, Oregon*

# APPENDIX B

# IEEE P802.11
# Wireless LANs

## Approved Minutes of the IEEE P802.11 Full Working Group

**July 12 - 16, 2004**

**Portland Hilton, Portland, Oregon, USA**

## 8th Joint 802 Wireless Opening Plenary: Monday, July 12, 2004

### *1.1. Introduction*

1.1.1. Meeting called to order by Stuart J. Kerry at 1:30PM

1.1.2. The agenda of the 86th session of 802.11 is in doc: IEEE 11-04-592r4. This session is including 802.11, 802.15, 802.18 RREG TAG, 802.19 Coexistence TAG, 802.20 MBWA, and 802.21.

1.1.3. Stuart J. Kerry reminds the group regarding the rules against audio recording or photographs without permission.

1.1.4. Count of new participants at this meeting: 63.

1.1.4.1. There are 459 people in the room.

1.1.5. Secretary – Tim Godfrey

1.1.6. Officers and Chairs of 802.11:

| IEEE 802.11 WORKING GROUP OFFICERS | | | |
|---|---|---|---|
| Name | Position | Work Phone | eMail |
| Stuart J. Kerry | IEEE 802.11 WG Chair<br>Philips Semiconductors, Inc.,<br>1109 McKay Drive, M/S 48A SJ,<br>San Jose, CA 95131-1706, USA<br>Fax:+1 (408) 474-5343 | +1 (408) 474-7356 | stuart.kerry@philips.com |
| Al Petrick | WG 1st Vice-Chair / Treasurer<br>Policies & Treasury | +1 (321) 235-3423 | apetrick@icefyre.com |
| Harry R. Worstell | WG 2nd Vice-Chair / WNM SG Chair<br>Attendance, Ballots, Documentation & Voting | +1 (973) 236-6915 | hworstell@att.com |
| Tim Godfrey | WG Secretary<br>Minutes | +1 (913) 664-2544 | tim.godfrey@conexant.com |
| Terry Cole | WG Technical Editor<br>Standard & Amendment(s) Coordination | +1 (512) 602-2454 | terry.cole@amd.com |
| Brian Mathews | WG Publicity SC Chair<br>Communications & Reports | +1 (321) 259-0737 | brian@linux-wlan.com |
| Teik-Kheong "TK" Tan | WNG SC Chair | +1 (408) 474-5193 | tktan@ieee.org |
| John Fakatselis | TGe Chair | +1 (321) 327-6710 | john.fakatselis@conexant.com |
| Sheung Li | TGj Chair | +1 (408) 773-5295 | sheung@atheros.com |
| Richard H. Paine | TGk Chair | +1 (206) 854-8199 | richard.h.paine@boeing.com |
| Bob O'Hara | TGm Chair | +1 (408) 635-2025 | bob@airespace.com |
| Bruce P. Kraemer | TGn Chair | +1 (321) 327-6704 | bruce.kraemer@conexant.com |
| Clint Chaplin | TGr Chair | +1 (408) 528-2766 | cchaplin@sj.symbol.com |
| Donald E. Eastlake 3rd | TGs Chair | +1 (508) 786-7554 | donald.eastlake@motorola.com |
| Lee Armstrong | WAVE SG Chair (TGp Chair Elect) | +1 (617) 244-9203 | LRA@tiac.net |
| Stephen McCann | WIEN SG Chair | +44 (1794) 833341 | stephen.mccann@roke.co.uk |
| Charles R. Wright | WPP SG Chair | +1 (978) 268-9202 | charles_wright@azimuthsystems.com |

### *1.2. IP Statements (Letters of Assurance)*

1.2.1. Stuart J Kerry calls for any letters of assurance related to IP for any Working Groups represented in this joint meeting.

1.2.1.1. None.

### *1.3. Announcements*

1.3.1. Members are cautioned to not leave personal items unattended in the meeting rooms.

### *1.4. Policies and procedures*

1.4.1. Petrick reviews the documents containing the 802.11 policies and procedures. Current P&P document is 00/331r7. Updates in 421r1 was posted in March. The latest red-line document is 04/510r0

1.4.2. Al Petrick presents the overview of policies and procedures from the presentation in 04/424r2.

1.4.2.1. Review of officer duties.

1.4.2.2. Review of voting tokens – 802.15 through 802.20 will continue to use paper tokens. 802.11 is using printed voting status on their registration badges. We are continuing this from the March meeting. There were only 16 discrepancies. If anyone else has a question about voting status, see Al Petrick or Harry Worstell.

1.4.2.3. Hierarchy of policies and procedures.

1.4.2.4. The use of Roberts Rules of Order latest edition.

1.4.2.5. Review of registration and media recording rules.

1.4.2.6. Review of attendance list and recording procedures, and rules for statements to the press.

1.4.2.7. Review of attendance procedures, and rules for voting rights (earning and maintaining). More details in document 04/422r2

1.4.2.8. Review of membership and anti-trust rules.

1.4.2.9. Review of IEEE-SA Standards Board Bylaws on Patents in Standards. This information was last updated in February 2004.

1.4.2.10. The following text from document 04/424r2 was read in its entirety to the membership by Al Petrick:

# *IEEE-SA Standards Board Bylaws* on Patents in Standards

**6. Patents**

IEEE standards may include the known use of essential patents, and patent applications, provided the IEEE receives assurance from the patent holder or applicant with respect to patents essential for compliance with both mandatory and optional portions of the standard. This assurance shall be provided without coercion and prior to approval of the standard (or reaffirmation when a patent becomes known after initial approval of the standard). This assurance shall be a letter that is in the form of either

a) A general disclaimer to the effect that the patentee will not enforce any of its present or future patent(s) whose use would be required to implement the proposed IEEE standard against any person or entity using the patent(s) to comply with the standard or

b) A statement that a license will be made available without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination

This assurance shall apply, at a minimum, from the date of the standard's approval to the date of the standard's withdrawal and is irrevocable during that period.

**Approved by IEEE-SA Standards Board –, March 2003, Feb 2004**

# Inappropriate Topics for IEEE WG Meetings

- **Don't** discuss licensing terms or conditions
- **Don't** discuss product pricing, territorial restrictions or market share
- **Don't** discuss ongoing litigation or threatened litigation
- **Don't** be silent if inappropriate topics are discussed… do formally object.

**If you have questions,**
**contact the IEEE Patent Committee Administrator**
**at patcom@ieee.org**

**Approved by IEEE-SA Standards Board – December 2002**



1.4.2.11. The rules and status of copyright are reviewed.
1.4.2.12. Meeting Etiquette
1.4.2.12.1. Stuart J. Kerry reminds the membership that meetings are to be conducted in an orderly and professional manner. Roberts rules requires that conversations are through the chair. Members exhibiting inappropriate conduct will be removed.

### *1.5. Review of the Agenda*

1.5.1. The joint meeting agenda is reviewed
1.5.2. The agenda is approved with unanimous consent

### *1.6. Matters arising from the Minutes*

1.6.1. No matters arising from the minutes
1.6.2. The minutes from Garden Grove are approved with Unanimous consent.

### *1.7. Interim Meetings*

1.7.1. September 12-17, Berlin Germany.
1.7.1.1. Registration for meeting and hotel are available on the web site.
1.7.1.2. Members must provide credit card to guarantee the hotel and also to pay the meeting fee. We have a 300 room block at the Estrel Hotel.
1.7.1.3. The Hilton will be an overflow hotel.
1.7.1.4. There is a 3 tier registration fee, based on time of registration. We will have an early-bird for $700US until the end of the month. Regular is $900US, after August 27, the fee is $1100US.

1.7.1.5. Cancellation – If you cancel before 25 August, there is $100AU fee. No refund after August 25th. In addition, 2 room nights must be paid to the hotel if canceling.

1.7.1.6. Meetings will be managed by Tourhosts of Australia.

1.7.1.7. Booking at the Estrel is only until the 18 but not beyond.

1.7.1.8. The IEEE rate at the Estrel is 139 Euros.

1.7.2.

1.7.3. November 14-19, 2004: Plenary San Antonio TX

1.7.4. January 16-21, 2005, Interim, Monterey, CA

1.7.5. March 13-28, 2005, Plenary, Atlanta, GA

1.7.6. May 15-20, Sydney Australia.

1.7.6.1. At the Hilton in Sydney which has been recently renovated.

1.7.7. July 17-22, 2005, Plenary, San Francisco, CA

1.7.8. September 18-23, 2005 – Boston (tentative)

1.7.9. November 13-18, 2005, Plenary, Vancouver BC

1.7.10. January 2006 – Interim TBD

1.7.10.1. Straw Poll on locations.

1.7.10.1.1. Hawaii – (Maui or Kauai) 176

1.7.10.1.2. California 26

1.7.10.1.3. Florida 26

1.7.10.1.4. Mexico 116

1.7.11. March 12-17, 2006 – New Orleans

1.7.12. May 15-19, 2006

1.7.12.1. China

1.7.12.2. Istanbul, Turkey

1.7.12.3. Yokohama, Japan

1.7.12.4. Seoul, Korea

1.7.13. July 2006, San Diego

1.7.14. September 18-22, 2006 (unknown, - but North America)

1.7.15. November 2006 – Dallas downtown.

### *1.8. Attendance and Network*

1.8.1. Al Petrick reviews document 04/422r4 and the instructions for accessing the meeting attendance and document server at 802wirelessworld.com.

1.8.2. Going forward there is no grace period for forgetting to log attendance during meeting sessions.

1.8.3. Instructions for uploading and downloading documents are reviewed.

1.8.4. The wireless network overview is explained.

1.8.5. Members are reminded to verify their virus and firewall protection is up to date.

### *1.9. Joint Treasurer report*

1.9.1. John Barr gives the report for the joint 802.11/802.15 treasury.

1.9.2. Document 802.15/04/333r1.

1.9.3. Expenses at Anaheim were $209K, and income was $291K, giving a surplus of $83K.

1.9.4. $60K was targeted to help reduce costs for Berlin meeting.

1.9.5. Since we have our own treasury, we have to carry the reserve to cover cancellations or penalties.

1.9.6. Discussion

1.9.6.1. When do we expect to achieve the goal of $68K reserve? In January 2005.

### *1.10. Report on ExCom activities*

1.10.1. Bob Heile presents document 15-04-332r0

1.10.1.1. There is an a problem with the IEEE SA Ballot Tool.

1.10.1.2. John Hawkins replaces Bill Quackenbush as 802 treasurer.

1.10.1.3. An architecture group was established to look at 802 issues. WGs are to nominate 2 people to participate.

### *1.11. 802 PARs*

1.11.1. New PARs for approval at this meeting

1.11.1.1. 802.3ar: Frame Expansion

1.11.1.2. 802.11p: Wireless Access for the Vehicular Environment

1.11.1.3. 802.11T: Wireless Performance Prediction

1.11.1.4. 802.16e modification

1.11.1.5. 802.16f: MIB

1.11.1.6. 802.16g: Management Plane Procedures and Services

1.11.1.7. 802.18 TV Band from 802.18 SG1 (Proposed as P802.22)

1.11.2. Comments due by Tuesday at 5:00PM, responses due Wednesday by 5:00PM.

### *1.12. 802.11 Agenda*

1.12.1. Voter Summary in 04/511r1

1.12.1.1. We have 350 voters, 146 nearly voters.

1.12.1.2. We have lost 147 voters due to failing to respond to LB69 and LB70. These individuals have been contacted by email. These members have the right to appeal. (Send to Harry Worstell and Stuart J. Kerry)

1.12.1.3. Appeals are a one-time proposition. There will be no second chances.

1.12.1.4. We went from 548 to 350 voters.

1.12.2. Review of 802.11 agenda

1.12.2.1. Stuart J. Kerry reviews the 802.11 agenda for the week. 04/592r3.

1.12.2.2. The agenda is adopted with Unanimous consent.

1.12.3. Matters arising from the minutes of 802.11 Garden Grove – none

1.12.3.1. The minutes are approved with Unanimous consent.

1.12.4. WG Policies and Procedures.

1.12.4.1. Al Petrick reviews document 04/750r0 regarding the current state of P&P.

1.12.4.2. Current document is 00/331r7. 421r1 was created in March, with changes.

1.12.4.3. Document 331r7 with changes was created as 04/510r0 and posted in March. There are no new comments on that document.

1.12.4.4. At the May meeting, we announced that this document would be voted upon at this meeting.

1.12.4.5. Motion: Move that document 04/510r0 becomes the policies and procedures for IEEE 802.11 WG and be posted on the IEEE 802.11 WG website after the close of the 802.11 July 2004 Plenary.

1.12.4.5.1. Moved Al Petrick
1.12.4.5.2. Second Colin Lanzl
1.12.4.5.3. Vote: passes 137 : 0 : 0

### 1.12.5. Documentation update

1.12.5.1. Harry Worstell reminds members to continue using the old format for the document number in the upper right hand corner of the documents (not the filename).

### 1.12.6. TGe – John Fakatselis

1.12.6.1. Received results of first Sponsor Ballot. Will address comments. Will ask for extension of the PAR Wednesday or Friday.

### 1.12.7. TGj – Sheung Li

1.12.7.1. TGj completed first sponsor ballot. The results from the IEEE SA 66 are read: There were 93 in the pool. 66 affirmative, 9 negative with comments, 0 negative without comments, 3 abstain, 78 votes received. Met 83% return, 88% affirmative.

1.12.7.2. TGj expects to complete comment resolutions

### 1.12.8. TGk – Richard Paine

1.12.8.1. Details in 04/739r1

1.12.8.2. Reviewing draft 0.14.

1.12.8.3. Hoping to finish and have LB this week.

1.12.8.4. Still issues with security of measurement frames.

### 1.12.9. TGm – Bob O'Hara

1.12.9.1. Will meet in Salon 3 across the street.

### 1.12.10. TGn – Bruce Kraemer

1.12.10.1. CFP was issued in May. Will discuss results, and prepare for presentations that begin in September.

1.12.10.2. Joint sessions with 802.18, .19, and .21.

1.12.10.3. Will have nominations for vice chair and editor.

1.12.10.4. Stuart Kerry announces that candidates for editor and vice chair should see himself or Bruce Kraemer .

1.12.10.5. 802.11n will have priority in the Berlin meeting, with 32 hours. There are currently 61 proposals.

### 1.12.11. TGr – Clint Chaplin

1.12.11.1. Will elect editor and secretary. Document 04/761 has the agenda. Will work on framework document in preparation for possible Call for Proposals.

### 1.12.12. TGs – Donald Eastlake

1.12.12.1. First meeting – will elect secretary and editor. Agenda in 04/663r2.

### 1.12.13. WNG – TK Tan

1.12.13.1. Four sessions this week. Will have an update from Darpa XG project.

1.12.13.2. Re-affirmation of motion from May to form AP study group, which passed with Unanimous consent.

1.12.13.2.1. Move that the WNG SC recommends that the IEEE 802.11 WG form a study group to determine how to formally describe the Access Point functions and behaviors (ref 11-

04/604r0), with the intent to create a PAR and five criteria to form a new Task Group.

1.12.13.3. Move to reaffirm the decision of the May 2004 interim 802.11 WG session that approved by unanimous consent the formation of an AP Functional Description Study Group and forward to 802 ExCom for approval.

1.12.13.3.1. Moved TK Tan
1.12.13.3.2. Second Clint Chaplin
1.12.13.3.3. Vote (802.11 members) Passes 122 : 1 : 1

1.12.14. WAVE SG – Broady Cash

1.12.14.1. Will discuss the draft submissions to the draft amendment, and respond to any comments on the PAR and 5C.

1.12.15. WEIN SG – Steven McCann

1.12.15.1. Agenda is in 04/689r1. Will refine scope and draft PAR and 5C. Will address specific issues with technical submissions. Looking for volunteers for liaisons to 3GPP. Joint meetings with TGr, and with 802.21. WEIN will be in an ad-hoc session for the joint meeting with 802.21 on Wednesday.

1.12.16. WNM – Harry Worstell

1.12.16.1. Working on PAR and 5C. Will vote to approve this week. Will consider proposals on direction. Looking for secretary for group.

1.12.17. WPP – Charles Wright

1.12.17.1. The LB to confirm forwarding PAR and 5C was approved. Will resolve comments on PAR and 5C, and hear presentations.

1.12.18. 5GHz chairs ad-hoc – Al Petrick

1.12.18.1. First meetings were in May. Generated protection statement for 802.11a in 5GHz band. Will work with 802.18 this week to complete the document.

1.12.19. WG Technical Editor – Terry Cole

1.12.19.1. Delayed until Wednesday

### *1.13. 802.15 Agenda*

1.13.1. Voter status – 234 voters, 80 nearly voters – could have up to 314 at this meeting

1.13.2. P&P documents will be combined and updated at the next plenary.

1.13.3. TG1a – Tom Seip

1.13.3.1. Will meet one time – in the process of instituting a Sponsor ballot. Will plan for future activities of BT sig.

1.13.4. TG3a – Bob Heile

1.13.4.1. Will continue downselection process. Special orders were postponed from Anaheim. Will vote on Wednesday.

1.13.5. TG3b – John Barr

1.13.5.1. MAC amendment for 802.15.3. Have issued a call for submissions, and have listed contributions received. Will have presentations tomorrow, and make decisions Thursday

1.13.6. TG4a – Pat Kinney

1.13.6.1. Alt Phy for 802.15.4. Will have tutorials on location awareness. Wednesday will work on selection document, and start on CFP.

1.13.7. TG4b – Robert Poor

1.13.7.1. Revision of the 802.15.4 spec to clean up holes. Main activity is tutorial, review contributions, and form draft.

1.13.8. SG 3C – Reed Fisher

1.13.8.1. MMwave PHY for 802.15.3. Issued call for applications, ending August 31st. Working on PAR and 5C documents.

1.13.9. TG5 – John Booth

1.13.9.1. Mesh Networking. There has been limited response to CFP. Will discuss whether to extend or proceed.

### *1.14. Joint Publicity*

1.14.1. Greg Rasor, Brian Matthews.

1.14.2. Will receive updates from industry groups, press releases, media coverage

### *1.15. 802.18*

1.15.1. Carl Stephenson presents document 18-04-027.

1.15.2. FCC extended comment deadline on 3GHZ NPRM will move from 802.18 document to 802 document..

1.15.3. Prepared documents for industry Canada regarding 5470-5725.

1.15.4. Approved PAR and 5C for WG on WRAN using TV band.

1.15.5. Will process comments on NPRM, and work on 5GHz protection criteria.

### *1.16. 802.19*

1.16.1. Steve Shellhammer presents document 19-04-0023r1

1.16.2. 802.19 TAG produced proposed changes to 802. P&P for coexistence. A LB was unanimously approved. These proposed rule changes were discussed within ExCom, and will be presented to 802.11, 15, and 16.

1.16.3. There will be a tutorial Tuesday at 6:30 on Coexistence.

1.16.4. There will be a joint meeting with 802.11n Wednesday.

1.16.5. The new rules will require that each group create a coexistence assurance document, and 802.19 will develop an Coexistence assurance method document.

1.16.6. The document will be updated and presented on Wednesday.

### *1.17. 802.20*

1.17.1. Jerry Upton presents document 20-04-xxx

1.17.2. 802.20 can be signed for attendance at this session.

1.17.3. Document server on Neptune/mbwa

1.17.4. 802.20 and 802.21 have reciprocal attendance

1.17.5. Will work on requirements document this week on Tuesday and Wednesday.

1.17.6. Will then work on evaluation criteria, channel models, traffic models, etc. Will look at work plan schedule.

1.17.7. We have an agreement with all 802. groups (except 802.2, 3, and 16) to grant member access to documents.

### *1.18. 802.21*

1.18.1. Ajay Jajkumar presents document 21-04-xxx

1.18.2. Review of officers. Attendance is still TBD – 802.21 has not been added to the 802wirelessworld system. Will use paper attendance recording.

1.18.3. Working on requirements and comments on the requirements. Working on handover usage scenarios.

1.18.4. There will be joint meetings with 802.11.

1.18.5. Documents are on server handover (10.0.1.21)

### *1.19. Announcements*

1.19.1. Stuart J. Kerry personally thanks Al Petrick and Harry Worstell for running 802.11 while he was attending to his brother's funeral.

### *1.20. Adjourn of the Joint Meeting*

## 2. Wednesday, July 14, 2004

### *2.1. Opening*

2.1.1. The meeting is called to order by Stuart J. Kerry at 10:35AM

2.1.2. Following the agenda in document 04/592r4

2.1.2.1. Changes to agenda 802.18 PAR

2.1.2.2. 802.11e PAR extension

2.1.2.3. 802.19 coexistence rules proposal

2.1.2.4. AP Methodology

2.1.2.5. Chair nominations on AP Methodology SG

2.1.2.6. SEC Architecture SC

2.1.3. There are 378 people in the room

### *2.2. Announcements*

2.2.1. Social is by bus at Crystal Ballroom. Shuttles from 6:00pm to 10:30pm.

2.2.2. There are still some CDs available of the 2004 standards if you didn't get one in November.

2.2.3. TGs announces an informal gathering to discuss submissions this afternoon at 1:30pm.

2.2.4. TGn announced that nominations for vice chair and editor were open, but the elections are postponed indefinitely – at least until November

2.2.5.

### *2.3. Agenda*

2.3.1. The agenda is affirmed.

2.3.2. There is no WAVE meeting on Thursday. There is an informal WAVE meeting this afternoon.

2.3.3. TGn a

### *2.4. LOA letters*

2.4.1. The chair asks for any IP letters

2.4.1.1. None

### *2.5. Attendance*

2.5.1. Harry Worstell reports that about 150 voters lost rights due to non-response on the last letter ballots. Some have been restored based on the use of the one-time appeal. Anyone who has appealed but not received voting tokens, see Harry.

2.5.2. Some members have not sent in the voter status request. All members are required to send in a request to continue to be a voter in 802.11. The request period closed on June 30th. If you didn't, you need to send a request to get your voting status back.

2.5.2.1. The same appeal would be used for failing to request voting rights as for failing to respond to Letter Ballots.

2.5.3. The chair notes that the attendance recording method is on the honor system. We are coordinating with WG and TAG chairs and performing snap audits of certain individuals.

2.5.4. Discussion

2.5.4.1. Sometimes specific groups are not available to sign in on the server? We will fix this.

2.5.4.2. A member suggests that sign in time for sessions be extended into the break. The chair rules this is not possible – the 2 hour slot is sufficient.

2.5.4.3.

2.5.5. The chair reminds members that discussions is by addressing the chair. This is part of our P&P.

### *2.6. Approval of Agenda*

2.6.1. The agenda is approved by Unanimous consent

### *2.7. Liaison Reports*

2.7.1. 802.11 to 802.15.3a – Atul Garg

2.7.1.1. No Report

2.7.2. 802.11 to 802.18 Denis Kuahara

2.7.2.1. Report in document 18-04-0028

2.7.2.2. RR TAG SG1 is working on TV Spectrum Re-use, developing PAR and 5 Criteria

2.7.2.3. Next meeting will be in September

2.7.3. 802.11 to WiFi Alliance – Bill Carney

2.7.3.1. Report in document 04/808

2.7.3.2. Nearly 1500 devices certified, new logo program in effect.

2.7.3.3. WPA is mandatory as of Sept 2003. WPA2 certification starts in September 2004. There will be an 18 month time before WPA2 becomes mandatory.

2.7.3.4. CE products are expected to be introduced this year. WFA is starting QoS certification based on WME subset. Additional features from 802.11e will be added at a later date. WFA will announce a new name for consumer branding of QoS features.

2.7.4. 802.11 to JEDEC JC61 – Tim Wakely

2.7.4.1. No Report

2.7.5. 802.11 to IETF – Dorothy Stanley

2.7.5.1. Report in document 04/776

2.7.5.2. 802.11 EAP Method Requirements – input from 802.11 has been provided to IETF. Based on IETF comments, the document was updated in May. Now before the IESG. There will be a motion to revise incorporating latest changes in 04/160r6.

2.7.5.3. CAPWAP WG – IETF requested 802.11 to review CAPWAP taxonomy document. Ad hoc group has completed this work and provided comments.

2.7.6. 802.11 to MMAC – Inoue-san

2.7.6.1. Report in document 04/809

2.7.6.2. Committees (until March 2004): High Speed Wireless Access Committee (HiSWAN WG, CSMA WG). Wireless Home-Link Committee (Wireless 1394 WG, UWB WG).

2.7.6.3. MMAC-802.11 WG was formerly called T71 Ad hoc WG. Standardizing in parallel with TGj

2.7.6.4. Support of new frequency bands and new rules for the existing wireless LAN systems

2.7.6.4.1. 5.470 – 5.725 GHz band

2.7.6.4.2. Information Council of MPHPT recently recommended to allocate this band for wireless LAN/wireless access systems.

2.7.6.4.3. 5.250 – 5.350 GHz band

2.7.6.4.4. Center frequency shift for 5.150 – 5.250 GHz band

2.7.6.5. Discussion

2.7.6.5.1. What is the meaning of center frequency shift? To coordinate with USA allocation

## *2.8. Reports*

2.8.1. Bonneville Tiger Team

2.8.1.1. Al Petrick reports in place of Brian Mathews. There is no Report – Will present update in Berlin

2.8.2. Secretaries Tiger Team

2.8.2.1. Harry will issue report by Friday of this week.

## *2.9. Old Business*

2.9.1. 802.18 PAR and 5C response from 802.11

2.9.1.1. Al Petrick presents the 802.11 response to the 802.18 PAR, contained in document 04/798:

2.9.1.1.1. Suggested changes to scope: a. Scope suggests that Cognitive functions are exclusive to point-to-multipoint systems.

2.9.1.1.2. Comment on scope: “2. Are there other standards or projects with a similar scope? (Item 15 of the PAR): We believe a No answer is inadequate and requires an explanation. For example; why 802.16d and 802.16e, 802.11j, 802.11h are not discussed as having similar or different scope and application.”

2.9.1.1.3. 3. Distinct Identity (PAR 5 Criteria): The justification of distinct identity is insufficient. For example;

2.9.1.1.3.1. a. With respect to point-to-multipoint systems the only distinction of the proposed project is the frequency of operation.

2.9.1.1.3.2. b. With respect to Cognitive radio functions, we note that these apply equally to FCC Part 15 systems such as; 802.11, 802.15 and 802.16.

2.9.1.1.4. 4. Technical Feasibility (PAR 5 Criteria):

2.9.1.1.4.1. We believe the subsequent discussion does not support the elements above and we believe further study is needed. This is particularly true of the Cognitive radio functions.

2.9.1.1.5. 5. General Recommendation: The 802.11WG recommends that the 802 ExCOM sponsor an executive study group to further develop the scope of the Cognitive radio functions and their application to the wireless IEEE 802 systems and propose one or more PARs as applicable.

2.9.1.2. Stuart J. Kerry informs the group that a duly-constituted ad-hoc group created these comments on behalf of 802.11.

2.9.1.3. Carl Stephenson, 802.18 chair, takes the floor and provides the 802.18 response to these comments directly to the 802.11 members.

2.9.1.3.1. Carl presents Document 18-04-031

2.9.1.3.2. Developed by 802.18 and 802.18 SG1 as an official response.

2.9.1.3.3. The 802.18 group presents a rebuttal to the 802.11 comments.

2.9.1.3.4. They believe that a new 802 working group is needed to address the TV-band application and unique requirements.

2.9.1.3.5. They believe that the 802 working group should be formed without further delay for additional study.

2.9.1.3.6. Carl reads an email from Victor Talow, SR VP of MS TV organization of telecasters: Victor supports the effort to establish a new working group for standardizing unlicensed operation in the TV band.

2.9.1.3.7. Carl reads a message he from Vina Newrock from the Canadian Research Center. Canada is also very interested in this TV band activity.

2.9.1.4. Stuart notes that the ExCom makes the determination of whether a new WG is formed, or the PAR goes to an existing WG.

2.9.1.5. Discussion

2.9.1.5.1. In support of the 802.18 chairs position, and believes a separate WG is needed.

2.9.1.5.2. Stuart Kerry notes that the position of the Ad Hoc group was not yet approved by the full WG. Al Petrick will bring a motion on Friday for the entire 802.11 WG to vote on to confirm the official WG position.

2.9.1.5.3. Stuart J. Kerry announces that there will be an ad-hoc meeting to resolve this issue. It will be posted on the message boards. Al Petrick will coordinate this activity.

### 2.9.2. 802.11i

2.9.2.1. Stuart J. Kerry thanks Dave Halasz for his work in leading the 802.11i task group. Dave thanks the all the members of the TG that helped, including Editor Jesse Walker, and Secretary Frank Ciotti.

### 2.9.3. 802.11e PAR Extension

2.9.3.1. The 802.11e Task Group filled in the extension form in document 04/791. It is purely a procedural form that changes nothing substantive in the PAR, but only extends the TG duration.

| |
|---|
| 2.9.3.2. Move to submit document 11-04-0791-00-000e as the PAR extension request for TGe. |

2.9.3.2.1. Moved John Fakatselis on behalf of TGe
2.9.3.2.2. Discussion
2.9.3.2.2.1. What is the new date of extension? The standard extension is for four years.
2.9.3.2.2.2. The motion passed unanimously in TGe with 20-30 voters.
2.9.3.2.3. Vote: Passes 137 : 0 : 0

### 2.9.4. 802.19 proposed changes to 802 P&P for Coexistence

2.9.4.1. Steve Shellhammer, 802.19 chair, presents document 19-04-0010r6.
2.9.4.2. 802.19 plans to move to conduct an 802 ExCom Letter Ballot.
2.9.4.3. If passed the changes would take effect in November.
2.9.4.4. Would require an addition to the PAR process to specify that WGs create Coexistence Assurance documents (if applicable).
2.9.4.5. A new procedure to forward a draft wireless standard would require a Coexistence Assurance document that would address coexistence with all relevant 802 wireless standards.
2.9.4.6. Discussion
2.9.4.6.1. How may votes would 802.19 have in a sponsor ballot pools? It would be one vote. It is not a veto power.
2.9.4.6.2. 802.19 has a TAG vote. 802.19 members can still vote as an individual in addition.
2.9.4.6.3. Is it the intention to preclude 802.19 from becoming a bottleneck that could impede progress due to lack of time. Correct – 802.19 could abstain due to lack of time like an individual voter.
2.9.4.6.4. The wording of the procedure needs to be fixed. Agreed.
2.9.4.6.5. Would it be possible to remove the reference to unlicensed bands? No, the ExCom specifically limited this to unlicensed bands.
2.9.4.7. Stuart J. Kerry asks Al Petrick to form an Ad Hoc to develop an 802.11 position on this topic by Friday. See Al Petrick for details.
2.9.4.8. Steve Shellhammer states that 802.19 will hold a joint meeting with 802.11 TGn today after lunch.

### 2.9.5. EAP Methodology Requirements

2.9.5.1. Move to request Stuart J. Kerry, Chair of IEEE 802.11 to send the letter in 04/160r6 to Harald Alvestrand IETF Chair, with copies to the IAB and the IESG, Requesting publication of the “EAP Method Requirements for Wireless LANs” as an IETF Informational RFC.
2.9.5.1.1. Moved Dorothy Stanley
2.9.5.1.2. Second Sandy Turner
2.9.5.1.3. Discussion
2.9.5.1.3.1. Correction to the spelling of Alvestrand. No objection to amendment.
2.9.5.1.4. Vote: Passes 127 : 0 : 4

### 2.9.6. Chairs Nominations for AP Functionality SG

2.9.6.1. Dorothy Stanley was nominated by Darwin Engwer
2.9.6.2. Is there any objection to affirm Dorothy Stanley?
2.9.6.2.1. None
2.9.6.3. Dorothy is elected chair by acclamation.
2.9.6.4.

### 2.9.7. 802 Architecture Standing Committee

2.9.7.1. Stuart J. Kerry reviews the presentation sent to the reflector regarding the 802 Architecture Standing Committee.

2.9.7.2. This is not approved until a vote tomorrow. It would be chaired by 802.1 chair Tony Jeffree. There would be a maximum of 2 participants from each WG. The WG chair plus one other.

2.9.7.3. We may have to have two to have an alternate.

2.9.7.4. Stuart J. Kerry is looking for volunteers among people who really understand the standard.

2.9.7.5. Discussion

2.9.7.5.1. We have been discussing architecture within 802.11 for a long time. The best way to couple in our concerns to ExCom would be to create an 802.11 Architectural TAG. We could have the chair of our TAG serve as the liaison to ExCom's committee.

2.9.7.5.2. This should be an ad-hoc to let people discuss both the top-down and bottom-up perspectives. An all-encompassing architecture would be a difficult thing. Suggest another Ad Hoc to discuss how this could be addressed.

2.9.7.5.3. Stuart Kerry assigns Harry Worstell to convene an Ad Hoc group to discuss this.

2.9.7.5.4. 802.1 has produced an architecture, but it doesn't correspond in many cases. Some mechanisms are not being used. Is this a way for 802.1 to gather additional input since few members attend 802.1?

2.9.7.5.5. We don't want this group to have any improper use against or for any other WG.

2.9.7.5.6. How soon do we need to identify volunteers? We need to know by September, so they meetings can start in November.

2.9.7.5.7. Disagrees that the preservation of layering is required. New layers have been created. There may be dissention of opinions.

### *2.10. Announcements / Discussion*

2.10.1. Procedural question on document 04/0767r0

2.10.1.1. A paragraph seems to imply that standards should consider existing implementations.

2.10.1.2. Concern that implementations are used to influence drafts.

2.10.1.3. Requests the chair clarify if drafts are provided for the purpose of implementations.

2.10.1.4. This was regarding Task Group E

2.10.1.5. The WG Chair requests that this be taken off-line.

2.10.2. Document Preparation Instructions

2.10.2.1. Straw Polls: Do members plan to submit? Know where the templates are? Do they know how to fill in fields in Word / PowerPoint / Excel

2.10.2.2. Darwin Engwer presents a list of specific instructions for how to fill in templates and fields for document submissions.

2.10.2.3. Is this worth providing on the web site or server? The group is Unanimous that this should be provided.

2.10.2.4. Darwin Engwer and Harry Worstell will create the formal document of instructions.

2.10.2.5. Suggestion that instructions should be put right in the template.

2.10.3. The 802.18 document was 18-04-0031.

### *2.11. Recess*

2.11.1. The meeting is recessed at 12:19pm

# 3. Friday, July 16, 2004

## *3.1. Opening*

3.1.1. The meeting is called to order by Stuart J. Kerry at 8:00AM.

3.1.2. This session has a hard stop at 12:00 noon, due to the following ExCom meeting.

3.1.3. The chair informs the group that we will adhere to the times for standing orders strictly.

3.1.4. Estimate of 200 people in the room.

## *3.2. Review of officers*

3.2.1. Harry Worstell is in charge of attendance, ballots, documentation and voting.

3.2.2. Al Petrick is in charge of Policy and Treasurer

3.2.3. Tim Godfrey is Secretary

3.2.4. Terry Cole is Technical Editor

3.2.5. Brian Mathews is publicity chair.

## *3.3. Agenda*

3.3.1. From document 04/592r4 – there are no changes for this session so far.

3.3.2. Stuart J. Kerry reviews the agenda for this session.

3.3.3. The agenda is approved with Unanimous consent.

## *3.4. Announcements*

3.4.1. In the standing orders section, we have two motions: empowerment and teleconferences. Chairs are requested to review their motions at the break.

3.4.2. Members are reminded to sign in.

3.4.3. The chair notes that attendance is on the honor system, and some members may have signed in for others.

3.4.4. CAC members are requested to review their slots for the Berlin meeting. Updates are due in 2 weeks.

## *3.5. Letters of Assurance*

3.5.1. The Chair has not received any LOAs./

3.5.2. The chair verifies if all members are aware of the IEEE patent policies. The membership assents.

## *3.6. Documentation Update*

3.6.1. Remember to correctly format the upper corner of documents. The format has not changed – do not use the filename format.

## *3.7. Group Reports*

3.7.1. TGe

3.7.1.1. Report in document 04/840

3.7.1.2. Sponsor Ballot completed with 84%. This meeting addressed all 377 comments. Will conduct recirculation SB after this meeting. Will plan for

December RevCom submission. A comment resolution meeting will be held

3.7.1.2.1. The WG chair addresses a question from the floor from Jennifer Bray: She asked the for his opinion about the use of implementations. The chair declines to answer because the question refers to his personal sponsor ballot comment, and he didn't want to influence the body. Question 1 answer: Standards move ahead, but standards are not to be used for products in the market place. It is an unadopted draft, per the ballot instructions and draft headers. Question 2 answer. Should implementations be considered? We are individual technical experts. Refer back to question 1 We are looking for high quality – 75% is no excuse for reducing quality. The chair declines to answer, noting we produce quality drafts. The member can bring this matter to the LMSC if they wish.

### 3.7.2. ANA Status

3.7.2.1. There are no new requests for assignment or revocation of numbers. It is important to send them by email. There is at least one motion outstanding for such a change.

### 3.7.3. TGj

3.7.3.1. Report in document 04/844

3.7.3.2. SB of Draft 1.5 was approved with sufficient return rate. A comment resolution was held. We want to have a very high quality document suitable for submission to RevCom and standards groups in Japan. TGj will have motions to initiate SB recirc, authorize a comment resolution ad-hoc, and conditionally submit to RevCom. Expecting to be done by September.

### 3.7.4. TGk

3.7.4.1. Report in 04/842

3.7.4.2. Worked on security for measurement frames, MIB review, and integration of Draft 14. Security of measurement frames will be recommended to be handled in a new SG. A motion to initiate LB will be made. Will continue weekly teleconferences. Will have LB comment resolution at next meeting.

### 3.7.5. TGm

3.7.5.1. Report in document 04/699

3.7.5.2. Worked on standard updates, based on submissions and open issues. Three submissions were received and discussed and adopted. They will generate new next in 802.11-rev-ma.

3.7.5.3. Clarify the broadcast SSID = rename to "wildcard'. Clarify use of status and result codes, and probe requests.

3.7.5.4. Halfway complete with work items.

3.7.5.5. Tracking document is 04/801.

### 3.7.6. TGn

3.7.6.1. Report in document 04/839

3.7.6.2. Comparison document was updated – all others remain the same. Timeline remains as planned. Proposals to be posted August 13th.

3.7.6.3. Estimated first LB July 2005.

3.7.6.4. September meeting will be on proposal presentations.

3.7.6.5. Bruce clarifies that partial proposals can be merged to create new proposals. There will be a revised document posted.

3.7.6.6. Stuart notes that TGn will have 34 hours of meeting. Stuart and Harry will assist in running TGn in Berlin.

3.7.6.7. The AP functionality SG does have slots in Berlin.

3.7.7. TGr

3.7.7.1. Report in 04/846

3.7.7.2. Selected editor and secretary, framework documents, scope and requirements, had presentations. Joint meetings with TGs and 802.21. Will continue to have joint TGr/TGs meeting once per session. Ad Hoc meetings were set up: Security for TGr, Current BSS Transition description, and Test Methodology.

3.7.7.3. In September, complete framework. CFP is open – proposals to be presented in November. Letter of Intent required by August 17th, Presentations on server by October 15th.

3.7.8. TGs

3.7.8.1. Report in document 04/xxx

3.7.8.2. Will have teleconferences. In September, will work on requirements and functional specs. CFP is expected in November.

3.7.9. Publicity

3.7.9.1. Report in document 04/838

3.7.9.2. Completed industry group updates, reviewed press releases, and other media coverage.

3.7.9.3. Planning for press releases for 802.11J, 802.11K and 802.11E.

3.7.9.4. Q&A

3.7.9.4.1. there is a document number conflict for 04/838 be sure to get the right one.

3.7.10. WNG

3.7.10.1. Report in document 04/755r1

3.7.10.2. WNG had updates from other standard groups and projects, XG communications, TV spectrum NPRM. There were several presentations on AP functional descriptions and behavior. The SG request on management frame security was approved.

3.7.11. WEIN SG

3.7.11.1. Report in document 04/834r0

3.7.11.2. Refined scope, PAR and roadmap. Open issues include Air Interface and Network to Network issues.

3.7.11.3. Steven requests volunteers liaisons with 3GPP.

3.7.11.4. Held joint sessions with 802.21 – will ensure that PARs are separate and non-overlapping. WEIN will address only 802.11-specific issues.

3.7.11.5. Will work to complete PAR and 5C in Berlin.

3.7.11.6. Will forward liaison letter to IETF.

3.7.12. WNM SG

3.7.12.1. Report in document 04/848r0

3.7.12.2. Still looking for permanent secretary. Completed PAR and 5C, will forward to ExCom.

3.7.13. WAVE SG

3.7.13.1. Report in document 04/837

3.7.13.2. Discussed draft submissions regarding draft amendment. Passed motion to extend SG. Will have a draft submission in September to integrate submissions up to this point. Will have motion in ExCom to approve PAR and 5C to begin Task Group.

3.7.14. WPP

3.7.14.1. Report in document 04/781

3.7.14.2. There were 53 attendees. There were no comments from other 802 groups on the PAR and 5C. There were 6 technical presentations. There

was discussion of the name of the SG, but the name will go away when the groups becomes a TG. The name in the PAR is “evaluation of wireless performance”.

3.7.14.3. Will have motions for teleconferences and extending the SG.

3.7.14.4. Will forward PAR and 5C to NesCom.

#### 3.7.15. WG Ad Hoc Committee

3.7.15.1. Report in document 04/845r0

3.7.15.2. Responded to 802.18 PAR - generated response documents regarding scope and distinct identity. We believe that the 802.18 responses satisfied our concerns. Straw Poll approved supporting 802.18 PAR.

3.7.15.3. 802.19 coexistence changes to 802 P&P – reviewed latest document requiring CA to be tagged to WG and SG Letter Ballots. There will be an ExCom Letter Ballot on this topic. We will be able to forward comments through Stuart Kerry on this issue. Straw Poll indicates that we are satisfied with the changes.

3.7.15.4. 5GHz RLAN protection – We had a teleconference to generate text and analysis. There will be another teleconference to finalize for September. Will review in Berlin.

3.7.15.5. Q&A

3.7.15.5.1. Regarding the responses to the 802.18 PAR – we missed the opportunity for the WG to discuss this issue as a whole. Requests that the chair allocate time on Monday plenary sessions to address such issues.

3.7.15.5.2. The WG chair notes that PARs are posted on the reflector 30 days before meetings. He also notes that the ad-hoc group was going on.

#### 3.7.16. WG Technical Editor

3.7.16.1. Report in 04/005r5

3.7.16.2. 802.11i will be published on July 24th. 802.11h will have an errata due to publishing error.

3.7.16.3. Looking for a rollup of 802.11g/h/i. Also considering the rollup of 802.11e and j.

3.7.16.4. ISO/IEC ballot has closed. 802.11g/h are submitted for fast-track.

3.7.16.5. Q&A

3.7.16.5.1. Was the errata in 802.11h been fixed in the submission to ISO? We have ways to get this corrected.

#### 3.7.17. 802.19 report

3.7.17.1. We are up to revision 7 of the 802.19 P&P changes as a result of WG input. Have coordinated with all wireless WGs. Had a tutorial on Coexistence.

3.7.17.2. Have first draft of Coexistence Methodology document. Created list of standards in unlicensed bands, will also include drafts.

3.7.17.3. Q&A

3.7.17.3.1. Stuart J. Kerry requests that 802.19 documents are copied to 802.11 reflector

### *3.8. Special Orders / Motions*

#### 3.8.1. TGe

3.8.1.1. Request the working group to authorize two sponsor group recirculation ballots, requesting that the sponsor group approve forwarding the 802.11e draft to RevCom for publication

3.8.1.1.1. Moved Kitchin on behalf of TGe

3.8.1.1.2. Motion ID 493

3.8.1.1.3. Discussion

3.8.1.1.3.1. There is a lot of traffic on the reflector regarding power save modes? Is it done? A lot of work was done this week, and many resolutions were made. Based on the discussion this week and the resolutions, the Task Group believes the issue is solved.

3.8.1.1.3.2. The WG chair notes that debate is limited to 1 minute per person.

3.8.1.1.3.3. Can the recirculation be extended to longer due to the number of changes? Suggests 20 to 25 days.

3.8.1.1.3.4. We have specific dates in our procedure 10 document.

3.8.1.1.3.5. Without specific durations in the motion, can we meet the schedule?

3.8.1.1.3.6. We need to have a package for RevCom by the end of October.

3.8.1.1.3.7. There are specific dates for meetings.

3.8.1.1.3.8. The TGe editor says that 25 day recirculation will work.

3.8.1.1.3.9. the WG chair states that the recirculation will be 25 days.

3.8.1.1.4. Vote: Motion passes 147 : 1 : 1

3.8.1.2. Request the task group and the working group to authorize two properly constituted meetings, which may be conducted by telephone, to resolve any comments that might arise as a result of the first and second sponsor group recirculation ballot.

3.8.1.2.1. Moved Kitchin on behalf of TGe

3.8.1.2.2. Discussion

3.8.1.2.2.1. Can we have telephone votes? There is no current mechanism.

3.8.1.2.2.2. What about dates and times? They are in the next motion. We do need to specifically authorize the meeting.

3.8.1.2.2.3. What kind of meeting? Ad Hoc / Formal / etc. This motion is as suggested. It needs to say it is a task group meeting.

3.8.1.2.2.4. The WG chair questions why telephone meetings? If it turns out there are few comments, F2F meeting might be unnecessary.

3.8.1.2.2.5. Objects – resolving comments from a SB should be done at regularly scheduled sessions.

3.8.1.2.2.6. Isn't it the WG chairs prerogative for how comments are resolved?

3.8.1.2.2.7. We have to specify the number of ports for teleconferences. How would we know?

3.8.1.2.2.8. The WG chair rules that this is not by telephone, but a physical meeting, published in advance. Any objections?

3.8.1.2.2.9. Time limit reached: Defer…

3.8.2. TGj

3.8.2.1. Motion: Believing that sponsor ballot comment responses in 11-04/703R1 and the document mentioned below satisfy IEEE-SA rules for sponsor ballot recirculation, authorize a sponsor ballot recirculation of P802.11j draft 1.6 to conclude no later than 9/13/2004.

3.8.2.1.1. Moved Sheung Li, on behalf of TGj

3.8.2.1.2. Motion ID 494
3.8.2.1.3. Vote: Motion passes 103 : 0 : 0

3.8.2.2. Motion: Believing that their work will be progressed significantly and the work conducted per IEEE-SA rules, and believing the meeting has been announced at least 30 days in advance using the WG 802.11 reflector, move to authorize an ad hoc meeting to resolve P802.11j sponsor ballot recirculation comments

3.8.2.2.1. Moved Sheung Li on behalf of TGj
3.8.2.2.2. Motion ID 495
3.8.2.2.3. Discussion

3.8.2.2.3.1. Where has the meeting been announced? On the technical reflector – it was conditional on approval. It will be held on August 13th in San Jose.

3.8.2.2.4. Vote: Motion passes 116 : 0 : 4

3.8.2.3. Motion: believing that the sponsor ballot recirculation of P802.11j D1.6 will likely result in approval of the draft, conditional upon sponsor recirculation approval of D1.6 and review by the comment resolution group that it be placed on the next available RevCom agenda.

3.8.2.3.1. Moved Sheung Li on behalf of TGj
3.8.2.3.2. Motion ID 496
3.8.2.3.3. Vote: Motion passes 106 : 0 : 0

3.8.2.4. Motion: believing that the first sponsor ballot recirculation may not be successful and that subsequent recirculation will likely result in approval of the draft, authorize a SB recirculation of the P802.11j draft produced subsequent to the ad hoc meeting to conclude no later than 11/15/2004 and request that approval of the aforementioned draft be placed on the next available RevCom agenda.

3.8.2.4.1. Moved Sheung Li on behalf of TGj
3.8.2.4.2. Motion ID 497
3.8.2.4.3. Vote: Motion passes 98 : 0 : 1

### 3.8.3. TGk

3.8.3.1. Move to authorize a 40-day Working Group Letter Ballot of 802.11 TGk, draft 1.0 to conclude no later than 9/13/2004.

3.8.3.1.1. Moved Richard Paine on behalf of TGk
3.8.3.1.2. Motion ID 498
3.8.3.1.3. Vote: Motion passes 106 : 0 : 6

### 3.8.4. TGn

3.8.4.1. Motion: Request the .11 WG Chair that a formal liaison with 802.19 be created.

3.8.4.1.1. Moved Bruce Kraemer on behalf of TGn
3.8.4.1.2. Discussion

3.8.4.1.2.1. The WG chair will ask for volunteers after approval.

3.8.4.1.2.2. These liaisons are approved by the WG chair with Unanimous consent of the body.

3.8.4.1.3. Colin Lanzl is nominated as the 802.19 Liaison. No other volunteers.

3.8.4.1.4. The body affirms Colin Lanzl as the 802.19 liaison by acclamation.

3.8.4.2. No action was taken on the 802.21 liaison at this time.

### 3.8.5. WNG

3.8.5.1. Move that the WNG SC recommends that the IEEE 802.11 WG form a study group to examine how to formally describe the IEEE 802.11 Management Frame and Control Frame protection functions and behaviors, with the intent to create a PAR and five criteria to form a new Task Group.

3.8.5.1.1. Moved TK Tan on behalf of WNG

3.8.5.1.2. Discussion

3.8.5.1.2.1. Stuart J. Kerry notes that this has been considered as Maintenance, but it was not appropriate.

3.8.5.1.2.2. What will be the relation to the Security SC? They are separate.

3.8.5.1.2.3. It may not be possible to protect control frames, but still in favor of this. Will unify security for management frames.

3.8.5.1.2.4. Would this start in Berlin? The WG states that it would not start until November.

3.8.5.1.2.5.

3.8.5.1.3. Vote: Approved with Unanimous consent.

### 3.8.6. WAVE SG

3.8.6.1. Motion: Believing that sufficient interest continues and that the PAR and 5 Criteria can be completed per IEEE-SA guidelines during the extension period, request that 802.11 WG continue the charter of the WAV-SG through the January 2005 meeting.

3.8.6.1.1. Moved Broady Cash on behalf of WAVE

3.8.6.1.2. Discussion

3.8.6.1.2.1. There is a PAR going to ExCom today? Yes – it was approved in May, and also with a 15 day LB.

3.8.6.1.3. Vote: Motion is approved with Unanimous consent

### 3.8.7. WEIN SG

3.8.7.1. Move to request the IEEE 802.11 Working Group to extend the (WIEN) Study Group for another 6 months.

3.8.7.1.1. Moved by Steven McCann on behalf of WEIN

3.8.7.1.2. Discussion

3.8.7.1.2.1. Requests a vote on the motion.

3.8.7.1.3. Vote: Motion passes 96 : 0 : 7

3.8.7.2. Move to request the IEEE 802.11 Working Group to approve document 11-04-833r0 and request the IEEE 802.11 Working Group chair to forward it to the IETF.

3.8.7.2.1. Moved by Steven McCann on behalf of WEIN

3.8.7.2.2. Discussion

3.8.7.2.2.1. Steven McCann shows the letter and reads part of it to the body Document 04/833r0

3.8.7.2.2.2. Why is this a priority in creating the PAR and 5C? It is to assist WIEN in creating PAR and 5C.

3.8.7.2.3. Vote: approved by Unanimous consent

3.8.8. WNM SG

3.8.8.1. Move to approve the PAR document IEEE 802.11-04/537r5 and 5 Criteria document IEEE 802.11-04.0681r1 for the Wireless Network Management Study Group and forward to ExCom for Approval.

3.8.8.1.1. Moved Harry Worstell on behalf of WNM SG

3.8.8.1.2. Discussion

3.8.8.1.2.1. Concerns about the PAR – not clear on what the group is going to do. Schedule is aggressive. Lack of explanation in the PAR. Proposes sending PAR to Letter Ballot and collect and address comments.

3.8.8.1.2.2. The SG has considered this thoroughly. The timeline is less aggressive than TGk.

3.8.8.1.2.3. Believes this work should not start until TGk is completed. This work should be concurrent with TGk since there is commonality and a need for coherence between groups.

3.8.8.1.2.4. Is there an empowerment to allow changes to the PAR or 5C in Berlin? Yes.

3.8.8.1.2.5. It would be easier to deal with issues in our WG, rather than have other WGs make comments in November. There is no rush to approve today – suggests it would be approved in September. These group meetings have been posted in advance, and those that worked hard on the PAR and 5C did their best effort. These concerns should have been brought to the SG meetings.

3.8.8.1.2.6. Before we proceed, the WG chair asks for a straw poll: Voting members only. Should this PAR and 5C go to ExCom? Appears to be even for and against.

3.8.8.1.2.7. We could either go to WG Letter Ballot, or further work in Berlin.

3.8.8.1.2.8. Any objection to withdraw motion from the floor? None.

3.8.8.1.3. The WG chair will conduct a 40 day Letter Ballot on the PAR and 5C, and comments will be addressed in Berlin.

3.8.8.1.4. Any objection? None

3.8.8.1.5. Discussion

3.8.8.1.5.1. Since this is a SG can anybody vote? No, this is a WG letter ballot. Any comments from non-voters should be sent to Harry Worstell WNN Chair.

3.8.8.2. Move to request the IEEE 802.11 Working Group to extend the Wireless Networking Management Study Group for another 6 months.

3.8.8.2.1. Moved Harry Worstell on behalf of WNM

3.8.8.2.2. Vote: Approved by Unanimous consent

3.8.9. WPP

3.8.9.1. Request that 802.11 WG continue the charter of the Wireless Performance Prediction SG through the January 2005 meeting.

3.8.9.1.1. Moved Charles Wright on behalf of WPP

3.8.9.1.2. Vote: Approved by Unanimous consent.

3.8.10. Technical Editor

3.8.10.1. Move to submit 802.11i for ISO Fast Track approval through the UK national body. Robin Tasker has volunteered to make the submission and Terry Cole will be the project editor.

3.8.10.2. Moved Terry Cole

3.8.10.3. Vote: Approved by Unanimous consent

### 3.8.11. WG Motions

3.8.11.1. Move to empower the IEEE 802.11 Working Group, Task Groups, Study Groups, and Standing Committees to hold an interim session September 12-17, 2004, to conduct business as required.

3.8.11.1.1. Moved Harry Worstell

3.8.11.1.2. Second Al Petrick

3.8.11.1.3. Discussion

3.8.11.1.3.1. Why do we need to do this? This is because an interim doesn't always have a Quorum.

3.8.11.1.4. Vote: Motion approved by Unanimous consent

3.8.11.2. Move to empower the following TGs/SGs to hold teleconference calls beginning no sooner than July 26th, 2004 through 15 days pas the end of the September Interim session.

3.8.11.2.1. Moved Harry Worstell

3.8.11.2.2. Second Colin

3.8.11.2.3. Discussion

3.8.11.2.3.1. Would it be possible to use a common timezone for all teleconferences? The WG Chair states that the time zone to be used is that of the IEEE office in New Jersey.

3.8.11.2.3.2. The duration needs to be 15 days past the November session, since it is a plenary? No, we authorized ourselves to extend it at the Interim meeting.

3.8.11.2.3.3. Can we adjust the schedule so that all meetings are not on Wednesday?

3.8.11.2.3.4. Having this schedule on the web site would be helpful. The WG chair states it will be posted on the front page of the web site.

3.8.11.2.3.5. The WG chair points out that all information still has to be posted on the reflector.

3.8.11.2.4. Vote: motion passes with Unanimous consent

### 3.8.12. 802.18

3.8.12.1. Closing Report in document 802.18 04/0036

3.8.12.1.1. Worked on PAR for TV band, received input on 5GHz protection. Will create ITUR contribution.

3.8.12.1.2. In September will prepare additional documents, and hold joint meetings and briefings

3.8.12.2. Discussion

3.8.12.2.1. What is the status of the PAR? It was responding to WG comments, attempting to satisfy issues and answer questions. Were there any major objections? There were minor process issues from the wired groups. There were objections from 802.16 – they feel it is their area.

3.8.12.3. Motion: To approve document C80216-04_20.doc (a .16 document reviewed and approved by .18 as a contribution to ITU-R WP9B on Fixed Wireless Access) authorizing the Chair of 802.18 to do necessary editorial and formatting changes, submit to the EC for approval, submit to IEEE-SA for approval, and submit the document to the ITU-R in a timely fashion.

3.8.12.3.1. Moved Carl Stephenson on behalf of 802.18

3.8.12.3.2. Second Al Petrick

3.8.12.3.3. Discussion

3.8.12.3.3.1. What are the issues here? There is work going on in WP9B with respect to broadband access in the licensed bands. This is a revision to point to 802.16 as well as ETSI BRAN standards. To further internationalize 802.16.

3.8.12.3.4. Vote: Motion passes 55 : 0 : 28

## 3.8.13. TGe – continued

3.8.13.1. Motion back on the floor:

3.8.13.2. Request the task group and the working group to authorize two properly constituted meetings, which may be conducted by telephone, to resolve any comments that might arise as a result of the first and second sponsor group recirculation ballot.

3.8.13.2.1. Moved Kitchin on behalf of TGe

3.8.13.2.2. Discussion

3.8.13.2.2.1. What was the vote tally? There were zero disapproves and zero abstains. There were either 17 or 18 voters approving.

3.8.13.2.2.2. The motion on the screen does not reflect the WG chairs changes. Requests an amendment.

3.8.13.2.2.3. Any objection to amend the motion to remove the option of telephone meetings, and

3.8.13.2.2.4. Suggestion that the TGe be specifically stated.

3.8.13.3. Motion as amended: Request the Task Group E and the Working Group to authorize two properly constituted meetings to resolve any comments that might arise as a result of the sponsor group recirculation ballots.

3.8.13.3.1. Amendment approved with Unanimous consent.

3.8.13.3.2. Discussion

3.8.13.3.2.1. What about stating when and where? There is a separate motion that specifies them.

3.8.13.3.2.2. If there is a need for a Venue, it would be hosted in Portland by Sharp.

3.8.13.3.2.3. This motion is simply to obtain authorization.

3.8.13.3.2.4. Need to authorize TGe to conduct a meeting, not request.

3.8.13.4. Motion as amended: Authorize Task Group E to hold two Ad-Hoc comment resolution meetings to resolve any comments that might arise as a result of the sponsor group recirculation ballots.

3.8.13.4.1. Any objection to the amendment? None

3.8.13.4.2. Discussion

3.8.13.4.2.1. Do we need an authorization to issue drafts? Is the Ad-Hoc meeting authorized to issue a new draft? It is a Sponsor Group – we don't need to.

3.8.13.4.3. Vote on the motion: passes 73 : 1 : 3

3.8.13.5. Motion to Approve the 802.11 TGe sponsor ballot package as specified in document 04-841r0

3.8.13.5.1. Motion ID 502

3.8.13.5.2. Moved Kitchin on behalf of TGe

3.8.13.5.3. Discussion

3.8.13.5.3.1. Is this procedure 10? No this is just the package, so we can point to the specific documents.

3.8.13.5.3.2. Can we amend the document to 841r1 to correct a date internally to September 7th.

3.8.13.5.3.3. Amendment approved with Unanimous consent

3.8.13.6. Motion to Approve the 802.11 TGe sponsor ballot package as specified in document 04-841r1

3.8.13.6.1. Amendment approved with Unanimous consent.

3.8.13.6.2. Discussion

3.8.13.6.2.1. Does this meet the ExCom time requirements? Yes.

3.8.13.6.2.2. What if they ask if we voted on it before we produced the document? R1 is on the server?

3.8.13.6.3. Vote: Motion passes 77 : 0 : 2

3.8.13.7. Motion: Request the LMSC ExCom conditional approval to forward the P802.11 TGe draft, as defined in the package approved as document 04-841r1, to RevCom for publication, provided the conditions specified in LMSC procedure 10 should be met.

3.8.13.7.1. Motion ID 503

3.8.13.7.2. Moved Duncan Kitchin on behalf of TGe

3.8.13.7.3. Second Colin Lanzl

3.8.13.7.4. Vote: Motion passes 74 : 0 : 3

### *3.9. New Business*

3.9.1. Security Study Group

3.9.1.1. The Security SG is looking for Nominations.

3.9.1.1.1. Jesse Walker nominated by Harry Worstell

3.9.1.1.2. Any others? None

3.9.1.1.3. Jesse is willing and supported by his sponsor.

3.9.1.1.4. Jesse Walker is elected SG Chair by acclamation

3.9.2. Wireless Performance Task Group

3.9.2.1. Charles Wright has been WPP SG chair.

3.9.2.2. Charles Wright is nominated by Colin Lanzl as WPP Task Group chair.

3.9.2.3. Charles Wright is willing and has sponsorship.

3.9.2.4. Charles Wright is elected TG chair by acclamation

3.9.3. 802.21 liaison

3.9.3.1. Any nominations for 802.21 Liaison? None

3.9.3.2. The WG chair requests nominations to be sent to him by email.

### *3.10. Next Meeting*

3.10.1. Berlin, Germany, September 12-17th

3.10.1.1. The WG chair displays the tentative meetings schedule graphic. TGn has 34 hours. The final agenda will be published 30 days in advance.

3.10.1.2. The hotel and registration is open on the web site.

### *3.11. Adjourn*

3.11.1. The meeting is adjourned at 11:25AM

**IEEE P802.11**
**Wireless LANs**

# Minutes of 802.11 Task Group E
# MAC Enhancements - QoS

## Portland, OR

**Date:** July 12-16, 2004

**Author:** R. R. Miller
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# 1. Monday 4:00 pm Afternoon Session, July 12, 2004

## 1.1. Opening

### *1.1.1. Call to order*

1.1.1.1. John Fakatselis (JohnF) called the meeting to order.

1.1.1.2. Meeting begun at 4:07 pm.

## 1.2. Agenda

### *1.2.1. Review of the agenda*

1.2.1.1. JohnF showed the tentative meeting agenda, 11-04-0592-00-0000

1.2.1.2. 11-04-0592-00-0000-802-11-wg-tentative-agenda-july-2004.xls, on the screen and reviewed the proposed agenda:

1.2.1.3. We would like to go over the objectives, approve the last meeting minutes, have a few papers, and then address the comment resolution process. We shall also need to approve a PAR extension. We will break for dinner at 6 pm, and resume in the evening.

1.2.1.4. Potentially the week will be used for comment resolution. If we are successful in resolving all of the comments, we shall recirculate the draft.

### *1.2.2. Approval of the agenda*

1.2.2.1. JohnF: Is there any discussion on the agenda?

1.2.2.2. JohnF: Hearing none. Any comments, or objections? May we approve the agenda?

1.2.2.3. JohnF: I see no objections, so the agenda is approved.

### *1.2.3. PAR Extension*

1.2.3.1. JohnF: The original PAR expires in November, so we will have to apply for an extension. Duncan will help us with framing this extension.

## 1.3. Reviews of voting rules and process

### *1.3.1. Structural Review*

1.3.1.1. JohnF: TGE uses Roberts Rule of Order. You must be a voting member to bring a motion. If you are not a voting member you may ask a voting member to act on your behalf. Please do not vote if you are not a voting member. Any questions? Hearing, none we shall proceed. We will work on comment resolution. So, I am going to ask, "Are there any questions on the minutes?" "Are there any objections to accepting the minutes?" Hearing none, the minutes are approved.

1.3.1.2. JohnF: I would like to invite Srini to give us an update on comment status.

1.3.1.3. Srini: The sponsor ballot closed about 2 weeks after the meeting with additional comments. We should proceed the same as last time, breaking into ad-hoc groups. The comments are listed in document 546r4. There are about 20 editorial comments, the balance are technical.

1.3.1.4. JohnF: I would like to divide into sub-groups. Srini, what do you recommend for the groups?

1.3.1.5. Srini: EDCA, Power-Save and Other.

1.3.1.6. JohnF: We shall divide into three groups and will work privately on resolutions to provide a list of recommended resolutions later in the week. I shall give priority to the ad-hoc groups, but I will also allow individuals to submit separate resolutions. Any suggestions or questions? Any objection to dividing into ad-hoc groups?

1.3.1.7. Mathilde: Would like to make motions on individual resolutions.

1.3.1.8. JohnF: Wait until we get to that point. Whenever we deal with the resolution process, I will ask for individual and ad-hoc motions before we break. You will have a chance at the 7:30 pm session tonight.

## 1.4. Process

### *1.4.1. Call for Papers*

1.4.1.1. IvanO: I have a paper, document 0744, with companion 0745 offering normative text regarding Block ACK. The material was submitted at 10 o'clock this morning.

1.4.1.2. JohnF: Does this paper address a comment? It would be best to do that.

1.4.1.3. JohnK: I have a paper with motions on TSPEC parameters, document 0767 submitted about 10 minutes ago (4:10 pm). Would like to do it at the 7:30 session. There is no normative text.

1.4.1.4. JohnF: I have three papers so far.

1.4.1.5. Floyd: I have a paper (0694) with normative text to be brought later. It has been on the server since last Friday.

1.4.1.6. Greg: I don't have a document number, but have prepared a paper on power save and will address when it is my turn.

1.4.1.7. JohnF: I would like to get the papers out of the way as soon as possible so ad-hoc groups can have the benefit of the information.

1.4.1.8. Srini: I submit document 0768 with a list of contributors to TGe, and would like the membership to check the names and add names who feel they should be listed. Later I would like to have a motion to add this list. We don't have such a list now, but I was instructed to add one.

1.4.1.9. JohnF: Are there any more papers? Between now and 6 pm, we shall handle this business. Mathilde will present first with a paper and motions on comment resolutions. We will continue with Ivan's paper. Then we shall hear from Srini. But before we start, who will lead the ad-hoc groups? For Power save, Floyd volunteers. For EDCA, Matthew Fischer is sought (not in attendance). Default to Srini. Srini will also handle the "Other" group's comments.

### 1.4.2. Individual Comment Resolutions

1.4.2.1. Mathilde: I shall present two motions regarding power save. Concerns focus on final frame in the service period. When a service period is initiated and the AP sends frames to the station, we must make sure the last frame has the End of Service bit set. For reference, see Benveniste comment 9. Row 198. The motion would be to add text at the end of sub-cause (g).

1.4.2.2. JohnF: This will be part of resolutions? Yes.

1.4.2.3. Mathilde: I wish to make a motion:

1.4.2.4. "Move to adopt as the resolution to comment Amann/7. In the section entitled "AP operation during CP", add the following text at the end of sub-clause (g):

1.4.2.5. 'The frame with the ESOP sub-field in the QoS Control field set to 1 shall be the last frame transmitted by the QAP to the non-AP QSTA using the APSD during the SP' Comments addressed: Amann/7

1.4.2.6. JohnF: Are there any suggestions before we make the motion?

1.4.2.7. Duncan: How many comments are addressed?

1.4.2.8. Mathilde: One.

1.4.2.9. AndrewE: Why are you bringing this as an individual vs. ad-hoc group?

1.4.2.10. Mathilde: I want to get it over with up front.

1.4.2.11. Greg: Is this duplicating something that's already been said in the draft?

1.4.2.12. Mathilde: There are many possibilities, so we must make explicit so that in all conditions the EOS bit is set properly.

1.4.2.13. Greg: Will we stipulate exactly how the AP will do it, or allow the AP to decide how to handle it?

1.4.2.14. Mathilde: The second.

1.4.2.15. JohnF: Any friendly suggestions?

1.4.2.16. Floyd: Make third to last rather than last sentence in the comment.

1.4.2.17. JohnF: Do I have a second?

1.4.2.18. Second: Jennifer Bray

1.4.2.19. JohnF: Is there discussion on the motion?

1.4.2.20. MarkB: Clause (g) is already pretty large, so is this covered already. I don't think we need more words.

1.4.2.21. Mathilde: Must make sure it is the last frame transmitted in service period.

1.4.2.22. Duncan: Given what we've heard, the way we've dealt with this in the past is to let the editor handle it. Isn't this an editorial change?

1.4.2.23. Srini: I'm not sure how to resolve the comment.

1.4.2.24. Mathilde: With differing priorities in different streams, the low priority frame could be the last stream being released. If the high priority buffer has many frames and the low has few, the low priority frame could arrive first. If that happens, the EOS bit will put the station to sleep, but there may still be high priority traffic. We must ensure the last frame transmitted to the station has the EOS bit set.

1.4.2.25. JohnF: Any more discussion?

1.4.2.26. Duncan: Do we have an agreement from the commenter that this would change a "no" to a "yes"?

1.4.2.27. Mathilde: Yes.

1.4.2.28. AndrewE: What about the concern on retries? [Discussion]

1.4.2.29. JohnF: Any more discussion? We can vote against the resolution. Put back the motion.

1.4.2.30. Mathilde: I move to table the motion.

1.4.2.31. JohnF: Is there a second? Jennifer Bray. Is there any objection to table? Hearing none, the motion is tabled.

1.4.2.32. Mathilde: Benveniste/10 is the next comment I wish to address. The problem is that if the ACK to downlink frame with EOS set is missing it's possible that

the frame might not be received by the station. This would trigger a repeat. If the frame is received, but the ACK is lost, the station will have gone to sleep. In such a case, the service period should be considered ended, but currently it would be "awake" now. Mark, want to add any more?

1.4.2.33. MarkB: Essentially this change is trying to maintain alignment with (h). I think it does help the alignment.

1.4.2.34. GregC: This seems similar to rules for bursting frames. Rules say if you don't have an ACK, the burst is ended, regardless of whether in a service period or not. The rules for bursting anytime seem to cover this, so not really a "loose end".

1.4.2.35. AndrewE: It is probably necessary to correct this, though.

1.4.2.36. JohnF: I would like to ask you to make a motion.

1.4.2.37. Mathilde: "Move accept the proposed resolution to comment Benveniste/10"

1.4.2.38. JohnF: Motion seconded? Jennifer seconds

1.4.2.39. JohnF: Any discussion? No. Any objection to accepting this motion? Seeing none, the motion passes.

### *1.4.3. Paper Presentation Preparation*

1.4.3.1. Ivan are you ready with your paper?

1.4.3.2. IvanO: My paper doesn't address a comment, but I would like to insert anyway.

1.4.3.3. JohnF: If it doesn't address a comment, I don't know how to allow---it would be out of order.

1.4.3.4. Mathilde: Does anyone else remember a comment like that?

1.4.3.5. Greg: There have been many comments like that, but not recently.

1.4.3.6. JohnF: The paper will be out of order, since we can't couple to a comment.

1.4.3.7. IvanO: Can someone put in a comment with it so we can address next go-round?

1.4.3.8. JohnF: No, that would conflict with the process.

1.4.3.9. IvanO: I have no choice but to withdraw it. I will try to find someone with a related comment, and bring it up later.

1.4.3.10. JohnF: Any other papers?

1.4.3.11. Floyd: I have a paper to present now.

1.4.3.12. Secretarial note: JohnF Exits 5:05, Mathilde temporarily takes chair, John returns at 5:10 pm.

### *1.4.4. Presentations*

1.4.4.1. Floyd: This paper addresses enhancements to APSD, building upon discussion in Anaheim expressed in a joint proposal document 694. There was a motion at the last meeting, but time ran out.

1.4.4.2. Secretarial note: JohnF Exits 5:05, Mathilde temporarily takes chair, John returns at 5:10 pm. Floyd presents paper.

1.4.4.3. Floyd: I request a Straw Poll: "Do we agree that we want the Max SP Length Static?" Yes or no. Yes 11, No 0.

1.4.4.4. Floyd: I request another Straw Poll: "Do we agree that the downlink AC should be disabled/enabled?" Yes 6, No 0

1.4.4.5. Floyd: I request another Straw Poll: "Do we agree that uplink AC should be disabled/enabled?" Yes 8, No 0

1.4.4.6. Floyd: I request another Straw Poll: "Do we agree with TSPEC signaling to override AC configuration?" Yes 10, No 1

1.4.4.7. Floyd: I request another Straw Poll: "This proposal recaptures the More Data ACK bit. Should we do so?" Yes 6, No 2

1.4.4.8. Floyd: I request another Straw Poll (responding to request from Mathilde): "Do we agree that the QAP should be able to turn down particular configuration of

the ACs selected at (re)association time?": Yes 11, No 1 This concludes the straw polls I need.

## 1.5. Closing

### *1.5.1. Recess*

1.5.1.1. Any objection to recess? Hearing none, we are in recess until 7:30pm

1.5.1.2. Recess at 6:00 pm.

# 2. Monday 7:30 pm Evening Session July 12, 2004

## 2.1. Opening

### *2.1.1. Call to order*

2.1.1.1. JohnF: The meeting is called to order.

2.1.1.2. Meeting in session at 7:36 pm.

## 2.2. Process

### *2.2.1. Presentations (continued)*

2.2.1.1. JohnK: John presents document 0767, with treatment of resolutions related to TSPEC parameters.

2.2.1.2. JohnK: I wish to make several motions:

2.2.1.3. "Move to decline del Prado1, Soomro2 and Kerry2 for reasons stated in bullet point 3, slide 7 and all bullet points on slide 6 of 0767r0."

2.2.1.4. Srini Seconds

2.2.1.5. JenniferB: I move to table the motion, based on the fact that none of the commenters is present.

2.2.1.6. JohnF: We shall vote on tabling the motion. The vote fails 3 yes,10 no, 0 abstain.

2.2.1.7. JohnF: We now vote on the motion itself. The vote passes. 10 yes, 2 no, 1 abstain..

2.2.1.8. JohnK: "Move to decline del Prado2, Soomro1, Soomro3 and Kerry1 for reasons stated on slide 3, bullet point 2 of 0767r0"

2.2.1.9. Second Srini

2.2.1.10. JohnF: We shall vote on the motion. The motion passes 10 yes, 2 no, 1 abstain.

2.2.1.11. JohnK: "Move to accept the suggested resolution in Kandala 50"

2.2.1.12. Second Srini

2.2.1.13. JohnF: We shall vote on the motion. The vote passes 9 yes, 0 no, 4 abstain. Are there any other comment actions.

2.2.1.14. Srini: I have written resolutions for about 25 comments in advance corresponding to "low hanging fruit", which I hope to present tomorrow.

2.2.1.15. JohnF: Anything else?

2.2.1.16. MarkB: I would like to conduct some straw polls on APSD.

2.2.1.17. JohnF: OK, Proceed.

2.2.1.18. MarkB: "Should multiple ACs per service period be allowed?" I would like to poll "yes" and "no", including voters and non-voters. My intention is to encourage discussion on the issue.

2.2.1.19. JohnF: (responding to discussion by Mathilde on Wi-Fi dialogs regarding APSD) I want to divide this away from Wi-Fi issues. Straw Polls are not debates, they should be kept simple. If you don't understand all the details, then say "I abstain/don't know".

2.2.1.20. Greg: We should have four categories instead. "Yes", "No", "Abstain" and "Don't Know"

2.2.1.21. JohnF: OK, let's take the vote. 14 yes, 1 no, 2 abstain, 3 don't know.

2.2.1.22. MarkB: "Should multiple ACs per service period be mandatory (for stations implementing APSD assuming the traffic is present?" 0 yes, 11 no, 0 abstain, 4 don't know.

2.2.1.23. MarkB: "Should overlapping service periods be allowed?" 2 yes,10 no, 4 don't care/abstain, 3 don't know.

2.2.1.24. JohnF: Any other members with comments or presentations?

2.2.1.25. IvanO: Srini found comment 0328 on line 564, Mike Moreton/16, relevant to my paper. I would like to present it now, with a motion and vote tomorrow. Presents document 0744 (author will add title page to file on server) on Block ACK.

2.2.1.26. JohnF: A reminder regarding ad-hoc Power-Save, EDCA and Other. Floyd has indicated that he will remain in the room, so that anyone wanting to discuss power-save resolutions could do so.

## 2.3. Closing

### *2.3.1. Recess*

2.3.1.1. Unless there is an objection, I will recess until 10:30 am Tuesday. Seeing none, we are recessed until then.

2.3.1.2. Recessed at 8:37 pm.

# 3. Tuesday 10:30 am Morning Session July 13, 2004

## 3.1. Opening

### *3.1.1. Call to Order*

3.1.1.1. JohnF: The meeting is called to order

3.1.1.2. Reconvene at10:35 am.

## 3.2. Comment Resolution Process Update

3.2.1.1. JohnF: Duncan, do you want to help with the PAR extension?

3.2.1.2. Duncan: Not ready yet. Will work for readiness at 1:30 pm session.

3.2.1.3. JohnF: I am going to give Srini an opportunity to discuss the comments and resolutions recorded so far. Then I shall recess for members to review the document. Then we shall do a block vote on the resolutions after re-convening.

3.2.1.4. Srini: Document 0627r2 contains the current resolution spreadsheet with comment resolutions I have added.

3.2.1.5. Floyd: While we wait for Srini to set up, I would like to say that the ad-hoc group has been working on power save, with discussion of several proposals for resolution of power save issues. We plan to move on 0695r1 later, as it contains normative text for power save joint ad-hoc recommendations.

3.2.1.6. Srini: This document (627r2) has been on server since last Friday, with comments with resolutions written. Green rows mark ad-hoc group recommendations completed last time, but not acted upon. I shall ask that we

examine the document and then do a block acceptance. These are fixes for minor bugs or issues visited several times over the past years with member-determined agreement on way to go.

## 3.3. Closing

### *3.3.1. Recess*

3.3.1.1. JohnF: Any questions for Srini? No. Any objections to recess until 11:00 am? Hearing none, we are recessed until 11:00 am.

3.3.1.2. Recessed at 10:49am.

## 3.4. Opening

### *3.4.1. Call to Order*

3.4.1.1. JohnF: The meeting will come to order.

3.4.1.2. Meeting in session at 11:00 am

## 3.5. Process

### *3.5.1. Comment Resolution Motions*

3.5.1.1. Srini: There was some confusion. The document contains several resolutions, and I shall be asking that we act on all of them, not just the green ones. I wish to move that we accept the resolutions as written. Are there any questions or comments that would prompt us to remove any of the proposed resolutions?

3.5.1.2. AndrewE: Comment #23?

3.5.1.3. Srini: Comment 23 had a long resolution, and it will be removed from the block motion.

3.5.1.4. AndrewE: Comment #86?

3.5.1.5. Srini: This is a comment wondering if 802.11e can be used for medical applications, especially life-critical ones.

3.5.1.6. Duncan: There is a liability here in using unlicensed for life-critical functions.

3.5.1.7. Srini: We shall remove this one.

3.5.1.8. AndrewE: Comment #289?

3.5.1.9. Srini: Would you like it removed?

3.5.1.10. Estrada: No, just questioning…No need to remove.

3.5.1.11. Srini: This is only an editorial comment. If no more issues, I wish to move:

3.5.1.12. "Move to accept the resolutions as written in 04/627r2 for the comments for which resolutions have been written in 04/627r2 with the exception of comments, Amann/5 (Comment #23), Cooper/1 (Comment #86), and Siep/10 (comment 284)."

3.5.1.13. Greg seconds.

3.5.1.14. JohnF: Is there any objection to passing this motion? Seeing none, the motion passes unanimously.

## 3.6. Closing

### *3.6.1. Recess*

3.6.1.1. JohnF: Is there any objection to recessing to allow the ad-hoc groups to process resolutions? Seeing none we are recessed until 1:30 pm.

3.6.1.2. Recessed at 11:10 am.

# 4. Tuesday 1:30 pm Afternoon Session July 13, 2004

## 4.1. Opening

### *4.1.1. Call to Order*

4.1.1.1. JohnF: Called meeting to order

4.1.1.2. Meeting reconvened at 1:39 pm.

## 4.2. Resolution Progress Discussion

4.2.1.1. JohnF: Are there any resolutions or papers?

4.2.1.2. Floyd: I will be bringing a motion to the floor on behalf of the ad-hoc power-save group.

4.2.1.3. JohnF: I would like to go through the PAR extension request. I would like to determine that the group is OK with submitting Duncan's work on extending the PAR.

4.2.1.4. Duncan: Basically a formality, but necessary. The only substantive bit is why an extension is required, and why the extra time will help. 90% of draft is stable, agreed to by Srini. Corrected mistake on "first draft date" on form to March 01 from March 04. No document number yet.

4.2.1.5. JohnF: Must get document number for motion: [Supplies number] 04-0791.

4.2.1.6. "Move for TGe to submit a PAR extension request as presented in Document 11-04-0791-00-000e" Seconded by Duncan

4.2.1.7. JohnF: Let's vote. Vote Yes 27, No 0, Abstain 0 Is there any other resolution business ready?

4.2.1.8. Floyd: "Move to instruct the TGe editor to incorporate the normative text in document 11-04-0695r0 into the 802.11e draft, with the following changes to the definition of the Max SP Length in document 11-04-0695r0

4.2.1.9. - The Max SP Length is shortened to two bits (bit 1 and bit 2 in the QoS Info field) and the More Data Ack bit (bit 3 in the QoS Info field) is retained

4.2.1.10. - The final two paragraphs of document 11-04-0695r0 are modified as follows (shown on the next page…)

4.2.1.11. 'Move to instruct the editor to incorporate the following text into the 802.11e draft (changes relative to document 11-04-0695r0 are shown in blue)

4.2.1.12. Max SP Length subfield is 2 bits in length and indicates the maximum number of downlink frames the QAP may deliver to a non-AP QSTA during any service period triggered by the non-AP QSTA. Values in the Max SP Length subfield shal be set as follows by a non-AP QSTA.

4.2.1.13. Max SP Length = 00 QAP may release all buffered frames

4.2.1.14. Max SP Length = 01 Maximum of 2 frames per SP

4.2.1.15. Max SP Length = 10 Maximum of 4 frames per SP

4.2.1.16. Max SP Length = 11 Maximum of 6 frames per SP'

4.2.1.17. Non-AP QSTA shall set bit 1, bit 2 and bit 4 thru bit 7 to zero if it does not wish to enable U-APSD triggering and delivery mechanisms during (re) association or if the QAP has indicated not supporting APSD through the APSD subfield in the Capability Information Field"

4.2.1.18.

4.2.1.19. Greg: Is there any way we can adopt a "merger" of Floyd's and Mathilde's proposals?

4.2.1.20. JohnF: [to Floyd] Do you wish to continue?

4.2.1.21. Floyd: Yes Motion seconded by JohnK.

4.2.1.22. JohnF: Any discussion?

4.2.1.23. Jennifer: Would it be possible to modify this later in the week?

4.2.1.24. JohnF: Can move to reconsider later in the week.

4.2.1.25. Duncan: Move to table. ThomasK seconds

4.2.1.26. JohnF: Let us vote on the motion. Vote Fails 5-15-7 Back to the main motion. More discussion?

4.2.1.27. AndrewE: Speak in favor. Proposal in circulation for several weeks downloaded last Thursday, with much discussion following. Enough time to formulate concerns regarding the issues involved. To delay would invoke downside because will pick up more comments on recirculation. Progress will be slowed by trying to add more.

4.2.1.28. JohnF: Speak against the motion?

4.2.1.29. Greg: I advocate a joint proposal, without ambiguity regarding More Bits.

4.2.1.30. JohnF: Before I ask for a second are there any comments? [Much discussion on details of implementation and candidate changes]

4.2.1.31. JohnK: Suggest 10 minute recess to allow for further wording

## 4.3. Closing

### *4.3.1. Recess*

4.3.1.1. JohnF: Do we have anything else before we break? Is there any objection to 15 minute recess? Hearing none, we are recessed until 2:45 pm.

4.3.1.2. Recessed at 2:27 pm.

## 4.4. Opening

### *4.4.1. Call to order*

4.4.1.1. JohnF: The meeting is called or order.

4.4.1.2. Meeting called to order at 2:45 pm

## 4.5. Process

### *4.5.1. Comment Resolution*

4.5.1.1. JohnF: There is a motion on the floor.

4.5.1.2. Duncan: Can we move to postpone? I would like to move to postpone until 1:30 pm tomorrow.

4.5.1.3. JohnF: There is a motion to postpone. I believe this motion is debatable. Is there a second? Greg seconds. Any debate on motion?

4.5.1.4. MarkB: Can we confirm there is still enough time for the editor to meet time constraints?

4.5.1.5. Srini: I think it can be ready.

4.5.1.6. Duncan: I move “To postpone the main motion brought by Floyd Simpson until the TGe Wednesday afternoon session beginning at 1:30 pm”

4.5.1.7. JohnF: Is there any objection to postpone. Hearing no objection, the motion is postponed as stated. Srini, you have the floor.

4.5.1.8. Srini: I would like to get a feel for the disposition of the group for the comment on line 151. I wish to move:

4.5.1.9. Move to resolve comment 151 with the resolution: “ Comment declined. The group believes that there are benefits to using the mechanism in certain cases”

4.5.1.10. Second MarkB

4.5.1.11. JohnF: Any discussion on the motion? None Any objection to accepting the motion. None, so motion passes unanimously.

4.5.1.12. Srini: The next comment is 153, More Data Ack Bit. There a few who think it should be kept. I wish to move:

4.5.1.13. Move to resolve comment 153 with the resolution: " Comment declined. The group believes that there are benefits to using the mechanism in certain cases"

4.5.1.14. Second MarkB

4.5.1.15. JohnF: Is there any objection to accepting the motion. None, so motion passes unanimously.

4.5.1.16. Srini: Next is comment 282.

4.5.1.17. Duncan: I suggest that this comment be declined, as it has no technical impact.

4.5.1.18. JohnF: Do you wish to so move?

4.5.1.19. Duncan: I move to decline the comment

4.5.1.20. Move to resolve comment 282 with the resolution: "Comment declined. The comment has no technical impact."

4.5.1.21. Second Ivan

4.5.1.22. Duncan: I move to call the question. JohnK seconds.

4.5.1.23. JohnF: Are there any objections? No. The question is called. We shall vote. The vote is technical, requiring 75%. The motion passes 9 yes, 3 no, 4 abstain..

4.5.1.24. Srini: Next comment is 186. This should not have been accepted because we did not have a consensus.

4.5.1.25. JohnF: To allow reconsideration you must state why you feel it is necessary.

4.5.1.26. Srini: It is better handled in the fast-roaming TG.

4.5.1.27. JohnF: You are the commenter. You have no reason to say it is incorrect. Therefore, I see no basis for reconsideration.

4.5.1.28. Duncan: I feel that the load element is necessary, but motion must be brought for reconsideration by someone who voted for it..

4.5.1.29. Mathilde: I voted for it and I move that we should reconsider.

4.5.1.30. MarkB seconds for reconsideration.

4.5.1.31. JohnF: Is there any objection to reconsider? None, so motion to reconsider passes.

4.5.1.32. Duncan: Move to amend the motion to resolve comment 183 with the resolution: "Comment declined. the functionality provided by the QBSS Load element is different from that being considered by the Fast Roaming TG."

4.5.1.33. Seconded by Ivan

4.5.1.34. Any objection to accepting this motion? None, so motion passes.

4.5.1.35. JohnF: Anything else from anyone in the room? In order to go for RevCom in November, we must finish the draft this week.

4.5.1.36. Srini: We have 138 comments remaining. 546r5 will be the new comments document and I will upload shortly.

## 4.6. Closing

### *4.6.1. Recess*

4.6.1.1. JohnF: If there is no objection, we will recess until 8:00 am tomorrow. Seeing none, we are recessed.

4.6.1.2. Recess at 3:22 pm.

# 5. Wednesday 8:00 am Morning Session July 14, 2004

## 5.1. Opening

### *5.1.1. Call to Order*

5.1.1.1. JohnF: The meeting is called to order

5.1.1.2. Meeting called to order at 8:09 am

## 5.2. Process

### *5.2.1. Comment Resolution Continuation*

5.2.1.1. JohnF: We would like to pick up with Floyd, whose motion was postponed until Wednesday afternoon.

5.2.1.2. Greg: The compromise has been up on the server since last night. We need the motion to have an r1 instead of r0, and must list the comments addressed.

5.2.1.3. Srini: You can do the latter by making a separate motion.

5.2.1.4. JohnF: Where do we stand on power-save resolutions?

5.2.1.5. Floyd: We have resolved 19 power-save comments. About 38 will be resolved by the compromise proposal. There's an additional 5 or so which could be addressed by Annex H being worked by Mathilde. I will produce a document addressing the remaining 19.

5.2.1.6. JohnF: Please add a note describing the color-coding you are using.

5.2.1.7. IvanO: I have a motion regarding Block ACK. On Monday I presented a document outlining a proposal for improving Block ACK capabilities. I wish to move:

5.2.1.8. "Request that the Editor incorporate changes in document 11-04-0745-00-000e relating to Block Ack Identifier (BID) into the TGe draft."

5.2.1.9. JohnF: Who is the commenter to which this is attached? 0328, Mike Moreton

5.2.1.10. Second by Srini

5.2.1.11. JohnF: Call the question. Vote: 1 yes, 4 no, 14 abstain

5.2.1.12. JohnK: I wish to address a resolution on the TSPEC. I wish to move:

5.2.1.13. "Move to accept the following resolution to Myles/20. 'Comment declined. Although the TSPEC has many parameters, there is an Annex that describes their use for typical applications, aiding developers. Moreover, accepting this change would not fix anything that is broken with the protocol, nor add any required functionality.' "

5.2.1.14. Greg seconds

5.2.1.15. Hearing no discussion. Is there any objection to accepting the motion. No objections. The motion passes unanimously.

5.2.1.16. JohnK: Comment 316, Tan/7 I wish to move:

5.2.1.17. "Move to decline the comment Tan/7 for the same reason as in comment 151"

5.2.1.18. Mat Sherman seconds.

5.2.1.19. Any more discussion?

5.2.1.20. JohnF: I call the question. Is there any objection to accepting this motion? None. Motion passes unanimously.

5.2.1.21. JohnK: Comment 175.

5.2.1.22. "Move to decline the comment Kandala/55 for the reason that "the group believes there is benefit to this feature."

5.2.1.23. Moved by JohnK, seconded Bob Miller

5.2.1.24. JohnF: Any discussion? Hearing none, is there any objection to accepting this motion? None. The motion passes unanimously.

5.2.1.25. JohnK: I wish to propose Kandala/57 consideration. I wish to move:

5.2.1.26. "Move to accept the proposed resolution to Kandala/57"

5.2.1.27. Greg seconds

5.2.1.28. JohnF: Is there any discussion on the motion? None. Is there any objection to accepting the motion? None. Hearing none, the motion passes.

5.2.1.29. JohnK: I'm done.

5.2.1.30. JohnF: We appear to have a shot at recirculation, so we should try to complete resolutions to all comments. Are there any other resolutions ready?

5.2.1.31. Floyd: I wish to announce that 0804 is on the server with proposed resolutions shown in green. I want to bring forward the vote on the motion to this morning.

5.2.1.32. JohnF: I do not want a protest by someone who anticipated the previously announced schedule to miss the activity. I would like to recess until 1:30 pm.

## 5.3. Closing

### *5.3.1. Recess*

5.3.1.1. JohnF: We are recessed.

5.3.1.2. Recessed at 9:10 am.

# 6. Wednesday 1:30 pm Afternoon Session July 14, 2004

## 6.1. Opening

### *6.1.1. Call to Order*

6.1.1.1. JohnF: I call the meeting to order.

6.1.1.2. Meeting in session at 1:40 pm

## 6.2. Process

### *6.2.1. Continuation of Comment Resolution*

6.2.1.1. JohnF: We are continuing to resolve the EDCA comments to complete the comment resolution process. Floyd, please begin with the power-save resolutions.

6.2.1.2. BobM: Minutes up to the end of the morning meeting of July 14 are now available on server as document 0813.

6.2.1.3. Floyd: 0804r1, on sheet 1 there are 19 green comments of a total of 62. The ones colored yellow we believe will be resolved with the "compromise" proposal to be discussed later. The 5 remaining white ones will have to be addressed to close out the power-save resolutions. I wish to move:

6.2.1.4. "Move to accept the resolutions in document 0804r1 that are colored in green"

6.2.1.5. JohnF: We need to determine if there are any exceptions for the block motion.

## 6.3. Closing

### *6.3.1. Recess*

6.3.1.1. Is there any objection to a 15 minute recess to allow members to review the resolutions. Hearing none we are recessed until 2:05 pm.

6.3.1.2. Recessed at 1:49 pm.

## 6.4. Opening

### 6.4.1. *Call to Order*

6.4.1.1. JohnF: I call the meeting to order.

6.4.1.2. Meeting in session at 2:05 pm

## 6.5. Process

### 6.5.1. *Continuation of Comment Resolution*

6.5.1.1. JohnF: We revisit the motion brought by Floyd. Are there any resolutions members would like to pull out for separate discussion?

6.5.1.2. "Move to accept the resolutions in document 0804r1 that are colored in green except Benveniste/10,14,15"

6.5.1.3. Greg seconds.

6.5.1.4. Any discussion. None. Is there any objection to accepting this motion. Seeing none, the motion is passed. We had a motion to postpone on a motion, which will be brought up now.

6.5.1.5. JohnF: There has been a good deal of discussion regarding this motion, and I would like to entertain friendly changes to create a final motion. Floyd, please create the modified motion and show the original and modified text. [Blue is added/modified, red is old text]

6.5.1.6. Move to instruct the TGe editor to incorporate the normative text in document 11-04-0695r2 11-04-0695r0 into the 802.11e draft, with the following changes and which addresses the comments listed on slide 3.

6.5.1.7. – Delete section 7.3.1.9 of doc 11-0400695r2

6.5.1.8. – Remove following 2 sentences from section 11.2.1.4:

6.5.1.9. "The QAP may reject (re)association requests if it is incapable of supporting the U-APSD usage selection a non-AP QSTA has made in (re)association requests. QAP shall inform non-AP QSTA its rejection by including Status Code 44 in (re)association responses."

6.5.1.10. to the definition of the Max SP Length in document 11-04-0695r0

6.5.1.11. – The Max SP Length is shortened to two bits (bits 1 and 2 in the QoS Info field) and the More Data Ack bit (bit 3 in the QoS Info field is retained

6.5.1.12. – The final two paragraphs of document 11-0400695r0 are modified as follows (shown on next page…)

6.5.1.13. 'Move to instruct the editor to incorporate the following text into the 802.11e draft (changes relative to document 11-04-0695r0 are shown in blue)

6.5.1.14. Max SP Length subfield is 2 bits in length and indicates the maximum number of downlink frames the QAP may deliver to a non-AP QSTA during any service period triggered by the non-AP QSTA. Values in the Max SP Length subfield shal be set as follows by a non-AP QSTA.

6.5.1.15. Max SP Length = 00 QAP may release all buffered frames

6.5.1.16. Max SP Length = 01 Maximum of 2 frames per SP

6.5.1.17. Max SP Length = 10 Maximum of 4 frames per SP

6.5.1.18. Max SP Length = 11 Maximum of 6 frames per SP'

6.5.1.19. Non-AP QSTA shall set bit 1, bit 2 and bit 4 thru bit 7 to zero if it does not wish to enable U-APSD triggering and delivery mechanisms during (re) association or if the QAP has indicated not supporting APSD through the APSD subfield in the Capability Information field"

6.5.1.20. Comments addressed by the motion:

6.5.1.21. Amann/7, Amann/11, Barr/7, Barr/8. Barr/9, Barr/13, Barr/14, Barr/16, Barr/21, Barr/25, Barr/26, Barr/27, Barr/28, Bjose/28, Ecklund/1, Ecklund/2, Ecklund/3, Ecklund/4, Ecklund/5, Ecklund/6, Ecklund/7, Ecklund/8, Hansen/10,

Hansen/12, Kandala/9, Kandala/22, Benveniste/6, Benveniste/7, Benveniste/8, Benveniste/12, Benveniste/13, Myles/1, Myles/2, Myles/3.

6.5.1.22. Amann/7, Amann/11, Barr/7, Barr/8. Barr/9, Barr/13, Barr/14, Barr/16, Barr/21, Barr/25, Barr/26, Barr/27, Barr/28, Bjose/28, Ecklund/1, Ecklund/2, Ecklund/3, Ecklund/4, Ecklund/5, Ecklund/6, Ecklund/7, Ecklund/8, Hansen/12, Kandala/9, Kandala/22, Benveniste/6, Benveniste/7, Benveniste/8, Benveniste/12, Benveniste/13, Myles/1, Myles/2, Myles/3.

6.5.1.23. Motion to amend the motion as shown by Floyd. AndrewE seconds

6.5.1.24. Is there any objection to amending the motion as shown. None. Therefore the motion to amend passes. The motion is now:

6.5.1.25. Move to instruct the TGe editor to incorporate the normative text in document 11-04-0695r2 into the 802.11e draft, with the following changes and which addresses the comments listed on slide 3.

6.5.1.26. – Delete section 7.3.1.9 of doc 11-0400695r2

6.5.1.27. – Remove following 2 sentences from section 11.2.1.4:

6.5.1.28. “The QAP may reject (re)association requests if it is incapable of supporting the U-APSD usage selection a non-AP QSTA has made in (re)association requests. QAP shall inform non-AP QSTA its rejection by including Status Code 44 in (re)association responses.”

6.5.1.29. Comments addressed by the motion:

6.5.1.30. Amann/7, Amann/11, Barr/7, Barr/8. Barr/9, Barr/13, Barr/14, Barr/16, Barr/21, Barr/25, Barr/26, Barr/27, Barr/28, Bjose/28, Ecklund/1, Ecklund/2, Ecklund/3, Ecklund/4, Ecklund/5, Ecklund/6, Ecklund/7, Ecklund/8, Hansen/12, Kandala/9, Kandala/22, Benveniste/6, Benveniste/7, Benveniste/8, Benveniste/12, Benveniste/13, Myles/1, Myles/2, Myles/3.

6.5.1.31. [Discussion]

6.5.1.32. Moved by Floyd/Second AndrewE

6.5.1.33. JohnF: Is there any objection to accepting this motion? Seeing none, the motion passes unanimously. Is there any objection to recessing until 4:00 to allow ad-hoc committees to resolve the remaining resolutions?

## 6.6. Closing

### *6.6.1. Recess*

6.6.1.1. Seeing no objections, we are recessed.

6.6.1.2. Meeting adjourned at 2:59 pm.

## 6.7. Opening

### *6.7.1. Call to Order*

6.7.1.1. JohnF: I call the meeting to order.

6.7.1.2. Meeting in session at 4:05 pm

## 6.8. Process

### *6.8.1. Continuation of Comment Resolution*

6.8.1.1. JohnF: Informally, people who understand Annex H should try to get together so that resolutions can be completed. We are running low on time, and will have to post a document in time to act upon it. Our meeting tomorrow is late (4:00 pm) so we will not have a whole lot of time to act.

6.8.1.2. Mathilde: We will have to post a document by 12:00 noon. I need changes by 10:00 am in order to incorporate the inputs. Mathilde will submit a paper this evening for comment.

6.8.1.3. JohnF: [to Floyd] Please coordinate with members working on Annex H.

6.8.1.4. Srini: We have resolved a total of 1 comment for EDCA. We still have about 18 to go. I have a motion to bring on the "Other" comment resolutions. Reference for this block move is in document 0627r4. There are 28 resolutions included. I wish to move:

6.8.1.5. Move to accept the resolutions as written in 04/627r4 for the comments for which resolutions have been written in 04/627r4 with the exception of comments…

6.8.1.6. JohnF: Before I request a second, I would like to have any exceptions for resolutions members wish removed from the motion. None. Hearing none, the motion is without exceptions. The motion reads:

6.8.1.7. Move to accept the resolutions as written in 04/627r4 for the comments for which resolutions have been written in 04/627r4.

6.8.1.8. Ivan seconds.

6.8.1.9. JohnF: Is there any discussion on the motion? None.

6.8.1.10. JohnF: Is there any objection to accepting the motion on the screen? None. Seeing none, the motion passes unanimously. Is there any objection to recess for the ad-hoc groups to conduct their work on the balance of the comments? None.

## 6.9. Closing

### *6.9.1. Recess*

6.9.1.1. JohnF: Seeing no objections, we are recessed until tomorrow.

6.9.1.2. Meeting recessed at 4:20 pm.

# 7. Thursday 4:00 pm Afternoon Session July 15, 2004

## 7.1. Opening

### *7.1.1. Call to Order*

7.1.1.1. JohnF: I call the meeting to order.

7.1.1.2. Meeting in session at 4:00 pm

## 7.2. Process

### *7.2.1. Continuation of Comment Resolution*

7.2.1.1. JohnF: I wish to try to wrap up all of the technical comments, and then address some procedural issues. These procedural issues are related to making sure that we are ready for November. For example, we may have to pursue recirculation now, then prepare a procedure 10 process, ask for recirculation again, and then submit to Revcom.

7.2.1.2. Floyd: I wish to present some resolutions. 0804r2 posted to server yesterday, contains ~62 documents, with about 9 highlighted for action in this session. I wish to move:

7.2.1.3. Move to accept the resolutions provided and colored in green in document 04/0804r2 for the following comments Benveniste/14. Benveniste/15, and the resolutions provided and colored in yellow in document 04/0804r2 for comments Barr/18, Barr/23, Barr/24, Hansen/10, Benveniste/1 and Benveniste/11.

7.2.1.4. [Benveniste/4 and Benveniste/5 had been included in the motion, but were removed by friendly amendment by MathildeB]

7.2.1.5. JohnF: Does anyone need additional time to review these documents. No. Very well, may I ask for a second?

7.2.1.6. Srini seconds.

7.2.1.7. JohnF: Is there any discussion on the motion? None. Is there any objection to accepting the motion? None. Seeing none, the motion passes unanimously.

7.2.1.8. Srini: I wish to work with the group on documents 627r6 and 0771r2. In 627r6 we have 4 comments, missed during previous resolutions. Most of the comments are straightforward. I wish to move:

7.2.1.9. Move to accept the resolutions as written in 04/627r6 for the comments for which resolutions have been written in 04/627r6.

7.2.1.10. JohnK seconds.

7.2.1.11. JohnF: Is there any discussion on the motion? None. Is there any objection to accepting this motion? None. Seeing none, the motion passes unanimously.

7.2.1.12. Srini: The next motion is 077r2. There are 32 comments in the document; we have resolved 31 of them. I wish to move:

7.2.1.13. Move to accept the resolutions as written in 04/771r2 for the comments for which resolutions have been written in 04/771r2.

7.2.1.14. JohnF: Is there anyone who needs more time to review this document. None. May I have a second for the motion?

7.2.1.15. JohnK seconds.

7.2.1.16. JohnF: Is there any discussion on the motion? No. Are there any amendments? No. Is there any objection to accepting this motion? None. The motion passes unanimously.

7.2.1.17. Srini: I'd like to address the last remaining comment on line 6 (EDCA) in 04/0771r2.

7.2.1.18. MarkB: The reason for this is the More Data Ack issue.

7.2.1.19. Srini: I wish to move:

7.2.1.20. Move to accept the comment Kandala/41

7.2.1.21. Second by JohnK.

7.2.1.22. JohnF: Is there a need to discuss this motion? No. Hearing no wish to discuss, is there any objection to accepting this motion? None. Seeing none, the motion passes unanimously. I shall limit debate on the remaining comments/resolutions to 5 minutes each. The motions will be understood as approving acceptance of the resolution(s).

7.2.1.23. Mathilde: I wish to discuss Chaplin/3. There is no document reference.

7.2.1.24. "Comment declined. This is clear in Section 11.4.1.5 and the Annex of the TGe draft. The AP will observe medium access rules of Clause 9 using the EDCA parameter selected for the AP. The AP will transmit the buffered frames for a PS station as close to, and following, the scheduled wake up time by not transmitting to other stations."

7.2.1.25. JohnK seconds.

7.2.1.26. JohnF: Is there any discussion on line 62 on the screen. Is there any objection to accepting this resolution? No. The motion passes unanimously.

7.2.1.27. Mathilde: The next comment is on Line 61, Chaplin/2. "Comment declined. Replace the word "immediately" in H.4.2.2 with the words: ' The station will access the channel using normal EDCA rules. The station experiences less contention when it wakes up for scheduled APSD because there are fewer stations contending for the channel; other PS stations will not typically be awake competing for the channel at the same time' "

7.2.1.28. Srini: I suggest an alternate resolution: Delete Annex H.

7.2.1.29. JohnF: Time has expired for consideration of this resolution. Mathilde, do you wish to move on?

7.2.1.30. Mathilde: No. I want to stay with this one.

7.2.1.31. Jennifer seconds.

7.2.1.32. JohnF: Is there any discussion on the motion? Yes.

7.2.1.33. JohnK and DuncanK speak against the motion.

7.2.1.34. JohnK calls the question. Seconded by Duncan.

7.2.1.35. JohnF: It requires a 2/3 majority to call the question. Is there any objection to calling the question? None. Then we shall vote. Voting members, please. Hold up your tokens. The motion requires 75% to pass. It fails 3 yes, 13 no, 4 abstaining. We shall consider this comment unresolved. Next comment?

7.2.1.36. Mathilde: The next comment is Barr/10. "Alternate resolution: Change the paragraph to 'It should be evident that unscheduled service periods are useful if there exists at minimum one uplink and one downlink TESPEC; because if there is no downlink TSPEC, the QAP will not buffer frames for unscheduled delivery and if there is no uplink TSPEC the non-AP QSTA will be unable to issue trigger frames. A bi-directional reservation is considered to be equivalent to an uplink plus a downlink TSPEC with identical characteristics---including the setting of the APSD and schedule subfield---so a single admitted bi-directional reservation satisfies the minimal requirement. If necessary, the non-AP QSTA may establish an uplink traffic stream consisting of QoS-Null frames, and use these frames to trigger unscheduled service period each time the QSTA is ready to receive buffered frames and use these frames to trigger unscheduled service period each time the QSTA is ready to receive buffered frames via unscheduled delivery.' "

7.2.1.37. DuncanK calls the question. Second JohnK.

7.2.1.38. JohnF: Is there any objection to calling the question? No. Let us vote. The vote fails 2 yes, 14 no, 4 abstaining, so this comment will remain unresolved.

7.2.1.39. Mathilde: The next comment is Tan/3, line 60, referring to Annex H 4.1. "Accepted. Clarification is provided in document 04/073r4. Instruct the editor to… "

7.2.1.40. Srini: I protest. I need to have an explicit resolution.

7.2.1.41. JohnF: I have given the floor to Mathilde. She is almost done. We have a half hour before we are done.

7.2.1.42. Mathilde: "Accepted. Clarification is provided in document 04/073r4. Instruct the editor to incorporate the text of 04/073r4 into the TGe draft to address this comment."

7.2.1.43. JohnF: Is there a second for this motion?

7.2.1.44. Jennifer seconds.

7.2.1.45. JohnF: Is there discussion? Yes.

7.2.1.46. Duncan: If you look at the suggested change, it says clarify or remove it. I would like to remove the whole thing, and I will make a motion to that effect. I call the question.

7.2.1.47. Second JohnK.

7.2.1.48. JohnF: The question is called. We shall vote on calling the question. The vote passes 18 yes, 1 no, 1 abstain. We shall now vote on the motion. Vote fails 2 yes, 15 no, 5 abstaining, so this comment remains unresolved.

7.2.1.49. Mathilde: The next comment is Benveniste/4. "Accepted. Adopt the informative text in 04/073r4"

7.2.1.50. JohnK: I suggest that you also make the motion for Benveniste/5 as well.

7.2.1.51. Duncan: I'd like to lodge a point of order.

7.2.1.52. JohnF: I suggest you withdraw this. [Withdrawn] Is there any discussion. No discussion is proper unless there is a motion on the floor. OK the motion was completed. Mathilde, you can go ahead with discussion.

7.2.1.53. Mathilde: Discussions in Wi-Fi have centered on use of APSD for voice and data. After debating this for several months, several companies have designed it in, so now Wi-Fi has…

7.2.1.54. JohnF: Time has run out.

7.2.1.55. Duncan: I second the motion.

7.2.1.56. JohnF: Is there any discussion on the motion?.

7.2.1.57. JohnK: I move to amend the motion to include Benveniste/5 with Benveniste/4 in the resolution.

7.2.1.58. Duncan: I second the motion to amend.

7.2.1.59. JohnF: Are there any clarifications needed? No. Is there any discussion? Yes.

7.2.1.60. Mathilde: The reasons are different for resolving the two comments. I object to the amendment.

7.2.1.61. JohnK: My reading of Benveniste/5 and Benvieniste/4 is that they are the same, therefore the resolutions must be the same.

7.2.1.62. JohnK: I call the question. Seconded by Duncan.

7.2.1.63. JohnF: Is there any objection to call the question? Yes. We vote. The vote passes 21 yes, 0 no, 1 abstaining. So the question is called, we vote on the motion to amend. The vote passes 24 yes, 0 no, 3 abstaining.

7.2.1.64. JohnK: I call the question.

7.2.1.65. Duncan seconds

7.2.1.66. JohnF: We now vote on calling the question. Vote passes 21 yes, 1 no, 1 abstaining. We now vote on the main motion, now amended to include Benveniste/5 and Benveniste/4.

7.2.1.67. Mathilde: The motion now reads: “Comment Accepted. Adopt the informative text in document 04/073r4 in resolution of Benveniste/4 and Benveniste/5”

7.2.1.68. JohnF: We now vote on the motion. The vote fails 2 yes, 16 no, 2 abstain

7.2.1.69. JohnF: I would like to entertain some alternative resolutions.

7.2.1.70. Duncan: I have a motion:

7.2.1.71. Instruct the editor to make the following modifications to the draft in resolution of comments Tan/3, Chaplin/2, Benveniste/4, Benveniste/5, Barr/10 and Barr/11: “ Delete Annex H Subclause 4 and provide the following text as a comment resolution: ‘In order to resolve numerous points of confusion in the informative annex H.4, the text from that subclause has been removed.’ ”

7.2.1.72. JohnF: Mathilde has the floor.

7.2.1.73. Mathilde: I suggest a friendly amendment that we should take the entire document 073r4, take the relevant portions and take the changes and incorporate those, to preserve Annex H and avoid gathering more no votes than we had.

7.2.1.74. Duncan: I am not going to accept this as it is clearly not a friendly amendment; it changes the intent completely.

7.2.1.75. JohnK: I second the motion.

7.2.1.76. JohnF: Is there any discussion? Yes.

7.2.1.77. Jennifer: Why can’t we simply bring back the resolutions?

7.2.1.78. Duncan: It is impossible to bring back the previously voted resolutions, as it would be out of order.

7.2.1.79. JohnK: I wish to call the question.

7.2.1.80. Srini seconds.

7.2.1.81. JohnF: Are there any objections? Yes. We shall take a vote. The vote passes 10 yes, 3 no, 0 abstaining. The question is called.

7.2.1.82. Jennifer: Parliamentary inquiry?

7.2.1.83. Duncan: Motions which have been made cannot be called back, without motion to reconsider.

7.2.1.84. JohnF: Is there any further parliamentary inquiry? [pause] No. Is there any objection to continuing? [pause] No. Bob, please record in the minutes. We will now vote on the motion. It is technical. The motion passes 18 yes, 2 no, 2 abstaining. We have only two minutes left. Is there any objection to recess for dinner? No.

## 7.3. Closing

### *7.3.1. Recess*

7.3.1.1. JohnF: Seeing no objection, we are in recess.

7.3.1.2. Session recessed at 5:59 pm.

# 8. Thursday 7:30 pm Evening Session July 15, 2004

## 8.1. Opening

### *8.1.1. Call to Order*

8.1.1.1. JohnF: I call the meeting to order.

8.1.1.2. Meeting in session at 7:39 pm.

## 8.2. Process

### *8.2.1. Preparation for Recirculation and RevCom Submittal*

8.2.1.1. JohnF: All we have left is old business, new business, special orders, and approving a new draft. The next will be submission for recirculation and the necessary motions to do that. Duncan will assist with the recirculation process setup. We had a motion at the working group on Wednesday, and have done all the work to extend the PAR. I know Srini has two items. At 8:00 pm we shall start on the recirculation process.

8.2.1.2. Srini: I refer to Document 957r1, TGe's request to ANA.

8.2.1.3. Tgi has used the Status Codes 40-43 assigned to TGe. I wish to move:

8.2.1.4. Move to request the ANA to reassign Status Codes for the described settings in slide 3, preferably with the values in the left column.

8.2.1.5. JohnK seconds.

8.2.1.6. Duncan: I'm not sure whether these numbers are available. If you ask for specific numbers, you can get them if they are available. You need not ask for specific numbers.

8.2.1.7. JohnF: Is there any discussion? No. Is there any objection to passing this motion? No. The motion passes unanimously.

8.2.1.8. Srini: TGe also needs some new reason codes. I move:

8.2.1.9. Move to request the ANA to release Reason Code 36 and be made available for future assignments.

8.2.1.10. JohnK seconds.

8.2.1.11. JohnF: Is there any discussion? No. Is there any objection to passing this motion? No. The motion passes unanimously.

8.2.1.12. Move to request the ANA to assign Reason Codes for the described settings in slide 7, preferably with the values in the left column.

8.2.1.13. Seconded JohnK.

8.2.1.14. JohnF: Is there any discussion? No. Is there any objection to passing this motion? No. The motion passes unanimously.

8.2.1.15. Srini: I present document 768r1 on the screen. I have assembled some names of individuals I believe have contributed the standard, however I would entertain addition of others who feel they have contributed. [Members add some names, and Srini changes to 768r2] I wish to move:

8.2.1.16. Move to instruct the editor to add the names in 04/768r2 to the next TGe draft as contributors to the draft.

8.2.1.17. Seconded by BobM.

8.2.1.18. JohnF: Is there any discussion on this motion? No. Is there any objection to accepting the motion as shown? No. The motion passes unanimously. I want to give the floor to Duncan to provide motions to prepare the TGe draft for the RevCom review.

8.2.1.19. Duncan: In order to do this, we have to ask ExCom to submit the draft to RevCom at a plenary. In order to prepare for this we have to invoke Procedure 10 to allow a conditionally-approved draft to be forwarded. So we shall do two recirculations of the same document to meet the conditions for Procedure 10 (which requires no new comments). First, we will ask the editor to release a draft. Then we shall submit two requests for recirculation. Lastly, we shall prepare for submission to RevCom.

8.2.1.20. Duncan: I wish to move:

8.2.1.21. Instruct the editor to create a revision of the 802.11e draft, incorporating all comment resolutions accepted by the task group and noted in document 04-546r9 into draft P802.11e D8.0.

8.2.1.22. Document placed on server by Srini. Seconded by JohnK.

8.2.1.23. JohnF: Is there any discussion? No. Is there any objection by any voting member to passing this motion? No. The motion passes unanimously

8.2.1.24. Duncan: I wish to move:

8.2.1.25. Request the working group to authorize two15-day sponsor group recirculation ballots, requesting that the sponsor group approve forwarding the 802.11e draft to RevCom for publication.

8.2.1.26. Seconded by JohnK.

8.2.1.27. JohnF: Is there any discussion on the motion? No. Voters, please hold up your tokens. The vote is 17 yes, 0 no, 0 abstaining. The motion passes unanimously.

8.2.1.28. Duncan: I wish to move:

8.2.1.29. Request the task group and the working group to authorize a properly constituted meeting, which may be conducted by telephone, to resolve any comments that might arise as a result of the first sponsor group recirculation ballot.

8.2.1.30. Seconded by JohnK.

8.2.1.31. JohnF: Is there any discussion on this motion? No. Voters, please hold up your tokens. The motion passes unanimously 18 yes, 0 no, 0 abstains.

8.2.1.32. Srini: I would like to show document 841r0 on the server with TGe Sponsor Ballot Information in preparation for the submission process. The document specifies that the package includes the document itself, the 802.11 TGe draft 8.0, and the sponsor ballot comment resolution document IEEE 802.11-04-546r9. We should approve another resolution meeting in addition to the one just approved for resolutions from the second recirculation ballot.

8.2.1.33. Duncan: I wish to move:

8.2.1.34. Approve the 802.11 TGe sponsor ballot package as specified in document 04-841r0

8.2.1.35. Seconded by BobM.

8.2.1.36. JohnF: Is there any discussion on this motion? No. Voters, please hold up your tokens. The motion passes unanimously with 16 yes, 0 no, 0 abstains.

8.2.1.37. Duncan: I wish to move:

8.2.1.38. Request the task group and the working group to authorize a properly constituted meeting, which may be conducted by telephone, to resolve any comments that might arise as a result of the second sponsor group recirculation ballot.

8.2.1.39. JohnK seconds.

8.2.1.40. JohnF: Is there any discussion on this motion? No. Voters, please hold up your tokens. The motion passes unanimously with 18 yes, 0 no, 0 abstains.

8.2.1.41. Duncan: I wish to move:

8.2.1.42. Approve the 802.11 TGe sponsor ballot package as specified in document 04-841r0.

8.2.1.43. JohnF: Is there any discussion on this motion? No. Voters, please hold up your tokens. The motion passes unanimously 18 yes, 0 no, 0 abstains.

8.2.1.44. Duncan: I wish to move:

8.2.1.45. Request the working group to request of the LMSC ExCom conditional approval to forward the P802.11 TGe draft, as defined in the package approved as document 04-841r0, to RevCom for publication, provided the conditions specified in LMSC Procedure 10 should be met.

8.2.1.46. JohnK seconds.

8.2.1.47. JohnF: Is there any discussion on this motion? No. Voters, please hold up your tokens. The motion passes unanimously 18 yes, 0 no, 0 abstains. This brings to a close our scheduled work for this week. Is there anything else from anyone in the meeting?

8.2.1.48. MarkB: I have a particular issue that came up as part of the activity on APSD. May I present an short paper informally?

8.2.1.49. JohnF: You may proceed.

8.2.1.50. MarkB: I've prepared some slides which are not on the server. One of the sentences in the power-save resolutions yesterday was that the "QAP shall ignore subsequent trigger frames sent by a non-AP QSTA if it has already started an unscheduled SP for the station." The intention of this sentence is to further strengthen clause c) of 11.2.1.9 to avoid the client complexity of tracking multiple SPs. However, the protocol will still function (albeit less efficiently) even when SPs inadvertently overlap. Further, the normative statement is problematic because it places some additional and unnecessary restrictions on the AP.

8.2.1.51. I propose that we consider softening the sentence by replacing the "shall" with "should" (e.g. The QAP should not regard a frame as a trigger until the current SP has ended). We may also want to say that the "QSTA should not trigger-enable an AC that carries bursty uplink traffic"

8.2.1.52. Floyd: I support Mark's change.

8.2.1.53. [Discussion]

8.2.1.54. Duncan: I move to adjourn

8.2.1.55. Seconded by JohnK.

## 8.3. Closing

### *8.3.1.* *Recess*

8.3.1.1. JohnF: Is there any objection to recess the work of this task group? Seeing no objection, we are adjourned.

8.3.1.2. Session recessed at 8:59 pm.

# 9. ----------END OF MINUTES----------

# IEEE P802.11
# Wireless LANs

## Meeting Minutes for 802.11j July Plenary, 2004

**Date:** July 15, 2004

**Author:** Andrew Myles, et. al.
Cisco Systems
e-Mail: andrew.myles@cisco.com

## Wednesday, July 14, 4:00PM session

Called to order at 4:07pm

Chair reviewed IP policy

TGj approved agenda by unanimous consent

There was no further material to review on Japanese regulations (see 04/809 for mid week plenary report)

Chair reviewed status of ballot process, noting that the ballot process is owned by the Sponsor Ballot pool

Chair stated today's task is to review remaining Sponsor Ballot comments, so that:

- we can achieve a result much higher than 75%
- we satisfy or respond to all commenters

Chair stated that comment resolutions to date are in document 04/703-00

Peter Ecclesine (editor) stepped through comment resolutions to date and led a discussion on each of the resolved and unresolved comments

Move to accept 04/703-01 and instruct the editor to make appropriate changes to D1.5 and so construct D1.6

- Peter Ecclesine moves
- Andrew Myles seconds
- Yes: 14
- No: 0
- Abstain: 1
- Motion passes

Move to authorise a Sponsor Ballot recirculation of 802.11j D1.6 to conclude no later than 13 September 2004

- Pankaj Karnik moves
- Tom Schaffnit seconds
- Yes: 13
- No: 0

- Abstain: 1
- Motion passes

Move to approve an ad hoc meeting for the purpose of resolving comments in 802.11j D1.6 Sponsor Ballot recirculation to be held prior to 13 September 2004

- Andrew Myles moves
- Thomas Kurihara seconds
- Yes: 14
- No: 0
- Abstain: 0
- Motion passes

Move to authorise a Sponsor Ballot recirculation of 802.11j D1.7 to conclude no later than 15 November 2004, and request that approval of D1.7 be placed on the next available RevCom agenda

- Yasuhiko Inoue moves
- Gunnar Nitsche seconds
- Yes: 15
- No: 0
- Abstain: 0
- Motion passes

Recess for the day at 5:30 pm passes by unanimous consent

## Thursday, July 15, 1:30PM session

Called to order at 1:35pm

Move to request that approval of D1.6 be placed on the next available RevCom agenda

- Yasuhiko Inoue moves
- Peter Molnar seconds
- Yes:3
- No: 0
- Abstain:0

Adjourn for the session at 1:40 pm passes by unanimous consent

# IEEE P802.11
# Wireless LANs

## Minutes for the TGk July 2004 Session

**Date:**

July 15, 2004

**Author:**

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**Monday, July 12, 2004**
**4:00 PM – 6:00 PM**

1. Chair calls the conference to order at 4:00 PM
2. Attendance
3. Review IEEE 802 & 802.11 Policies and Rules
   a. Patent Policy
   b. Inappropriate Topics
   c. Documentation – 4 hour rule for changes that are normative
   d. Voting
   e. Roberts Rules
4. Objectives for Meeting 04-739r1
   a. Comment incorporation into new draft (D0.17)
   b. Security of Measurement Frames Vote
   c. Neighbor Report Vote
   d. MIBs Vote
   e. Incorporation of editor to do
   f. Next major milestone: Letter Ballot
5. Technical Presentation Review
   a. Vote on editor assigned comments
   b. Security Presentation
   c. Zhong
   d. Site Reporting
   e. Bernard – Security Presentation 722
   f. Black (6,11,75,76,96,162,163,191,194,221)
   g. Edney (53)
   h. Kwak (61,63,65,66,67,68,104,107,208,210,219)
   i. Olson (225)
   j. Approval of the teleconference minutes (Garden Grove – Portland)
   k. Moreton
   l. Autonomous Reporting (23) Black Document #758
   m. Black (15)
   n. Johnson (43)
   o. Kwak
   p. Vote on Letter Ballot
6. Move to accept modified agenda – motion passes unopposed
7. Motion for acceptance of editorial comments

   Move to accept the editor-to-do comment resolution from teleconferences contained in document 11-04-480r17.

   [40,41,42,78,79,80,82,83,84,86,91,98,99,100,101,103,106,112,115,116,119,120,121,122,124,126,133,139,140,146,147,150,151,152,153,155,158,159,162,164,166,167,169,170,171,175,177,178,180,181,183,188,189,195,196,197,199,200,201,202,203,204,205,206,207,209,212,214,215,216,217,220,222,223,224,228,230,236,237,238,240,242,243,244,245]

   Moved: Kwak
   Seconded: Johnson

For: 15 Against: 0 Abstain: 1

Motion passes 100%

8. Technical Presentation – Radio Measurement Action Protection - Jesse Walker - 11-04/685r0 & 11-04/686r0 (Normative Text)
   a. STAs will use 802.11k messages to optimize performance
   b. Two sources of errors
      i. Mis-measurement
      ii. 802.11k messages forgery
   c. Protect Radio Measurement frame from **forgery**, not measurement error
   d. Define an **optional** protection mechanism for Radio Measurement Action Frames
   e. Utilize **existing** security mechanism rather than creating new ones
   f. Define a new Action Frame attribute
      i. Protection-Capable or Non-Protection-Capable
      ii. Action Frames are Non-Protection-Capable by default (backward capability)
   g. Protection-Capable Action Frames are protected by the same Pairwise Cipher Suite as an ordinary Data MPDU.
      i. MPDU payload is TKIP or CCMP encrypted
      ii. MPDU payload and header are TKIP or CCMP integrity protected
      iii. Protected Frame subfield or Header Frame Control Field is set
      iv. Only cipher suites already implemented required
   h. Question – What is the timing on sending a protected Action Frame? Answer – all Radio Measurement Request/Response are class 3 frames. You can't protect anything until you have the keys.
   i. Comment – CCM is balanced to use the same key for authentication and encryption. Using CCM for encryption **only** breaks down in security scrutiny.
   j. Question – if there is a need for protecting action frames, why should a STA ignore an unencrypted Action Frame? Answer – if you receive a frame that is unencrypted you ignore it in this proposal.
   k. Comment – The reason why you negotiate is to reject forgeries. Any station that is in the Neighborhood may need information that the AP has.
   l. Question – Can we leave it to local policy to transmit Site Report in the clear? Answer - We voted that Action Frame as Class 3.
   m. Comment – In multi SSID you want to keep the secure channel secure and the insecure channel insecure and don't mix them.
   n. Comment – we **only** voted Request Frames as Class 3.
   o. Comment – we are introducing a different mechanism for 11k multicast and unicast, 11i, and 11h.
   p. Question – Why strive to make things better than 11i? Answer – we need to raise the issue so people are aware of security and functionality tradeoffs. Comment – we should distinguish between broadcast and unicasts.
   q. Question – Why have Protection-Capable? Answer – To make this framework backwards capable and extensible for any user of Action Frames. This does implement client functionality (Action Frames) which could be applicable to WMN. WMN is going to work within 11k for measurements.
   r. Comment – On slide 11 – negotiation model is all or nothing, it is not optional. The 4-way handshake is done in the OS. The driver is reconstructing the IE (Information Element). The driver will only pass up the stuff they know about.

s. Question – What if there are some Action Frames that not worth protecting? Answer – this is a valid observation. The task group looked at 3 levels of granularity (1) All Action Frames should be protected, (2) Different protection mechanism for different Action Frames, and (3) our proposal. Example of an Action Frame that shouldn't be protected is "What country am I in?"

t. Comment – If the AP does not support Protection-Capable, then the STA can't associate. Jesses will rework the presentation to address this issue.

9. Motion to modify the agenda to allow Mike to present early. Motion passes unopposed.
10. Motion to recess meeting 10 minutes early to allow Mike work in his presentation
    Moved: Worstell
    Seconded: Walker

    Motion passes unopposed
11. Meeting recess until 7:30 PM tonight.

**Monday, July 12, 2004**
**7:30 PM – 9:30 PM**

1. Chair calls meeting to order at 7:30 PM
2. Motion to amend agenda to allow Zhun to present prior to the other security presentations. Motion is rejected
3. Technical Presentation – Frame Encapsulation – Mike Moreton - 11-04/737r0
    a. Question – If it is not an Action Frame, why keep the Action Frame format? Answer - It makes it easier to keep a consistent format.
    b. Putting it into a data frame provides a mechanism for SME to talk to SME.
    c. Uses exactly the same protection as Data frames – even WEP or none.
    d. Advantages (1) Guaranteed to work on all existing hardware, (2) no extra configuration, (3) no need to define a new protection mechanism, (4) frame type field is protected in TKIP, and (5) extensible
    e. Disadvantages (1) SME-SME protocol
    f. Questions – How to stop someone across the DS from generating an Action Frame and sending it to one of the STAs?
    g. Question – What's to stop someone across the DS generating an Action Frame and sending it to the AP?
    h. Question - How do you stop these frames getting through before the keys are installed?
    i. Question – How do you allow STAs outside the BSS to participate? Answer – they can't just like the other security proposals.
    j. Question – How about broadcast Action Frames from and valid STA within the BSS?
    k. Extension – could probe a remote AP?
    l. Question – How does the affect quality of service? Management frames are generally prioritized over data frames. Answer – This should diminish the need to cheat because you can define priority.
    m. Comment – Are we defining a new data frame? Answer – we are defining a new Ether type not data frame.
    n. Comment – The PAR for 11k is to define interfaces to upper layers.
    o. Comment – There are 2 scenarios (1) Application and (2) MAC. Both mechanisms can work, but what is important is to decide which avenue we should go down. The TGi PAR was vague. If the group decides protecting management frames is at the application layer architecture, then it should be done in 802.16.
    p. Comment – This is already done at the bridging layer within access points today. There are a couple of advantages to this proposal (1) Legacy drivers can implement 802.11k and (2) 802.11k measurements can be sent at different priorities.
    q. Comment – you are giving up the ability to send management frames outside the BSS.
    r. Comment – Terming this as a mechanism for securing Action Frames is a Red Herring – it really defining a new mechanism for communicating.
    s. Question – is the tool we are trying to use to heavyweight? Do these frames need both authentication and encryption? Answer – The reason we are using encryption and authentication is because it is much easier.
    t. Comment – TGh and TGi created new action frames for a reason. Will this negate the ability to bridge packets at the chip level without popping out to software? Answer – the Ether type is on significant at the end points. The Bridge just passes it through.
    u. Comment – This is probably not the best approach, but it does offer simplicity and speed. If we adopt Jesse's proposal it will be backwards compatible with 11h/e.

v. Comment – All existing hardware has the ability to support this proposal.
w. Comment – This is a business driven argument, MAC versus and OS. Answer – There are Chip and OS people who both support this proposal.
x. Comment – If 802.16 and 802.20 make it; then, like 802.1, we have to create an architecture that can be extended. It still all done at the driver level.
y. Comment – The 11k frame management frame might become to large and require fragmentation.

4. Technical Presentation - IEEE 802.11k Security: A Conceptual Model – Aboba - 11-04/724r1
   a. Question – This means that you don't value confidentially? Answer – This is security of measurements and not reality. There is still a heavy burden on the AP to validate this information regardless if the data is secured or not.
   b. Comment – Commands to change settings should be covered by security. Measurements are not worthy of security.
   c. Comment – The group should carefully consider if we should add sample heuristics to determine if the data is good or bad.
   d. Comment – Measurements are hints, this is a correct statement. But what about your statement that an insecure Beacon is more accurate than a secure action frame? Answer – shelf life is more useful and the Beacon is the most real-time hint you can get.
   e. Question – Perhaps we should add security to Beacons and Probe Responses? Comment – all of the reports can be spoofed in the current draft.
   f. Comment – You might **not** want to throw away the data from a malfunctioning access point and/or station. You may want to go and repair the AP after determining that they are sending bad data.
   g. Comment – You don't want to throw out security, because your heuristics are not correct. You must have both.
   h. Question – Are there 11k situations that need protection? Answer – require a STA to go off-channel and do measurements. Comment – This proposal addresses reports, but does not address requests.
   i. Question – Can you distinguish between your proposal and Mike's proposals? Answer – They are very close. Comment – The normative text varies widely between the two proposals.
5. Discussion on addressing security
   a. Comment – we should go to letter ballot without security included in the draft.
   b. Comment – we have to put in normative text in the document very quickly.
   c. Comment – we have had several straw polls that indicated that we are not ready to go to Letter Ballot.
   d. Comment – It is the responsibility for this group to put out a Draft that is complete.
   e. Comment – I would rather sleep on the 3 proposals and allow the 3 groups to come together and present a unified proposal tomorrow morning.
   f. Comment – We could always add normative text after going to Letter and Sponsor Ballots.
   g. Comment – Every Task Group comes to this decision point. If you go to Letter Ballot, you will get thousands of comments which must be addressed.
6. Motion to recess early passes unanimously
7. Meeting in recess until 8:00 AM tomorrow morning.

**Tuesday, July 13, 2004**
**8:00 AM – 10:00 AM**

1. Chair calls the meeting to order at 8:00 AM.
2. Motion to modify agenda to allow 5 Editor-to-do comments and add a straw poll.
3. Motion
   Move to accept Editor-to-do resolutions from teleconferences [35, 61, 65, 72, 73] contained in 11-04-480r17.

   Moved: Kwak
   Seconded: Black

   For: 19 Against: 0 Abstain: 3
   Motion Passes 100%
4. Straw Poll regarding security

   **Straw Poll**
   How should action frames be protected?

   (1) By encapsulating Data Frame [Add Proposal Number] (10 Votes)
   (2) By protecting Action Frame [Add Proposal Number] (10 Votes)
   (3) By some other mechanism (1 Vote)
   (4) Action Frames should not be protected (1 Vote)

   No clear resolution for security.
5. Technical Presentation – Neighbor Report – Aboba - 11-04/0766r1 (PPT) & 11-04/735r3 (Normative Text)
   a. A report providing information on the Neighbors of the AP Answering the query.
   b. What is a Neighbor AP? A neighbor AP is defined as an infrastructure BSS where the BSA overlaps, or is adjacent to the BSA established by the AP sending the neighbor BSS report.
   c. Issues addressed by the Neighbor Report
      - (Unnecessary time spent scanning)
      - Inability to focus on APs of interest (RSN, QoS, PHY, etc.)
      - Scanning on media or channels with no relevant APs
      - Inability to do scheduled passive scanning
      - Inability to target a potential handoff candidate in an active scan
      - Issues addressed by the Neighbor Report (Pre-authentication attempts that can't succeed)
      - Target AP cannot be reached
      - Coverage overlap area insufficient

   **Motion**
   Instruct the editor to incorporate text from 11-04-0735-03-000k-site-report-enhancements.doc into the TGk draft

   Moved: Aboba
   Seconded:

   **Discussion on Proposal**

Question – you added a new element should septuples be changed? Answer – no.
Comment – Describe RSN bit. Answer – the AP has the same RSN security policy.
Question – How would an AP go about configuring trusted APs? Answer – (1) configure through the MIB and (2) via the default VLAN. You don't learn your neighbor list. Both ways are really configured through the MIB.
Comment – Using on VLAN ID seems short sited. The definition or reach ability needs to be expanded. This is a very simple Layer 2 geometry problem.
Comment – You can have an AP without an IP. Answer – yes you can, but it outside the scope.
Comment – You might need two bits for CMX.
Comment – There are other places in the draft which will need to be updated from site report to neighbor report (MIB).
Comment – TBTT allows you do passive scanning.
Comment – The mechanism for determining TBTT Offset is outside the scope.
Comment – To maintain the accuracy specified in the document time drift would need to be checked every 1.2 seconds.
Comment – Beacons are CSMA.
Comment – The Neighbor List is going to be very static in practice except for the TBTT Offset.
Comment – If this is device independent, then we should burden these devices (VOIP devices) which require this functionality. There is a bandwidth cost. You might be able accomplish this via a Passive San. There are devices on the market today which can accomplish this today for Rogue Access Point detection. Answer – we are only talking about 4 bytes.
Comment – It is no more efficient than a probe request/response. Answer – you are not changing channels.
Comment – Active scanning is no longer a viable option.
Comment – We might want to steal a bit from Lower PHY to increase efficiency.
Comment – This should increase standby battery life.
Comment – This useful information and should be included in a report. Why transmit the accuracy? Take the granularity of your TUs.

6. Meeting in recess until 10:30 AM today.

**Tuesday, July 13, 2004**
**10:30 AM – 12:30 PM**

1. Chair calls the meeting to order 10:30 AM
2. Resumption of Discussion on Motion on the floor– Neighbor Report – Aboba - 11-04/0766r1 (PPT) & 11-04/735r3 (Normative Text)

   **Discussion on Proposal (Continued)**
   Question – Not sure about the accuracy of the measurement. How does the client know the accuracy degradation? Answer – the algorithm is outside the scope. The STA itself must go out and maintain the accuracy.
   Comment – It might be beneficial to separate the TBTT out of the proposal.
   The proposal will be resubmitted on Wednesday

3. Technical Presentation - 'Additional' Site Report Mechanism – 11-04/0784r0 – Peyush Agarwal
   a. Question – How does this work in mesh? Answer – the MAC would be changing all of the time.
   b. Comment – On probe response there is only a single AP.
   c. Question - this mechanism builds a network based on Beacon Reports, so what is new? Answer – This enables an AP to build a database and provide it to the STAs.
   d. Comment – This uses the Probe mechanism to initially build the network and uses the DS to update the network.
   e. Comment – It is an automatic collection mechanism between AP to AP. The distribution is from AP to STA via the Site Report.
   f. Comment – this only works where the APs can hear each other.
   g. Comment – There are plenty of wireless networks where transmitters can't hear each other, but they do know they are neighbors.
7. Motion to modifying the schedule to allow MIB presentation on Wednesday. Motion passes unopposed.
8. Technical Presentation – Comment Resolution – 11-04/757r0 (Text) & 11-04/756r0 (PPT) - Simon Black
   a. Comment #6 – Should "MLME primitives" be linked to MIB attributes? Answer – Other groups like 11e have done in the past.
   b. Comment #11 – describe returning BSSMeasurementSet for a .11k STA
   c. Comment #17 – Mandatory response if STA incapable of making measurements
   d. Comment #74, 75, 76 – Clean up of the notes column of Table 12
   e. Comment #96 - Rewording of BSSID field in beacon request. BSS is not a property of a STA or and AP.
   f. Comment #191, 194 – leave as is
   g. Comment #221 – TSFType

   **Motion**
   Move to instruct the editor to apply the comment resolutions in document 11-04-757r0 when preparing the next version of the IEEE802.11k draft.

   Moved: Black
   Seconded: Barber

For: 14 Against: 0 Abstain: 1

Motion Passes 100%

9. Technical Presentation – Medium Sensing Time Histogram Corrections - 11-04-763r0 - Kwak
   a. Addresses Comments #161, 162, 163
   b. Comment – No indications out of the PHY to produce this information. You must ensure that each of the PHYs make this information available to the MACs.
   c. Comment – This could be a problem with the Noise Histogram as well.
   d. Question – Are the Bin durations still in time slots? Answer – yes.
   e. Comment – change Bin Interval to Bin Duration.
10. Technical Presentation – Comment Resolution - 11-04-762r0 - Kwak
   a. Addresses TPC Comments #61, 63, 65, 66, 67, 208, 210
   b. Addresses Beacon Reporting Conditions Comments #104, 219
   c. Comment – Averaged over 20 measurements, we have not defined increments or thresholds. Answer – Thresholds are relative to the serving AP's RCPI.
   d. Comment – Each packet received is a measurement.
   e. Comment – These measurements should be called out on a per packet measurements. Fragmentation will give you a measurement per fragmented packet.
   f. Comment – There is a concern about measuring across an entire packet. If you have short packet is better to measure only the Preamble.
   g. Comment – This does not have any thing to do with modulation only the power.
   h. Comment – The PHY has been modified in our text.
   i. Comment – You need to add (1) the primitives interface and (2) something in Clause 11.5 specifying which frame (Spectrum/Measurement) type you are using. Answer – this should is already specified in the category.
   j. Comment – The reporting conditions where specified, from last meeting, to be a single measurement. How do we reconcile this? Answer – This is a threshold.
   k. Question – Why 20? Answer – Because it brings the sampling error down to a fraction of dB. Answer – It is easier for a client to derive and average from a 2x number like 16 or 32. Joe will modify the text to indicate at least 20 so the implementer could do 32 if it was easier.
   l. Joe will make necessary modification and present on Wednesday.
11. Chair recesses meeting at 1:29 PM.
12. Meeting in recess until 1:30 PM today.

**Tuesday, July 13, 2004**
**1:30 PM – 3:30 PM**

1. Chair calls the meeting to order 1:30 PM
2. Technical Presentation - Radio Measurement Action Protection Normative Text – 11-04-686r1 - Walker

**Motion**

Move to instruct the P802.11k editor to incorporate submission 11-04/686r1 into the P802.11k draft.

Moved: Walker
Seconded: Qi

For: 12 Against: 5 Abstain: 4
Motion Fails at 71%

**Discussion on Motion**

Comment in favor of the motion
Comment – The wording on the MIB variable is unclear.
Comment – This MIB definition is only applicable to an AP.
Comment – 11i only applies non mutable data

3. Straw Poll on Security

**Strawn Poll**

In light of a security deadlock, would you consider moving ahead to Letter Ballot without a security proposal?

Yes: 24 No: 3

**Discussion on Straw Poll**

Comment in favor of poll – We are not required to define security and it can be defined later.
Comment in favor of poll – There are many more ways to bring down a wireless network.
Comment in favor of poll – This issue should be spun into a new task group.

4. Motion to proceed to Letter Ballot without defining a security policy

**Motion**

Move for TGk to proceed to a first Letter Ballot without including a security proposal
Comment – The wording on the MIB variable is unclear.

Moved: Walker
Seconded: Durand

For: 14 Against: 3 Abstain:3
Motion Passes at 82%

**Discussion on Proposal**

Question – Does this mean we have to undo something to get security in the proposal?
Comment – Friendly amendments add "first letter ballot"

5. Motion to accept teleconference minutes

**Motion**

Move to accept TGk cumulative teleconference call minutes (May-July) in document 11-04-0743r0.

Moved: Kwak
Seconded: Stanley

For: 16 Against: 0 Abstain: 3

Motion Passes at 100%

6. Technical Presentation – Autonomous Reporting – 11-04-758r0 - Black
   a. Addressed Comment #23
   b. Comment – Autonomous reporting is good. If you enabled this on a client, a client can continue to blast me with information that I don't want. Answer – you can turn that off.
   c. Comment – I can turn it off, but it is on by default. Every time a client roams into my BSS, I have to turn this feature on. Answer – you can broadcast this.
   d. Comment – If you broadcast this a client can still send several reports between broadcasts.
   e. Comment – We defaulted autonomous reporting on, because TGk's mission is to increase measurements. We could modify to default off by default.
   f. Question – As an implementer, when do I send the reports?
7. Comment #13 - Clause 11.7.2 – Black
   a. Problem – How does the need to return to the serving channel for a particular length of time between measurements relate to periodic measurements. This could result in no periodic measurements being made..
   b. Remedy – Clarify
   c. Comment – Joe presented last meeting and it was rejected.
   d. Resolution – Open – Joe Kwak will research
8. Comment #14 – Clause 11.7.2 – Johnson
   a. Problem - What is wanted in paragraph two? To always return to the serving channel after every non-serving channel measurement. Don't we want to be able to make multiple non-serving channel measurement in a row?
   b. Remedy - Delete paragraph 2 or make this paragraph clearer in its description.
   c. Resolution – open – assigned to Kwak
9. Comment #16 – Clause 11.7.5 - Black
   a. Problem - P40, L23 A STA may issue another measurement request while a previous measurement request is pending and has not yet started'. How does the sending STA know that the request is pending, or started since there is no start time specified. All it can determine is that there was a measurement request outstanding. The text needs to cover both measurements that have not been started and those in progress. It might be useful to get the partial results if there are any. The text here currently mandates discarding results.

b. Remedy - Clarify the behavior if a measurement request is received while a previous request is outstanding.
c. Comment – Station asking other stations for measurements will cause thrashing on the network. Our point of view has been AP centric. We do not have the ability to request measurements in IBSS.
d. Comment – Each station can only have 1 outstanding request. The source address does not matter, there can only be a single outstanding request.
e. Comment – A measurement requests can be a concatenation of many measurement requests.
f. Question – Why can't we leave it to the implementation to decide how to handle requests? Answer – How do I know how big the queue is? How do I know when I am going to receive the measurements.
g. Comment – I am favor of allowing the implementation to queue and add a reset option.
h. Comment – If am requesting measurements, I will send a reset and then a request.
i. Comment – Create a 2 deep queue (1) what you working on and (2) the latest request received.
j. Comment – Add a refused response as well.
k. Comment – Add "place in queue" to the response.
l. Motion to reject the comment
m. Comment – we shouldn't cancel, but clean it up.
n. New Remedy – A STA may issue another measurement request while a previous measurement request is in process,
o. Resolution – accept – instruct editor to make changes described in New Remedy.

10. Comment #17 - Clause 11.7.5 – Black
    a. Problem - P41, L11 If responses indicating refusal, or incapable are optional how are requesting STAs meant to get any information about what can and cannot be requested? One incapable refusal could save many wasted requests.
    b. Remedy - Make responses to measurement requests mandatory.
    c. Comment – This was resolved this morning - Make response in the case a requested STA is incapable of making a measurement mandatory.
    d. Resolution – accept – already contained in 11-04-757r0
11. Comment #20 – Clause 11.7.5 - Johnson
    a. Problem p40, l28-31 - This paragraph describes PS notification but doesn't list case of application information defined in 11.7.2
    b. Remedy – Add information about application-specific information or delete the sentence starting with "Rather"
    c. Comment – "rather" adds a great deal information to the sentence. The power save notification is important information.
    d. Question – Why do we care if it uses power save or not?
    e. New Remedy – Modify P40 l29-l31 "Rather, the measuring station is responsible for maintaining data services by using Power Save notification or other techniques."
    f. Resolution – accept – instruct editor to make change described in New Remedy.
12. Technical Presentation - Comment #43 – Johnson

**Motion**

Move to instruct the editor to replace the following sentence on P44, L38-40 of the TGk draft v0.14 within the latest editorial TGk draft.

"Otherwise, the Site Report elements shall contain information from the MIB table dot11RRMSiteReportTable concerning neighbor APs that match the current SSID the

requesting STA is associated with."

with
"Otherwise, the Site Report elements shall contain information from the MIB table dot11RRMSiteReportTable concerning neighbor APs that match the current SSID with which the requesting STA is associated."

Moved: Johnson
Seconded: Kwak

For: 17 Against: 0 Abstain: 0

Motion Passes 100%

13. Meeting is in recess until Wednesday at 1:30 PM.

**Wednesday, July 14, 2004**
**1:30 PM – 3:30 PM**

1. Chairperson calls meeting to order at 1:30
2. Review Agenda
3. Technical Presentation – Neighbor Report – 11-04-735r4 - Aboba
   - Change Site Report to Neighbor Report throughout the document
   - Clarification of what APs are contained in Neighbor List
   - Clarification of Reserved Field for WMX add 2 bits
   - Changes relating to TBTT
   - Comment Related to TBTT – This must be done in hardware. Answer – It does not require hardware, because it can be addressed in software. When you collect a Beacon Report you have timing information. The Beacon has the time that the Beacon was transmitted. You have the TSF of the remote and the TSF transmitting.
   - Question – What happens when the peer has a large receive queue?
   - Question – Is the Lower TSF mandatory?
   - Comment – Add some text if there about the offset

**Motion**
Move to instruct the editor to incorporate text from 11-04-0735-04-000k-site-report-enhancements.doc into the TGk draft

Moved: Aboba
Seconded: Harkins

For: 23 Against: 0 Abstain: 3

Motion Passes 100%

2. Technical Presentation – Action Frame Class Scope – 11-04-702-01

Motion
Move to instruct the editor to incorporate text from 11-04-0702-00-000k into the TGk draft

Moved: Edney
Seconded: Harkins

**Discussion on Proposal**
Comment – Simon Black would like to make a friendly

**Motion to Amend**
Move to instruct the editor to incorporate text from 11-04-0702-00-000k into the TGk draft with the following exceptions
(1) Delete bullet VII from Class 1 Frames and make editorial adjustments
(2) Remove the words “Containing measurement request and report messages” from bullet II Class 3 Frames

Moved: Black

Seconded: Lefkowitz
For: 19 Against: 3 Abstain: 5
Motion Passes at 83%

**Discussion on Proposal**
Comment – insert comments

**Amended Motion**
Move to instruct the editor to incorporate text from 11-04-0702-00-000k into the TGk draft with the following exceptions
(1) Delete bullet VII from Class 1 Frames and make editorial adjustments
(2) Remove the words "Containing measurement request and report messages" from bullet II Class 3 Frames

For: 22 Against: 1 Abstain: 5

Motion Passes at 96%

3. Technical Presentation – RM MIB Clarification – (11-04-821r0) - Olson

**Motion**
Move to instruct the editor to apply the comment resolutions in document 11-04-812r0 when preparing the next version of the IEEE802.11k draft.

Moved: Olson
Seconded: Johnson

For: 20 Against: 0 Abstain: 4

Motion Passes 100%

4. Comment #132 – Clause 7.3.2.22.5, 11.7.7.4 - Black
   a. Problem - P23, L9: power is measured 'when CCA indicates no 802.11 signal is present' I think CCA can only indicate the states busy, or idle.
   b. Remedy - Clarification required
   c. Comment - What does Idle mean
   d. New Remedy – Append to the end of the first sentence P22 L1 of D0.16 "Over the specified measurement duration when CCA indicates idle".
   e. Resolution – accept – instruct editor to make change described in New Remedy
5. Comment #137 – Clause 7.3.2.22.6 - Black
   . Problem - P21, L20: 'All information elements, except ...' Timestamp is not an information element, it is a fixed field. The same for Beacon Interval and Capability Information. The general statement about Beacon Report does not belong here.
   . Remedy - Replace whole paragraph with: 'The Received Elements portion of the Beacon report Contains a number information elements from the received Beacon, or Probe Response. All information elements that are present in the reported frame shall be included if the reported BSSID does not correspond to the BSS that the measuring STA is a member of. TIM elements shall be truncated such that only the first 4 octets of the element are reported.'

- New Remedy - The Received Elements portion of the Beacon report contains a number of information elements from the received Beacon, or Probe Response. All information elements that are present in the reported frame shall be included. TIM elements shall be truncated such that only the first 4 octets of the element are reported.
- Resolution – accept – instruct editor to make change described in New Remedy

10. Comment #143 – Clause 7.3.2.22.7 - Black
    - Problem - P22, L7 'BSSID contains the 6-byte BSSID of the STA that transmitted the frames.' BSSID is a property of a BSS, not a STA.
    - Remedy – Replace with 'The BSSID field contains the BSSID from the frames being reported.'
    - Resolution – accept – instruct editor to make change as described above
14. Comment #172 – 7.3.2.26 - Black
    - Problem - P28, L12 each quadruplet describes an AP. Quadruplet should be quintuplet and describes a BSS.
    - Remedy – Correct
    - Resolution – accept – no action needed, already accepted text to resolve
18. Comment #173 - 7.3.2.26 – Black
    - Problem – P28, L15 The BSSID is the address of the STA contained in the AP'. Would be better as 'The BSSID field contains the BSSID of the BSS to which the site report entry relates'.
    - Remedy - Consider suggested rewording.
    - Resolution – accept – no action needed, already accepted text to resolve
22. Comment #198 – Clause 7.4.2.3 - Black
    - Problem – Various editorials: P31, L9 Table 1 should be Table 19a P31, L11 Table 5 in 7.4.1 should be Table 20f in 7.4.2 P31, L9, L11, L13 remove 'equal' in each case
    - Remedy – Fix editorials
    - Resolve – accept – no action needed, already resolved in D0.15
26. Comment #211 – Clause A4.13 – Black
    - Problem - There are some PICS entries missing: (1) MIB (based on conformance groups) (2) RCPI in Probe Response
    - Remedy - Make new entries
    - Resolution – open – assigned Black/Gray
30. Comment #235 – Clause General – Black
    - Problem - The preamble says 'NOTE—The editing instructions contained in this supplement define how to merge the material contained herein into the existing base standard to form the new comprehensive standard as created by the addition of IEEE Std 802.11-1999 Reaff (2003). (1) We are writing an amendment (2) 'as created by the addition of IEEE Std 802.11-1999 Reaff (2003)' is meaningless and not relevant
    - Remedy - Reword: NOTE—The editing instructions contained in this amendment define how to merge the material contained herein into the existing base standard to form the new comprehensive standard.
    - Resolution – accept – no action need, already addressed in D0.16 – Black
    - Note to Editor – Now 11i has become part of the Base Draft in 11-04-703.
35. Meeting in recess until 7:30 tonight

**Wednesday, July 14, 2004**
**4:00 AM – 6:00 AM**

1. Chair calls the meeting to order at 4:08
2. Harry Worstell acting Chair
3. Technical Presentation - Measurement Duration – 11-04-560r1 (Normative Text) 11-04-559r1 (PPT) - Black
   - Added a "duration mandatory" bit
   - Related to Comment #15
   - Typo repeated "not"

   **Motion**
   To instruct the editor to apply the editing instructions in document 11-04-560r1 when preparing the next version of the IEEE802.11k draft.

   Moved: Black
   Seconded: Olson

   For: 17 Against: 0 Abstain: 1

   Motion Passes 100%

   **Discussion on Proposal**
   Comment – The Noise Histogram has a qualification to measure RPI density. Answer – you only make measurements in the idle periods.

4. Technical Presentation – AP Service Load – Joe Kwak - 11-04-550r1 and 11-04-0632r1 (Normative Text)
   a. Since DCF packets are lower priority than PCF or HCF packets, the DCF access delay values are sensitive to all PCF, HCF, and DCF channel loads
   b. While channel is busy for PCF or HCF, DCF backoff counting is suspended while access delay timing continues.
   c. Comment – Your measurements are against DCFs. Answer – DCF is constrained by the higher priority classes which means for a given period the Access Delay will grow.
   d. Comment – If I am a priority STA this would not be applicable. Answer – Their stream gives them priority, right.
   e. Comment – We are adding a mechanism which will be going away with 11e.
   f. Comment – It is primarily useful for DCF traffic which is low priority by nature. Answer – correct, but you still need to advertise a load. The load is still beneficial.
   g. Question – Are you getting station count from TGe? Answer – yes.
   h. Question – What if the AP/STA is not capable. Answer – It is defined in the 11k MIB.
   i. Question – Do you think this mechanism requires additional hardware? Answer – not necessarily, put possibly. These are MAC signals.
   j. Comment – These queues may not be available in some MACs
   k. Question – Could this be extended to ECDF? Answer – yes this basic concept could be extended to each class.
   l. Question – By measuring DCF aren't you measuring spare capacity? Answer – it is measuring the inverse of that. We are providing a good overall metric for loading.

m. Comment – In QoS, the schedule is not defined in the Standard.

**Motion**

Move to instruct the editor to incorporate text from document 11-04-0632-01-000k-BSS_Service_Load.doc into next TGk draft specification document

Moved: Kwak
Seconded: Andren

For: 6 Against: 5 Abstain:7
Motion Fails at 54%

5. Technical Presentation – MIB Comment Resolution – 11-04-816r0 - Gray
   - Comment – Need to incorporate Neighbor Report
   - Comment – Need to incorporate Conformance
   - Submit r1 for vote tomorrow
6. Late Comment#1 – Clause 11.7.4 – Bala (11-04-821r0)
   - Problem – Line 1: Should this not refer to "Measurement Request" instead of "Measurement Report"
   - Remedy - Replace "Measurement Report" with "Measurement Request"
   - Resolution – accept – instruct editor to make change as described above
7. Late Comment #2 – Clause 7.3.2.22.5 – Bala (11-04-821r0)
   - Problem – Regarding the text: RPI densities measured over the specified duration when CCA indicates no 802.11 signal is present. The CCA can be busy (based on the CCA mode setting) even when no 802.11 signal is present (for example when the measured signal energy is above ED threshold and the CCA mode requires ED threshold to be considered)
   - Remedy – Clarify
   - Resolution – decline – duplicate see Comment #132
8. Late Comment #3 – Clause 7.3.2.25 – Bala (11-04-821r0)
   - Problem – What does the channel list parameter which is part of the 'channel report' element pertain to (derived from the AP channel report table)? Are these channels relevant to the specific AP or is it any AP which is part of the ESS ?
   - Remedy – Clarify
   - Resolution – open – assigned to Black
9. Late Comment #4 – Clause 7.3.2.22.9 – Bala (11-04-821r0)
   - Problem – What should the RPI threshold be set to if medium sensing sub-type is not RPI time histogram?
   - Remedy – Clarify
   - Resolution – open – assigned to Kwak
10. Late Comment #5 – Clause 7.3.2.21.9 – Bala (11-04-821r0)
    - Problem – In the measurement request what if measurement duration is >= Bin Interval x Number Of Bins ?
    - Remedy – The receiver of the request should refuse it (reason being mal-formed request).
    - Resolution – open – assigned to Black
11. Late Comment #6 – Clause 7.3.2.22.8 – Bala (11-04-821r0)
    - Problem – Noise Histogram Report should bye Hidden Node Report
    - Remedy – It should be Hidden node report instead of Noise Histogram Report in this section
    - Resolution – accept – instruct editor to make change as described above
12. Late Comment #7 – Clause General – Bala (11-04-821r0)

- Problem – What is the need for autonomous reporting in 802.11k? I understand it was useful in the context of 802.11h to inform other STAs regarding the presence of a RADAR but for 11k, measurement reports should be generated only in response to specific requests so what is the point in generating and sending the reports if the receiver has no use for it ? As an exception, it may be OK to just allow autonomous site reporting by an AP to be broadcast to all STAs in the BSS since this is useful information which could be used by the STAs to use scanning and roaming optimizations.
- Remedy – Remove Autonomous reporting from 802.11k
- Resolution – open – assigned to Black relating to Comment #23

13. Late Comment #8 – Clause 7.3.2.2.26 – Bala (11-04-821r0)
    - Problem – Channel band is not mentioned or accounted for in the size of the quadruplet
    - Remedy – Replace 10 with 11 octets. Also mention channel band in the when you list what constitutes the quadruplet.
    - Resolution – decline – already addressed in 11-04-735r4 approved today
14. Late Comment #9 – Clause 11.5 – Bala (11-04-821r0)
    - Problem – In this section I notice that in the 4 paragraphs following "For the purposes of TPC" that procedures are effective if "dot11SpectrumManagementRequired" is set o TRUE. Should this not refer to 'dot11RadioMeasurementEnabled or dot11SpectrumManagementRequired' flag instead of just "dot11SpectrumManagementRequired' ?
    - Remedy – Replace “dot11SpectrumManagementRequired” with “dot11RadioMeasurementEnabled” or “dot11RadioSpectrumManagementRequired”.
    - Comment – Text reference spectrum management only
    - Resolution – decline
15. Late Comment #10 – Clause 11.7.6 – Bala (11-04-821r0)
    - Problem – “A STA may process only one periodic measurement per BSSID at any given time” – Does this refer to one periodic measurement request across all measurement types or does it refer to a per measurement type?
    - Remedy – Clarify
    - Comment – We only have one periodic measurement. Should we expand it now when we incorporate additional periodic measurements.
    - Resolution – decline – It is implicit only to one periodic measurement.
16. Meeting in recess until Thursday 1:30 PM.

**Thursday, July 15, 2004**
**1:30 PM – 3:30 PM**

1. Chairperson calls meeting to order at 1:30 PM
2. Motion to approve editor-to-do

**Motion**

Move to accept the editor-to-do comments from document 11-04-480r19 and 11-04-821r0.

11-04-480r19 [Comment #137, 143, 132, 43 (text in minutes), 20, 16]
11-04-821r0 [Comments #1, #6]

Moved: Gray
Seconded: Johnson

For: 15 Against: 0 Abstain: 3
Motion Passes 100%

3. Technical Presentation – MIB Comment Resolution – 11-04-816r1 & 11-04-825r0 - Gray
   a. Comment – Are the Descriptions corrections incorporated in this submission? Answer – no.
   b. Comment – There are a changes which are not address in submission

**Original Motion**

Move to instruct the editor to apply the comment resolutions in document 11-04-816r1 when preparing the next version of the IEEE802.11k draft.

Moved: Gray
Seconded

**New Motion Prior to Second**

Move to instruct the editor to replace TGk D0.16 Annex D with document 11-04-816r1 when preparing the next version of the IEEE802.11k draft

Moved: Gray
Seconded: Qi

**Motion to Amend**

Move to instruct the editor to replace TGk D0.16 Annex D with document 11-04-816r1 applying all subsequent approved MIB changes when preparing the next version of the IEEE802.11k draft.

Moved: Black
Seconded: Arden

For: 19 Against: 0 Abstain: 1

Amended Motion Passes at 100%

**Amended Original Motion**

Move to instruct the editor to replace TGk D0.16 Annex D with document 11-04-816r1 applying all subsequent approved MIB changes when preparing the next version of the IEEE802.11k draft.

Moved: Gray
Seconded: Arden

For: 19 Against: 0 Abstain: 0
Amended Motion Passes at 100%

4. Straw Poll regarding going to Letter Ballot

**Straw Poll**

Do you think TGk should go to Letter Ballot including all approved changes to the end of the session?

Yes: 8 No: 2 Abstain: 10
Affirmative on Straw Poll

5. Technical Presentation – Medium Sensing Time Histogram Corrections -11-04-763r1 - Kwak
   a. Addresses Comments #161, 162, 163
   b. Addresses - Added corresponding changes to Medium Sensing Time Histogram Request, per Bala's comments.
   c. Addresses - NAV histogram modified to indicate intervals when set, and not reset. Special value added to RPI Threshold field to use when Histogram is not RPI histogram.
   d. Joe will make motion in the evening session.
6. Technical Presentation – Comment Resolution - 1-04-762r1 - Kwak
   a. Addresses Comments (TPC Cleanup) #61, 62, 63, 65, 202, and 210
   b. Addresses Comments (Beacon Reporting Condition) #104, 219
   c. R1 addresses - Added Modifications to 10.3.16 (from TGh) to modify the MLME interface for TPC.
7. Technical Presentation - Neighbor Report Generation – 11-04-820r0 - Agarwal
   a. Question – How do you handle a down AP? Answer – manual configuration.
   b. Question – This only happens during MAC initialization? Answer – Also anytime there is a MAC change.
   c. Comment – The STAs will try to associate with Beacon, if it is one.
   d. Comment – There should be text regarding initialization. Answer – The MLME initialization is already defined in the standard.
   e. Comment – you can't delay boot time of an access point. Answer – You can pay for the delay on startup or while the AP is in service.

**Motion**

Move to instruct the editor to incorporate text from document 11-04-0820r0 into the next version of the IEEE802.11k draft.

Moved: Agarwal
Seconded: Moreton

For: 1 Against: 11 Abstain: 7
Motion Fails at .08%

**Discussion on Proposal**

Comment Against – Should be sending energy on a channel until you know about the channel.

Comment Against – The document is not formatted properly

*The motion was out of order, because Peyush Agarwal is not a voting member*.

8. Discussion on MIB Conformance Statement
   a. Comment – 11i and 11j created new conformance groups
   b. Comment – SMT5 – don't take into account 11e
   c. Olson/Black are working on submission
9. SDL Override
   a. Question – How did 11j do it? Answer – They did nothing.
   b. Comment – You only need a paragraph that describes that this is not included in the SDL.
   c. Comment – Terry will include a comment.
   d. Comment – 11i put something in Annex C
10. Meeting in recess until 4:00 PM

**Thursday, July 15, 2004**
**4:00 PM – 6:00 PM**

1. Chairperson calls meeting to order at 4:00 PM
2. Discussion on going to Letter Ballot
   - Option #1 – Empower the editor, Motion to WG asking to go to LB
   - Option #2 - Action item teleconferences aiming for LB in Sept.

**Strawn Poll**
How should we proceed to Letter Ballot:

1 – Empower the editor, Motion to WG asking to go to LB (8)
2 – Action item teleconferences aiming for LB in Sept. (6)

No clear distinction.

3. Discussion on virtual access point
   - There is trend where APs act as multi BSSs.
   - Put an information element in the Probe Request thereby reducing the amount of information you get back.
   - Probe Requests can be directed or non directed.
     - If it is non-directed, some MFG only respond on primary BSS
     - If it is directed, then respond to directed BSS.
   - Beacon Request/Response might not be fully defined for virtual APs
   - Put in a "Recommended Practice" for virtual APs
4. Motion for approval of working empowerment

**Motion**
Move to request the Working Group to authorize a 40-day Letter Ballot of 802.11TGk, draft 1.0 to conclude no later than 9/13/2004.

Moved: Gray
Seconded: OHara

For: 9 Against: 5 Abstain: 5
Motion Passes at 64%

**Discussion on Proposal**
Speak against motion – Still outstanding changes to the MIB which might have to come back to working group.
Speak against motion – Reservation on open items, we should wait one more cycle
Speak against motion – This will slow the group overall.
Speak for the motion – We have had plenty of comment review
Speak for the motion – We will get Letter Ballot comments sooner
Speak for the motion – Don't benefit in delaying another session
Comment – For an external observer – believes this TG has done a great job of producing a complete document.
Comment - Because we are at the level of detail for MIB Conformance Statements we have done more than most groups.

5. Motion to Empower Editor

**Motion**

To empower the TGK editor to produce a Letter Ballot draft (D1.0) based on approved documents from the Portland meeting

Moved: Johnson
Seconded: O'Hara

For: 17 Against: 0 Abstain: 2
Motion Passes at 100%

6. Motion to recess passes unopposed
7. Meeting is in recess until 7:30 PM.

**Thursday, July 15, 2004**
**7:30 PM – 9:30 PM**

1. Chairperson calls meeting to order at 7:30 PM
2. Comment Review with Editor on D0.17 compliation
   - Comment #35 – Open
   - Comment #61 – Comments unclear, no action taken – addressed in 11-04-762r1
   - Comment #65 – Comments not provided, no action taken – addressed in 11-04-763r1
   - Comment #159 – Comments unclear, no action taken - addressed in 11-04-763r1
   - Comment #202 conflicts #200 - Section has been removed and motion approved to correct
   - Comment #237 – not clear – at editors discretions
   - Comment #238 – Base standard is not clear on figure format – at editors discretions
   - Comment #240 – already addressed
   - Schedule for upcoming drafts
     - D0.17 posted tonight
     - D0.18 28th
     - D0.19 posted without change bars soon after left.
3. Technical Presentation – Comment Resolution (TPC, Beacon Reporting Condition) -11-04-762r1 Kwak

   **Motion**

   Move to instruct the editor to apply the comment resolutions in document 11-04-762r1 when preparing the next version of the IEEE802.11k draft.

   Moved: Kwak
   Seconded: Olson
   For: 12 Against: 0 Abstain: 0
   Motion Passes at 100%

4. Technical Presentation – Medium Sensing Time Histogram Corrections - 11-040763r1 Kwak

   **Motion**

   Move to instruct the editor to apply the comment resolutions in document 11-04-763r1 when preparing the next version of the IEEE802.11k draft.

   Moved: Kwak
   Seconded: Qi
   For: 12 Against: 0 Abstain: 0
   Motion Passes at 100%

5. Discussion on upcoming teleconference
   a. 07/21/04 – 2 hours starting at 7:00 AM Pacific
   b. 07/28/04 – 2 hours starting at 7:00 AM Pacific
   c. Chair will setup an 800 and DID (non US)
6. Motion for empowerment for future meetings

   **Motion**

   Move to request the working group to empower TGk to hold meetings as required to conduct business necessary to progress the Letter Ballots, conducting teleconferences, and handling other business necessary to progress through the IEEE standards process.

Moved: Kwak
Seconded: Ecclesine
Motion Passes 100%

7. Resume discussion of virtual AP
   - Put in a information element in Beacon and Probe Responses
   - How do we get the information without active scans
   - There is language in the country code element which does not totally describe how the element is used. It is not always used.
   - What about unicast Probe Response? Virtual AP will send on a single Probe Response.
   - The 2 options (1) Create a new measurement request/report {RSSI Ping}, (2) Include a new IE in the Probe Request.
   - Phase II – Add things in the Beacon that describes all Virtual APs within transmitter
8. Moved for adjournment (Moved: Black – Seconded: Kwak) passes unopposed
9. Meeting adjourned until Berlin

# 802.11m Report
# July 2004

# Goals for July 2004

- Develop updates to standard
  - Address submissions received
  - Continue work from spreadsheet of work items

# Submissions

- Are there any submissions?
  - 04/698 Use of Status and Result Codes
  - 04/759 Wildcard SSID
  - 04/795 Active Scan Inconsistencies
- Are there any new interpretation requests?
  - None

# Proposed Agenda

- Review IEEE Patent Policy
- Review interpretation request procedure
- New business
  - 04/698 Use of Status and Result Codes
  - 04/759 Wild Card SSID
  - 04/795 Active Scanning
  - 03/619 tracking document
- Adjourn

# Motion to adopt Agenda

- Moved: to adopt the agenda
- Mover: Simon Black, Michael Montemurro
- Passes: unanimous

# *IEEE-SA Standards Board Bylaws* on Patents in Standards

http://standards.ieee.org/board/pat/pat-slideset.ppt

# Interpretation Procedure

- http://standards.ieee.org/reading/ieee/interp/
- Send email to Linda Gargiulo (l.gargiulo@ieee.org)
- IEEE forwards requests to the WG
- WG responds

# Motion #2

- Moved: to adopt the text in 04/759 and to underline the first two occurrences of “wildcard” in the normative text.
- Mover: Simon Black, Michael Montemurro
- Passes: unanimously

# Motion #3

- Motion: to adopt the revised resolution proposed in 04/795 to item 27 in 04/801r0 for use of individual BSSID in Probe Requests.
- Mover: Darwin Engwer, Simon Black
- Passes: unanimously

# Motion #4

- Moved: to accept the following as the resolution to item 31 of 03/619:
  - Delete "If the medium is determined bythe CS mechanism (see 9.2.1) to be unavailable, the AP shall delay the actual transmission of a beacon" and combine the remainder of that sentence with the previous sentence.
- Moved: Dave Bagby, Donald Eastlake
- Passes: unanimously

# Motion #5

- Moved: to adopt the following as the resolution to item 35 of 03/619:
  - Change 9.3.2.1 to describe SIFS timing after Beacon for buffered mcast frames and first data frame or poll following mcasts. Delete "at least" from the second paragraph.
- Mover: Andrew Myles, Dave Bagby
- Passes: unanimously

# Motion #6

- Moved: to adopt the following as the resolution to item 53 in 03/619:
  - Delete "in the DA field" from 7.1.3.3.2 b) 2).
- Moved: Andrew Myles, Jan Kruys
- Passes: unanimously

# Motion #7

- Moved: to adopt the following as the resolution to item 50 in 03/619:
  - Change value of aPreambleLength from 20us to 16us in the table.
- Mover: Andrew Myles, Donald Eastlake
- Passes: unanimously

# Motion #8

- Moved: to adopt the following as the resolution to item 57 of 03/619:
  - In the second sentence, delete "initially" and from "as provided" to the end of the sentence.
- Moved: Donald Eastlake, Jan Kruys
- Passes: unanimously

# Motion #9

- Moved: to adopt the following as the resolution to item 67 of 03/619:
  - Insert the following as the first sentence of the second paragraph: "A fragment is an MPDU, the payload of which carries all or a portion of an MSDU or MMPDU." Also replace "fragment MPDU" with "fragment" wherever it occurs.
- Mover: Dave Bagby, Andrew Myles
- Passes: unanimously

# Motion #10

- Moved: to adopt the following as the resolution of item 68 in 03/619:
  - Replace the "a" prefix with "dot11" before LongRetryLimit in 6.2.1.3.2 b), 9.2.4, and 9.2.5.3.
  - Also before MaxTransmitMSDULifetime in 6.2.1.3.2 h) and 9.4 (twice).
  - Also before FragmentationThreshold in 9.1.4 (four times) and 9.4 (three times).
- Mover: Terry Cole, Donald Eastlake
- Passes: unanimously

# Motion #11

- Moved: to adopt the following as the resolution to item 70 of 03/619:
  - Change "dot11MultiDomainOperationImplemented" to dot11MultiDomainCapabilityImplemented" on page sta_Start_Ibss_3d(8) and 3201_d\StationConfig(5) and 14.8.2.20
- Mover: Terry Cole, Donald Eastlake
- Passes: unanimously

# Motion #12

- Moved: To adopt the text in 04/698r1 and incorporate it into the draft.
- Mover: Darwin Engwer, Terry Cole
- Passes: 1/0/1

# Motion #13

- Moved: To adopt the following as the resolution to item 84 of 03/619:
  - In 11.1.3.4, change dot11RegDomainsSupportEntry to dot11RegDomainsSupportedValue and add the value "Other (0)" to the "INTEGER SYNTAX" line for dot11RegDomainsSupportedValue in the MIB.
- Moved: Jon Rosdahl, Terry Cole
- Passes: unanimously

# Motion #14

- Moved: To adopt the following as the resolution to item 85 in 03/619:
  - Insert "and the dot11RegDomainsSupportEntry shall be set to Other" at the end of the sentence beginning "If the dot11MultiDomainCapabilityEnabled attribute is true". See item 84 and 86 for complete resolution.
- Mover: Jon Rosdahl, Darwin Engwer
- Passes: unanimously

# Work completed

- Adopted
  - Wildcard SSID
  - Directed Probe Request
  - Use of Status and Result Codes

# Summary

| | |
|---|---|
| Work Items at start | 75 |
| Work Items added | 2 |
| Work Items closed | 8 |
| Work Items to Editor | 11 |
| Work Items remaining | 58 |
| Percentage completion | 51% |

# Output Documents

- 759r0: “Wildcard” SSID
- 795r0: Directed Probe Requests
- 698r1: Use of Status and Result Codes
- 699r0: This report
- 801r0: Tracking list of work items

# Adjourn

- Meeting adjourned at 5:00pm, 7/15/2004

# Attendance

- Darwin Engwer
- Andrew Myles
- Jon Rosdahl
- Terry Cole
- Donald Eastlake
- Mike Montemurro
- Dave Bagby
- Jesse Walker
- Nancy Cam-Winget
- Jan Kruys

# Goals for September

- Consider new submissions
- Continue to process items in 04/801

# IEEE P802.11
# Wireless LANs

## Minutes of High Throughput Task Group Meetings

**Date:** July 12-16, 2004

**Author:** Garth Hillman
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## Abstract

Cumulative minutes of the High Throughput Task Group meetings held during the IEEE 802.xx Plenary meeting in Portland from July 12 through 16, 2004.

**Executive Summary (see closing report doc. 11-04-0839r0):**

1. **14 Technical presentations were heard**
2. **Clarification made to CC67**
3. **Joint meetings were held with 802.18, .19 and .21**
4. **Decision was made not to hold elections for the technical editor and vice-chair at this meeting or the September meeting**
5. **Overview of TGn timeline was presented**
6. **Logistics for the September meeting in Berlin, where the proposals will be heard for the first time, were agreed upon. Deadline for posting proposals is August 13.**

Detailed minutes follow:

**Monday July 12, 2004; 4:00 – 6:00 PM [~ 204 attendees]**

:

1. Meeting was called to order by Task Group chairperson elect Bruce Kraemer at 4:02 PM
2. New participants in .11n ~25
3. Voting for the week – Straw Polls are open voting unless indicated differently, otherwise voting members only
4. Chairs' Meeting Doc 11-04-0658r0
5. Chair read IEEE Patent Policy and issued a call to make patents known
6. No patents/patent applications were indicated
7. Chair noted topics NOT to be discussed during the week:
    a. license T&Cs
    b. territorial restrictions
    c. litigation
    d. pricing
    e. market share
8. Review of May Session – 11-04-0532r0 has the submissions given at that meeting
9. Plan for this meeting:
    a. Objectives for July
    b. Opening remarks
        i. Agenda
        ii. May minutes 11-04-0496r0
        iii. Other information items
    c. Status of Call for Proposals
    d. Technical Presentations
    e. Overall TGn timeline
    f. .19 liaison planning (joint meeting)
    g. Regulatory issues discussion with .18 (joint meeting)
    h. .21 liaison planning (joint meeting)
    i. TGn organization/officer planning
    j. Planning for September Berlin
    k. Correction to CC
10. **Motion to approve agenda by Colin Lanzl and seconded by George Vlantis**
11. Discussion
    a. Include meeting time for interpretations of FRCCs? A - OK
12. Motion passed (89,0,1)
13. Motion by Garth Hillman to approve May minutes was seconded by Colin Lanzl passed without comment
14. Total Letters of Intent to Propose = 21 complete + 41 partial = 62 total

15. Countries represented by looking at email addresses of respondents
    a. Canada
    b. Finland
    c. France
    d. Germany
    e. Ireland
    f. Japan
    g. Korea
    h. Netherlands
    i. Singapore
    j. Sweden
    k. Taiwan
    l. US
16. Next Critical Date August 13 for actual proposal
17. Discussion
    a. Can one person submit multiple proposals? A – yes
18. Presentations logged to date for presentation at this session:

| | | | |
|---|---|---|---|
| a. LDPC vs CC over 11n channels | Huaning Niu | 04-0682-r0 | Samsung |
| b. Performance comparison of antenna selection and DSTBC (M) | Henry Horng | 04-0681-r0 | Samsung |
| c. IEEE 802.11n MAC Design Considerations | Daqing Gu, J Tao | 04-0727-r0 | Mitsubishi |
| d. Antenna selection for MIMO systems | Andy Molisch | 04-0713-r0 | Mitsubishi |
| e. LDPC coding for MIMO systems | Jianxuan Du | 04-0714-r0 | Mitsubishi |
| f. Physical Layer Approach for 802.11n (M) | Mustafa Eroz | 04-0746-r0 | Hughes NS |
| g. PHY Design for Spatial Multiplexing MIMO | John Ketchum | 04-0721-r0 | Qualcomm |
| h. Link Level Sim results for Spatial Multiplexing MIMO | John Ketchum | 04-0720-r0 | Qualcomm |
| i. MAC Overview (M) | John Ketchum | 04-0717-r0 | Qualcomm |
| j. MAC Performance Results (M) | John Ketchum | 04-0279-r0 | Qualcomm |

19. New Technical Presentations

| | | | |
|---|---|---|---|
| a. Synchronization Requirements for 802.11n | John Kowalski | xxxxx | Sharp |
| b. 40 MHz-20 MHz Interoperability | Jeff Gilbert | xxxxx | Atheros |
| c. Channelization | John Sadowski from Intel to *precede* Gilbert's | | |
| d. ???? | Bart van Poucke | xxxxx | IMEC |

20. 14 Makes a total of 7 hours at 30 minutes each
21. Sequence of Presentations?
    a. John Ketchum volunteered to present two (#s 9&10) this evening
    b. Hughes volunteered to present tonight

c. Samsung volunteered to present #s1&2 this evening
d. Tuesday morning volunteers?
    i. John Kowalski volunteered

22. Time Line was outlined and will be reviewed Tuesday
23. Joint Sessions topic
    a. .19 Wed. 1:30-2:30 PM
    b. .21 Thursday 8:00 AM – 9 AM
    c. .18 Wed. 2:30-3:30 PM
        i. Colin Lanzl volunteered on Tuesday afternoon to chair an ad hoc meeting to generate a set of agenda topics for the joint meeting with .18 on Wed.
24. Nominations for Officers topic thoughts:
    a. Positions
        i. Technical Editor
        ii. Vice Chair
    b. Discussion
        i. Vice Chair needed now to help handle the 62 proposals
        ii. Not much editor can do until down selection is completed and a baseline doc is established
        iii. Floor noted that a tutorial session on technical editor's responsibilities is scheduled tomorrow evening
        iv. Chair stated he had no objection to electing both at this meeting
        v. Should we defer until November meeting?
        vi. Topic will be revisited later this week
25. Berlin Logistics Thoughts
    a. Implicit – all proposal presentations will be given in September
    b. Presentation times = available time/number of proposals
    c. Speaking Order – use random number generation
    d. Merger will impact time slot durations
    e. Discussion
        i. Chair will know length of time slots when he counts number of proposals on server after August 13
26. Correction to CC67
    a. Adrian P Stephens (11-04-725r0)
        i. Revision 28 changed simulation scenarios BDF to BDE in definition column
        ii. Proposal in Revision 30 change F to E
27. **Motion that CC67 in doc. 11-03-0814 (currently revision 30) be amended so that its "disclosure" entry references channel models B, D and E, and to accept document 11-03-0814r31 thus modified as the modified CC for the TGn selection process and instruct the chair to notify the members of the updated selection process – by Adrian Stephens and seconded by Colin Lanzl passed (65,0,3)**

28. Meeting was recessed at 5:50 PM until 7:30 PM tonight.

**Monday evening; 7-12-04; 7:30 – 9:30 PM;**

29. Chair reconvened at 7:33 PM
30. Presentation #1 – doc. 11-04-717r0; MAC Elements for 802.11n; Sanjiv Nanda; Qualcom
    a. Objectives and Requirements for MAC Enhancements
    b. Description of Proposed Enhancements
        i. Frame Aggregation
        ii. Backward Compatible PLCP Header
        iii. Compressed BlockAck
        iv. Adaptive Coordination Function (ACF): Enhancement of HCF
        v. QoS capable IBSS Operation: RRBSS (Round robin)
    c. System Simulation Results (separate presentation)
        i. ACF
        ii. EDCA with Frame Aggregation
    d. Conclusions
        i. Detailed design of MAC enhancements for MIMO OFDM
            a. Completely Backward Compatible
            b. Enhancements required for high throughput, low latency operation
            c. Features applicable to different operating regimes
        ii. List of proposed features
            a. Frame Aggregation. Aggregation Header.
            b. Extended SIGNAL field and PPDU Type
            c. Closed Loop Rate Control and MIMO Mode Control
            d. Compressed BlockAck
            e. SCHED Message, SCAP and Scheduled TXOPs
            f. Flexible Operating Modes with ACF
            g. RRBSS – QoS capable IBSS Operation. Token PPDUs.
        iii. Simulation results for ACF and EDCA. Next Presentation
31. Presentation #2 – doc. 11-04-716r0; System Performance Results for Scenario 1; Sanjiv Nanda; Qualcom
    a. The simulator is based on NS2
    b. Includes physical layer features
        i. TGn Channel Models
        ii. PHY Abstraction determines frame loss events
    c. MAC features

i. EDCA
ii. Adaptive Coordination Function (ACF): SCHED and SCAP
iii. Frame Aggregation
iv. ARQ with Block Ack
v. Closed Loop Rate Control (DRVF and DRV)
vi. MIMO Modes (ES [Eigen spreading] and SS [spatial spreading])

d. Transport
   i. File Transfer mapped to TCP
   ii. QoS Flows mapped to UDP
e. Conclusions:
   i. TGn Usage Models Scenario 1 requirements can be met and exceeded with 2x2.
   ii. Using Scheduled operation:
      a. MAC Efficiency is in the range 74%-78%.
      b. Scenario 1 HT: Throughput can be increased to above 100 Mbps
      c. Scenario 1 LD: Video stream latency can be reduced below 50 ms (from 200 ms). Total throughput: 103 Mbps
      d. Scenario 1 IR: Range of HDTV flows can be increased from 5 m to 25 m. Total throughput: 92 Mbps
   iii. MAC Efficiency of EDCA with Frame Aggregation is around 56% for 2x2 and falls to 35% for 4x4.
   iv. Throughput with 256 QAM (7 bits per symbol after 7/8 bit convolutional coding)
      a. ~15% throughput improvement with 256 QAM
      b. By setting Maximum MCS=5 bits/symbol obtain 80-92 Mbps for IR, LD, HT.
f. Comments:
   i. Make sure to carefully document the CC scenarios

32. Presentation #3 – doc. 11-04-746r0; Physical Layer Approach for .11n ; Mustafa Eroz; Hughes Network Systems
    a. Introduction:
       i. To meet .11n requirements must use MIMO systems if S/N and power are to remain unchanged in the wireless channel
       ii. Shannon Limit codes have been discovered and have been put into real systems in the 3G systems
       iii. Turbo codes in 1999; LDPC codes in BCTV in 2003
       iv. Conclusions:
          a. Advanced LDPC codes bring the performance of practical communication system very close to theoretical limits for single-input, single-output AWGN.
          b. With clever customization and optimization, LDPC codes can approach Shannon limit for MIMO fading channels as well.
          c. We intend to submit a physical layer proposal based on a set of LDPC codes highly optimized for 802.11n application before the next meeting.

33. Presentation #4 – doc. 11-04-682r0; LDPC Codes versus Convolutional Codes over MIMO-OFDM .11n Channels; Huaning Niu; Samsung Electronics
    a. Conclusions:
        i. Performance comparison of regular LDPC codes and convolutional codes in 11n channel models B and D is presented.
        ii. The indoor fading channel provides limited timing diversity, and cause degraded coding gain for LDPC codes in SISO link [2,3]
        iii. LDPC codes can effectively utilize the spatial diversity in MIMO link and the frequency diversity
34. Presentation #5 – doc. 11-04-681r0; Performance Comparison of Antenna Selection and DSTBC [Double Space Time Block Codes]; Henry Horng; Samsung Electronics
    a. Closed Loop simulation
    b. Open Loop simulation (DSTBC)
    c. Conclusions
        i. Channel correlation matrix plays an important role in system design
            a. Performance of the antenna selection is highly sensitive to channel correlation.
            b. DSTBC has less performance sensitivity to channel correlation. It provides better performance but with higher complexity (Require more RF chains, higher MIMO detection complexity).
            c. When channel is highly correlated (channel B with $\lambda/2$ spacing), SCK antenna selection gives the best design tradeoff (less RF chains, less complexity in feedbacks)
        ii. The effectiveness of antenna selection is reduced with higher frequency selectivity (as in the case of channel model D)

**Tuesday Morning 7-13-04; 8:00 – 12:30 PM [~191 attendees]**

1. Chair reconvened session at 8:03 AM
2. Chair updated status of session
3. Presentation #6; PHY Design for Spatial Multiplexing MIMO WLAN; 11-04-0721r0; John Ketchum; Qualcom
    a. Complementary to Sanjiv's presentations yesterday
    b. Introduce new OFDM symbol, long 256 sub-carriers to reduce overhead due to cyclic prefix
    c. Fully backward compatible with 802.11a/b/g
        i. 20 MHz bandwidth with 802.11a/b/g spectral mask
        ii. OFDM based on 802.11a waveform with additional long OFDM symbols (256 sub-carriers)
    d. Modulation, coding, interleaving based on 802.11a
        i. Expanded rate set
    e. Scalable MIMO architecture
        i. Supports a maximum of 4 wideband spatial streams

f. Two forms of spatial processing
    i. Eigenvector Steering (ES): via wideband spatial modes/SVD per sub-carrier
        1. Tx and Rx steering
        2. Over the air calibration procedure required
    ii. Spatial Spreading (SS): modulation and coding per wideband spatial channel
        1. No calibration required
        2. SNR per wideband spatial stream known at Tx
g. Sustained high rate operation possible via adaptive rate control
h. Only STAs need to calculate the SVD and sends resulting training sequence to AP
i. Summary
    i. MIMO PHY design builds on existing 802.11a,g PHY design
    ii. Two operating modes provide highly robust operation under a wide range of conditions
        1. Eigenvector Steering (ES) provides best rate/range performance
        2. Spatial Spreading (SS)
    iii. Adaptive rate control through low-overhead rate feedback supports sustained high throughput operation
    iv. Low-overhead training sequence exchange supports high-capacity Eigenvector Steered operation for best rate/range performance
    v. Spatial Spreading operation provides robust high throughput operation when Tx does not have sufficiently accurate channel state information

4. Presentation #7; 802.11n MIMO Link Performance, Some Simulation Results; 11-04-0720r0; John Ketchum; Qualcom
    a. Outline
        i. MIMO system overview
        ii. Link simulation overview
        iii. Preliminary simulation results:
            1. Throughput and PER performance with 802.11n channel B and rate adaptation (CC67)
            2. PER vs. SNR performance in AWGN (CC59)
        iv. Hardware prototype summary
    b. Summary
        i. Eigenvector steered mode supports high throughput operation in 2x2 and 4x4 configurations
        ii. Stable wideband spatial channels synthesized from Eigenmodes easily support 256 QAM under full PHY impairments
        iii. High throughput eigenvector steering operation proven in hardware prototype
    c. Questions
        i. none
5. Presentation #8; Synchronization Requirements and Solutions for 802.11n; 11-04-0775r0; John Kowalski; Sharp
    a. The Problem

i. Consumer electronic devices figure prominently in 802.11n usage models.
ii. CE devices however, require tight synchronization to maintain high quality audio if multicasting is done.
iii. This presentation presents some results on the state of the art for synchronization in 11a, and recommendations to improve it for 802.11n.
iv. Without some solution in this regard, the user experience of CE over 802.11n may be compromised.

b. Conclusions
i. The use of 8 byte 10ns unit time stamp in all QoS packets should be considered as option.
ii. A great improvement from legacy 802.11 (10us to 25ns) can be achieved.
iii. Synchronization can be further improved to acceptable stereo audio level by using higher precision oscillators (10ns)
iv. Presently investigating the effects of synchronization when MIMO preambles, other information, other preamble formats, etc. are used.

6. Presentation #9; 40/20/10 MHz Channelization for Robust, High-Performance, Cost Effective 802.11n Operation; 11-04-0786r0; John Sadowski; Intel
a. Why is this important?
i. Cost and Performance
1. Shannon's law
2. For comparable RF configurations
3. Higher S/N is higher cost therefore lower S/R is preferred
4. MIMO => multiple radios AND higher SNR
ii. Just increasing the channel BW most cost effective way to meet .11n spec
iii. Issue is that a wider channel reduces overall system capacity
iv. Not clear that two 20 MHz disjoint channels offers more system capacity than one 40 MHz channel
v. Gave cellular reuse example
vi. Simulation conditions enumerated
vii. Result – 40 MHz channel gave higher reuse numbers
viii. Conclusion 40 MHz is, wrt 20 MHz
1. Robust
2. Low cost
3. Low Power
ix. Questions
1. Would nearest neighbor problem not be exacerbated? A – not if the receiver adjusts RX threshold
2. Why 40 MHz mandatory vs Optional? A – you will loose efficiency if majority of BSS is 20 MHz
3. How do you deal with regulations which don't allow 40 MHz? A – cannot make spec which ties mandatory to the regulatory requirements of a country
4. How many rings? A – two rings and only co-channel

5. Channel propagation? A – TGn channels

7. Chair recessed meeting at 9:53 AM until 10:30 AM tomorrow morning

**Tuesday 7-13-04; 10:30 – 12:30 PM**

8. Chair reconvened meeting at 10:31 AM
9. Tech. Presentations
    a. Completed 9
    b. 5 left one of which has been withdrawn
    c. These will be slotted for Wed. at 4 PM
10. Chair introduced Time Line topic
    a. Relative to initial time line (11-03-488) we are ~ 1 year late
    b. At present, using average of other TG's we would get a ratified standard Dec. 2006 at the earliest
    c. Proposed the following dates as Schedule Highlights
        i. Issue First Letter Ballot on Draft 1.0 July 2005
            1. 3 sessions to review edit (Sep, Nov, Jan)
        ii. Issue First Sponsor Ballot Mar 2006
            1. 3 sessions to review & edit ( May, July, Sept)
        iii. Complete Sponsor ballot – accepted by ExCom Nov 2006
        iv. Publish Mar 2007
11. .19 Joint Meeting Wed 1:30-2:30 PM
    a. Goal - to assure that the proposed .11n standard and existing 802.xx standards will coexist
    b. Suggested change to PAR P&P - TG must issue a CA (Coexistence Assurance) doc
    c. No Discussion re: .19
12. .18 Joint Meeting Wed. 2:30-3:30 PM
    a. Topics
        i. MIMO
        ii. Regulatory issues around 40 MHz channelization
    b. Ad hoc meeting at 1:30 in hotel lobby to prepare a list of topics
13. .21 Joint meeting 8-9 AM Thursday Morning
    a. .21 doc for now must be retrieved from IEEE site not Wireless World
    b. Should we form an official Liaison?
14. Officer Nominations Topic
    a. On Monday Chair suggested Tech editor could be elected on Thursday and Vice Chair in November
    b. Additional thought
        i. tech editor will not have a doc to edit until after the down selection process

ii. use WG vice chairs to help prepare for September "Proposal" meeting
c. Chair considering "not" holding officer elections until Nov. at the earliest
d. Discussion
i. Why are we delaying this election? A – not enough work
ii. Let's hold straw poll? OK
iii. .11r and s have already elected a tech editor; what is different in our case? A – .11s chair said they wanted to have an editor to 'hit the ground running'
iv. Straw Poll – When do you want to hold officer elections?
1. July 2004 – 19
2. Later – 39
v. Chair said Nominations are now open for vice-chair and technical editor but the elections will not happen until Nov. 2004 at the earliest

15. Chair turned body over to Colin Lanzl and his ad hoc committee to develop an agenda for the .18 Joint meeting and the following questions/topics were generated:
a. Is the use of MIMO legal in all the important regulatory domains (NA, China, Japan, EU)
b. Are extended channels (multiples of 20 MHz a/g) legal 'All The Important Radio Regulatory Domains (ATIRRD)'
c. Are the 802.11 agh radio emission rules applicable in ATIRRD (TX power, DFS/TPC; channels; channel mask; …)?
d. What is the process of interacting with regulatory bodies; history and prior results
e. Is beam forming legal in regulatory domains? If yes how is it measured
f. If Regulatory Domains (RDs) don't have uniform rules how should .11n respond
g. If FRs violate any RD requirements, how can .18 help?
h. How is output power measured (per antenna or aggregate?)
i. Will DFS and TPC become a requirement in the US for all bands and when
j. How will DFS/TPC impact .11 in general and .11n in particular
k. When will the test procedures be in place to allow certification to occur
l. How does TGn deal with radar detection and channel avoidance
m. Has the FCC widened the 2.4 ISM bands or does it plan to do so?
n. What are the specifications across the regulatory domains? Will they enforce the spectral mask as well as the out-of-band emission across the band and bands beyond
o. For the extended channels what is the required output power and PSD mask that will be allowed?
p. Will RDs spec specific wave form modulation in addition to PSD masks?
q. Will RD constrain access methods (e.g., TDMA, OFDMA, …)?

16. Action - Colin will create a submission and send it to the .11n chair who will forward it to the .18 chair before Wed. meeting.
17. Chair recessed meeting at 11:45 and will reconvene at 1:30 PM on Wed.

**Wednesday 7-14-04; 1:30 – 3:30 PM**

1. Chair reconvened meeting at 1:34
2. Chair opened Joint meeting with .19 and Chair Steve Shellhammer and Vice-Chair Tom Siep
3. Proposed P&P rules change (19-04-10r6)
4. Will use balloting process to solicit acceptance
5. CA prior to first LB ballot but AFTER the down selection process
6. What is CA doc (19-04-25r0)
    a. Two way street
    b. Must coexist with CURRENT standards not drafts
    c. CA should reference (hopefully) an interference model for interference with EACH of the 802.xx standards
    d. Analysis needs to be in the ball park not +/- 1 dB
    e. Not intended to materially slow down the standardization process
    f. Show trends of relative performance
7. Questions:
    a. What is expected to happen at Ex Com (Paul Nikolich) on Friday? A – approval of Ex Com LB to affirm adoption at the Nov Plenary meeting
    b. Could you maintain a list of 802.xx bands licensed and unlicensed? A – unlicensed for sure
    c. Will .11n be grandfathered? A – as things have developed recently, probably not! This is a change
    d. How should .11n maintain relationship with .19? A – Colin Lanzl volunteered to be the liaison at the WG level
    e. Roles for Liaison? A – report to WG AND help development of the CA doc
    f. Chair asked Colin to create a document defining the duties of the Liaison spanning entire WG as well as .11n. Colin agreed and chair agreed to devote time at Thursdays' meeting for group comment and affirm the submission
    g. Prototype of CA? A – not now; presently working on methodology document
8. Floor suggested we use the 20 minutes before the .18 Joint Meeting to ask the TG for a list questions relating to the logistics of the Berlin meeting:
    a. What precisely must be uploaded on August 13 - doc, presentation, results?
    b. What can change wrt material on the server after Aug 13?
    c. Can new material be presented on the server after Aug 13?
    d. How many hours before the start of the session can anything be changed?
    e. If the numbers of presentations drops significantly can >1 hour be allotted?
    f. Partial and full presentations given at the same time?
    g. Can you yield your time?
    h. Can you yield your time to someone in particular?
    i. Any limitations on time for those that have submitted many partial proposals?
    j. Are there any limitations to what can change between rounds?
    k. Review logistics to voting rounds

l. Adrian will submit a submission listing the questions above. (doc. 11-04-0817r0)

9. Chair recessed at 2:17 until 2:30 at which time the .18 Joint meeting will be started.
10. Chair reconvened at 2:43 PM
11. Joint Meeting with .18 Radio Regulatory
    a. .11n questions for Carl in (11-04-0789r0)
        i. MIMO legal in ALL reg domains? A – No; in US channel bonding using MIMO may be controversial
        ii. Expand 2.4 band? A – nothing published yet in the US
        iii. How will bonded channels be handled? Expected that bonded channel would be uniform in the center. A – TBD in US
        iv. Will regulatory bodies spec modulation etc in addition to PSD? A – trend is to allow innovation
        v. Carl commented 183 states represented at the ITUR!! Most regulations not published in English
        vi. Can we formalize answers to these questions? A – Carl said he would get formal answers as time permits however .11n needs to formalize the questions first
        vii. Also, Julius Knapp from FCC will attend the Nov meeting
12. Andy Gowan from UK Office of Communication (Ofcom) took a crack at answering the set of questions in (11-04-0789r0)
    a. Are MIMO techniques legal? A – legal as long as allowable EIRP is not exceeded at any instant in time by the devices antenna array; note, this will apply to MIMO techniques using transmission delay techniques
    b. Bonding? A – limited by PSD and EIRP per ECC decision and ETSI standard; ETSI limited to 20 MHz channels; ETSI is presently reconsidering the 20 MHz limit; at present there is no channel plan in the ECC 5GHz decision; in general there is no channelization plans in the 2.4 GHz bands in Europe, just a PSD and EIRP limit
    c. Beam Forming? A – see b above
    d. DFS? A – limits based on PSD relative to 1 MHz ; EIRP gain achieved from beam forming still limited by EIRP limits
    e. OFDM or TDMA? A – no issue, quite open in ETSI standard and ECC decision do not mandate any modulation
    f. Jan Kruys was one of the authors of a paper by Intel and Cisco on MIMO and channel bonding techniques which was submitted to CEPT and he volunteered to make the content available which could be used as the basis of a submission to 801.11n.
    g. Andy stressed that these are his interpretations of the current rules and he recommended that the questions be formalized and submitted to Ofcom UK for an official answer.
13. Any other business?
    a. Review the agenda for remainder of this session?
    b. Presentations this afternoon (5 pending); Andy and Geoff will present first after the break
    c. .21 meeting tomorrow morning
    d. Plans for Berlin
14. Chair recessed the meeting until 4:00 PM at 3:23PM
15. Chair reconvened the meeting at 4:04 AM

16. Presentation # 10; 40 / 20 MHz Interoperability for Robust, High Performance, and Compatible 802.11n Systems; 11-04-0772r0; Jeff Gilbert; Atheros
    a. Introduction
        i. In IEEE presentation 802.11-04/0786, we described the benefits of 40 / 20 / 10 MHz channelization for speed, robustness, and low-cost
        ii. One key design issue is how to coexist and interoperate with legacy 20 MHz devices while operating in 40 / 20 MHz mode
        iii. Efficiency is critical – the legacy interop mechanisms cannot notably degrade performance (e.g. 11g)
        iv. This presentation details the 40 / 20 MHz PHY-level interoperation mechanisms
    b. Conclusions:
        i. Full interoperability between 20MHz and 40MHz
            1. Use differential sub-channel energy to detect 20MHz vs. 40MHz signal
            2. Duplicate legacy compatible preamble in 40MHz signal
                a. 20MHz STA can decode legacy SF (Signal Field)
                b. 40MHz STA can use simple combining scheme to decode both 20MHz and 40MHz signals
    c. Questions:
        i. If adjacent 20 MHz channels in use, what happens? A – packet silence techniques; yes 3 dB penalty for 20 MHz channel just to get the Signal field (SF)
17. Presentation #11; Antenna selection and RF processing for MIMO systems; 11-04-0713r0; Andy Molisch, MERL
    a. Outline
        i. System model
        ii. Performance analysis
        iii. Antenna selection algorithms
        iv. Effect of nonidealities
        v. RF preprocessing
        vi. Summary and conclusions
    b. Summary and Conclusion:
        i. antenna selection retains the diversity degree, but SNR penalty
        ii. for spatial multiplexing, comparable capacity if $Lr \geq Nt$
        iii. optimum selection algorithms have complexity N!/(N-L)!; however, fast, good selection algorithms exist
        iv. for low-rank channels, transmit antenna selection can increase capacity
        v. channel estimation errors do not decrease capacity significantly
        vi. frequency selectivity reduces effectiveness of antenna selection
        vii. RF preprocessing greatly improves performance, especially in correlated channels
        viii. Covariance-based (beam forming) preprocessing especially suitable for frequency-selective channels
        ix. switches with low attenuation required both for TX and RX

x. antenna selection is attractive for reducing hardware complexity in MIMO

18. Presentation #12; Preambles for MIMO Channel Estimation; (11-04-0794r0), Andre Bourdoux; IMEC
    a. Motivation
        i. MIMO-OFDM is key to achieve 100 Mbps at the MAC SAP
        ii. Conventional SISO preamble (11.a, g) is not sufficient
        iii. MIMO channel estimation requires a new preamble
    b. Recommendation
        i. Several preamble structures are possible for MIMO channel estimation
        ii. Preambles with simultaneous transmission from all TX antennas are mandatory
            $\Rightarrow$ no problem from AGC
        iii. Least-square solution provides better estimate, is mandatory for FDM-based preambles
    c. Questions
        i. Was Noise AWGN? A-y
19. Presentation #13; Transmit Processing a Viable Scheme MIMO – OFDM in 802.11n ; (11-04-0792r0), Andre Bourdoux; IMEC
    a. Recommendations
    b. MIMO-TX and MIMO-RX schemes are both interesting for 802.11n
    c. MIMO-TX needs channel knowledge at TX side
        i. Estimation in reverse link has lower latency
        ii. Delay between reverse link estimation and MIMO-TX transmission must be minimized
        iii. must be supported by MAC Protocol
    d. MIMO-TX has been demonstrated
        i. Real-time (VHDL, 5GHz band)
        ii. Wireless, 2x2 antennas
        iii. MIMO-OFDM-SDM (108 Mbps) and MIMO-OFDM-MRC (8 dB SNR improvement)
    e. Questions:
        i. None
20. Presentation #14; Co-Channel Interference in.11n Networks; (11-04-0819r0); Aon Mujtaba; Agere Systems
    a. System A
        i. Target a max PHY throughput greater than 200Mbps
        ii. Constrain BW to 20MHz
        iii. introduce 4 transmit antennas for spatial multiplexing
        iv. Assume 4 receive antennas
        v. 64QAM, R=3/4, GI=0.8us, 64-point FFT
        vi. Achieve: 216Mbps
        vii. System A: “4x4x20”

b. System B
   i. Target a max PHY throughput greater than 200Mbps
   ii. Enhance BW to 40MHz
   iii. introduce 2 transmit antennas for spatial multiplexing
   iv. Assume 2 receive antennas
   v. 64-QAM, R=3/4, GI=0.8us, 64-point FFT
   vi. Achieve: 243Mbps
   vii. System B: "2x2x40"
c. Conclusions:
   i. In an isolated cell, bandwidth expansion coupled with spatial multiplexing provides a more robust path to throughput enhancement
   ii. 2x2x40MHz is ~5dB more robust than 4x4x20MHz at 1% PER
   iii. In a multi-cellular deployment:
   iv. BW expansion increases Co-Channel interference
   v. SNR degradation due to CCI increase is balanced out by increase in link robustness
   vi. "comparable" capacity of 2x2x40 and 4x4x20 systems

21. Chair announced that all known presentations have been given
22. Chair reviewed morning session plans – Joint .21, plans for Berlin
23. Chair recessed at 5:42 PM until tomorrow morning 8:00 AM

**Thursday Morning; 7-15-04; 8:00 AM**

1. Chair convened the meeting at 8:02 AM
2. ~ 50 .11n members and ~20 .21 members were in attendance at 8:10
3. Joint meeting with .21 commenced
   a. Ajay Rajkumar (Lucent); Joint IEEE .21 and TG .11n Meeting doc (21-04-0082r0)
      i. Introduced his team
      ii. Focus – Facilitate roaming across heterogeneous networks
      iii. Some Elements of a solution might include
         1. Some 'make before break' mechanism
         2. Network neighborhood discovery mechanism needed
         3. Standardized MAC interface to higher layers
            a. MAC service model (e.g., Some sort of QoS continuity i.e., a QoS service/mapping leading to admission control)
            b. Transport link delivery
         4. Heterogeneous networks – e.g., Cellular and WLAN

iv. Questions:
1. How to handle different MAC layer architectures? A- use/define a new layer just below the IP layer
2. How will we get Cellular to cooperate? A – service continuity and session continuity is being investigate by Cellular as we speak

b. Bruce Kraemer, chair of .11n, described goals and status of TGn (11-04-0824r0)
i. Amendment to standard
ii. >100 Mbps at MAC Data SAP (not over-the-air rate)
iii. We are at the CFP stage and will hear initial proposals in Sept 2004
iv. LDPC coding, channel expansion, aggregation, MIMO are some of the likely candidates to be offered for the new standard
v. MAC SAP interface will not be altered
vi. Backward compatibility with .11 in at least one mode is a requirement with .11 and its amendments a,b,d,e,g,h,i,j assumed as the baseline to be backward compatible with
vii. Timeline reviewed
1. 1st LB fall of 2005 with 1st publication in 2007

4. Questions:
a. How does .21 fit with TGr and WIEN? A - TGr will deal with intra-ESS roaming and .21 will deal with inter-ESS. The question is the definition of an ESS; the relationship with WIEN is still under discussion
b. Will .21 protocol enable traffic across 3GPP - .16 - .11n interfaces? A - basically, that is the hope; the concept is just as cellular uses AAA service agreements today with other operators, why not .11 and .16?
c. What is the timeline to formulate interoperability mechanisms? A by Chair – within the next year; i.e., before the 1st draft
d. What does .21 need from TGn? A – TBD but will take as an action item within the 1 year window
e. Would .21 simulations be useful? A – too late to include in our down selection process as those have been defined in the CC and FRs but TGn would be open to inputs/useful mechanisms and would endeavor to incorporate them in the standard; the object is after all, a standard of high technical quality
f. Straw Poll - .11n members interested in establishing a WG liaison with .21 – (18 for,1 against,16 abstain)
g. Straw Poll - .21 members interested in establishing a liaison with .11 - (12,0,0)

5. Colin Lanzl lead a discussion re: Liaisons in general; (11-04-0823r0)
**a. Motion by Adrian Stephens that the .11n chair request of the .11 WG Chair that a formal liaison with .19 be created was seconded by Steve Shellhammer passed (44,0,2)**

6. Chair lead discussion of Logistics for Berlin doc. (11-04-658r3)
a. Overarching goal – timely high quality technical amendment
b. Answers to doc. 11-04-0817
i. Maximum time will be made available in Sept. meeting = 34 hours
ii. 62 presentations => ~.5 hours per presentation

iii. Equal time => time pool/# presentations
iv. All presentations will be heard in Sept.
v. Final time will be done on morning of Sept. 13
vi. No changes to presentation, order or time allocations after presentations begin on Monday Sept. 13
vii. Speaking order established on Monday Sept. 6
viii. Order will be established using a random process overseen by .11 WG chair
ix. Speaking order will be communicated asap on Monday Sept 6.
x. Doc. 11-04-0796r0 to be posted on Wireless World and will contain speaking order
xi. How to handle changes to docs posted on 8-13-04
    1. Presentations will be frozen for the week on morning of Sept 13
    2. Selection procedure doc remains (11-04-665r9) and contains definitions of Partial and Complete proposals
    3. What about mergers occurring in 10 day interval before Sept. 13?
    4. How do we handle the post presentation panel discussion?
    5. Potential solution - Mergers and re-presentations would be given in Nov, not Sept and followed by a panel discussion
    6. Voting would BEGIN in Nov. in San Antonio at the earliest
    7. What needs to be posted?
        a. Compliance with FRs, table 3.1 in FR doc
        b. Comparison Criteria table in section 4 of CC doc (pages 6-16)
    8. Discussion
        a. Limitations on changes between rounds of voting? A – none since changes are encouraged between rounds
        b. Limitation on time for those who have registered presentations? A – fixed
        c. Will everyone who is presenting know when the other presenters are presenting? A – yes
        d. To accommodate orders of the day in other Task Groups can presentation slots be exchanged? A – After discussion the conclusion was that presentation slots cannot be exchanged.
        e. Is swapping in general allowed? A – no
        f. Once agenda for week of Sept is approved at the start of the session it cannot be changed? A-yes
        g. What precisely must be on server? A – FR and CC material
        h. If someone opts out will slots be moved up? A – yes; accordion process
    9. Chair recessed at 10:02 until 10:30
    10. Chair reconvened at 10:37 AM
    11. Return to Discussion of Berlin Logistics
        a. Only complete presentations have voting status

   b. Partials can be combined to create a complete proposal; partials can combine with complete proposals to create a new complete proposal
   c. First voting will take place in November at the earliest
   d. How do we handle the merged presentation posting after Berlin? A – probably use the same format by requesting merged proposals be put on server in advance (at least 10 days) of November meeting
   e. What must be posted? A – Presentations, FR compliance, CCs, simulation results
   f. How much can change between 8-13 and 9-13? A – honor system, up to membership to decide with their votes
   g. Chair will take all comments into consideration and will create a separate procedure clarification doc and post by next week
   h. Adrian will repost his questions doc 11-04-0817 with the answers developed in the meeting today
12. Colin Lanzl motioned to adjourn this July session and was seconded by John Kowalski passed by acclamation.
13. Chair adjourned the July meeting at 10:52 AM
14. See you in September

# IEEE P802.11
# Wireless LANs
# Minutes of WAVE Study Group

**Date:** Portland, July 12 -16, 2004

**Author:** Filip Weytjens
Transcore
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## Tuesday, July 13, 2004 4:00PM Session

The meeting was started by Broady Cash. (ARINC) at 4:05PM. Broady substituted Lee Armstrong as the chair of the WAVE sessions. He went over the policies and rules and mentioned that there would be no meeting on Thursday.

The objective of the meeting was to discuss the amendment for WAVE and comments on the PAR and 5 criteria. At this point the letter ballot has passed and excom is reviewing the PAR and 5 criteria. A motion needs to be presented to the 802.11 body to extend the working period of the study group.

Minor changes were proposed to the agenda, which were approved by the group.

The minutes from previous meeting (May 2004) were reviewed and approved by the group.

The document under discussion was available on the server (document nr 11-04-0793-00-WAVE). It was presented by Broady. He discussed the DSRC concept, usages and the rules for the control and service channels. The definitions were addressed for the WAVE information element and action frame including the PST, VST, and safety messages. The different scenarios were described that are supported by the WAVE technology and he also discussed the supporting network technology.

The meeting was adjourned at 5:15PM until 7:30PM.

## Tuesday, July 13, 2004 7:30PM Session

The meeting started at 7:30PM.

Broady further discussed the presentation. The spectral masks were discussed and further detail was provided for the WAVE Information elements, and Action frames.

A question was raised on the beacon interval. Justin Mcnew (Technocom) explained that the beacon interval on service channel and control channel was the same and that the mechanism was already defined in 802.11h.

The meeting was adjourned at 8:00PM.

## Tuesday, July 13, 2004 8:00 AM Session

The meeting was started by Broady Cash. (ARINC) at 8:05AM. The goal was to address comments to the PAR and 5 criteria. No comments were received and therefore, the meeting recessed to prepare the motion.

The meeting was recessed at 8:10AM till 8:30AM.

The meeting reopened at 8:30AM with the motion to extend the Study group. The motion stated “Believing that sufficient interest continues and that the PAR and 5 criteria can be completed per IEEE-SA guidelines during the extension period, it was requested that 802.11WG continue the charter of the WAVE-SG through January 2005 meeting.” Wayne Fisher and Tom Schaffnit moved the motion. The result was 30-0-0.

The meeting was adjourned at 8:45AM.

# IEEE P802.11
# Wireless LANs

## TGr Meeting Minutes for July 2004 Session

**Date:** July 12-16, 2004

**Author:** Michael Montemurro
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## Monday May 12, 2004
4:00pm

Chair: Clint Chaplin
Secretary: Mike Montemurro

- Call to order
- Agenda – Document 11-04/761r0
- Review operating rules for a Task Group.
- Review IEEE 802 policies and procedures for Intellectual Property.
- Election of Task Group Secretary:
  - Michael Montemurro is the only person who has volunteered for this role.
  - Michael Montemurro is acclaimed as Task Group Secretary.
- Approve meeting minutes from last meeting 11-03/520r0.
  - No objections to approving the minutes.
- Approve teleconference meeting minutes 11-04/664r2.
  - No objections to approving the minutes.
- Election of Task Group Technical Editor:
  - Bill Marshall is the only person who has volunteered for this role.
  - Bill Marshall is acclaimed as Task Group Technical Editor.
- Discussion on the Agenda – Document 11-04/761r0.
  - Remarks on the agenda content – None.
  - Call for presentations:
    - Nancy Cam Winget – Establishing PTK Liveness - Document 11-04/707r0.
    - Jeremy Spilman – Roaming Test Methodology – Document 11-04/748r0.
      - This sounds like a proposal for a core document.
      - Why do we need a test methodology?
      - We need to be able to define a definitive test methodology to compare proposals.
      - We could compare proposals on an ad hoc basis without a test methodology defined.

        - Marian Rudolf – Discovery and Passive Scanning Discussion – Document 11-04/718
        - Marian Rudolf – Make before break handover – Document 11-04/719
            - Isn't Discovery out of scope for this work? This may be an informational presentation.
            - Do we have an approved scope document at this time? No, but we have an agenda item to discuss the scope document.
    - Any objections to approving the agenda as Document 11-04/761r1?
        - None
    - Agenda is approved.
- Discussion on Fast BSS-Transition Requirements – Document 11-04/666r1
    - Any objections to the Chair leading the discussion on this document? None.
    - This document hasn't been updated with the changes from the teleconference
    - Table this discussion until the document has been updated.
- Discussion on Fast BSS Transition Use Cases – Document 11-04/677r1
    - Perhaps we should split authentication from key management (key management being the handshakes and so forth).
    - Should we consider full authentication vs. pre-authentication?
    - The current table of use cases multiplies out to 135 combinations, some combinations are easy problems, and some combinations are hard problems.
    - The entries in the table are independent; that is, the entries in a particular row are not related.
    - Do we want to discuss fat AP architectures vs. wireless switch architectures?
    - AS communication time is not under TGr's control, and may not be under the control of the user.
    - The QoS decision result may not be done in the AP; the AP may refer to a central controller.
    - What's the minimum value for the roaming time metric?
    - Do we need to make an assumption about the AS architecture that the DS has?
    - We should take scanning time into account.
    - We can't define the DS problem away. Must be able to do fast roaming in a slow DS.
    - Components for Security and QoS that are normally in discovery phase may fall into TGr scope.
    - Parts of the solution that are demonstrably broken shouldn't be accommodated.
    - Can't assume DS architecture or AS architecture ( We need to capture in requirements doc.)
    - What is meant by RF coverage overlap? What cases should we attempt to solve, and which can we safely ignore (if we do inadvertently solve it).
    - There should be at some point in each proposal in indication of just which frame that triggers the switch of data from the old AP to the new AP. (unclear from discussion if this should be mandatory).
- Recess until the Monday evening session

# Monday July 12

7:30pm

- Call to order
- Continue Use Case document discussion:
  - Do we want to cover unplanned roaming versus "planned" roaming?
  - Unplanned roaming is cut-off from an AP.
  - At the point where we make a roaming decision, does it matter how the decision was reached (i.e. unplanned roam).
  - There are conditions under which you can do a fast roam and there are other conditions where you can't.
  - Some proposals may be applicable over more scenarios
  - The Access Point could force a STA to move
  - Add "planned" versus "un-planned" roam to use cases.
- Should we create a document to describe how roaming works now?

STRAW POLL: Should TGr describe the current process for BSS Transition?

a) Yes
b) No

Result: a – 29; b – 0.

MOTION: Move that TGr should describe the current process for BSS Transition to be included as informative text in the IEEE 802.11 TGr draft.

By: Charles Wright
Second: Bill Brasier
DISCUSSION: None.

Result: Yes - 20; No - 0; Abstain - 0. Motion passes.

- Volunteers to create the text: Bob Beach, Nancy Cam Winget, Haixiang He, Bill Brasier
- There are current guidelines for engineering an 802.11 network. Fast BSS-Transition assumes a well engineered network. Perhaps we need to define what that is.
- This sounds like a discussion we have earlier.
- We could document this in a use case.
- This would likely need to go into the requirements document.
- Discussion on the selection procedure:
  - How formal do we want this process to be?
  - Should we do this on an adhoc basis? We likely won't have a universal best.
  - TGn spend a year preparing documents before they called for proposals. They did a lot of work.
  - The formal process in not ambiguous.

STRAW POLL: All those who think they may bring a proposal for Fast Roaming to TGr, or know someone you might.

a) Number

Result: a – 8.

- Take a look at Document 11-03/665r9
  - They had Functional Requirements, Comparison Criteria, Usage Models.
  - They classified the proposals as complete or incomplete.

- Partial proposals may be combined to form a complete proposal.
- We need to decide what makes a proposal complete for our group.

STRAW POLL: All those who think they may bring a proposal for Fast Roaming to TGr, or know someone you might.

a) Craft a solution to the Fast Roaming problem as a body of the whole
b) Select a proposal from a group of candidates
c) other

Result: b – unanimous.

STRAW POLL: Does TGr want to use a formal selection process?

a) Yes
b) No

Result: a – 23; b – 0.

- We don't need to go through Comparison Criteria because all proposals are likely to meet the requirements.
- The possibility of 8 or more proposals dictates that there should be a formal selection process.
- Did TGi have a formal selection process? No.
- Should TGi have had a formal selection process?
- TGi crafted their proposal as it goes – the group had to go through the learning process
- The Chair will complete his selection process document and present it tomorrow – time permitting.

- Recess until the first session tomorrow

# Tuesday July 13

8:00am

- Call to order
- Discussion on the TGr Scope, Document 11-04/678r1
  - Is 802.11F in scope?
  - 802.11F is due to expire some time around now?
  - The content of 802.11F can be folded into a TGr amendment.
  - WEIN in the document should be WIEN.
  - Should replace Auth (Authentication server) with AS, the 802.1x acronym.
  - Make VLAN/SSID mapping should be in scope.
  - BSS-Transition should be out-of-scope.
  - What about APSD and 802.11e compliance?
  - Do we want to support Fast Transition if the STA is in Powersave mode? Yesterday we determined no.
  - Legacy power save should be out of scope. APSD should be in scope.
  - Determine the ability to support BSS-Transition for non-overlapping cells are in scope.
  - Support for tangential cells should be in scope.
  - Do you want to solve Fast BSS-Transition for the case where the STA cannot communicate with either AP for an interval in time?
  - We are assuming that changing frequencies are instantaneous seeing several AP's at the same time.
  - From a STA point of view, the STA doesn't know whether it's in or out of range until it sends a packet.
  - There are other ways to know about an Access Point without data communications. (for example, TGk has mechanisms to give the location of Access Points).
  - Most well designed networks are designed for overlapping coverage.
  - Customers decide how much overlapping coverage they want.
  - There are mechanisms that could be designed to work without overlapping coverage.
  - Do we want to assume that in all solutions, the STA must be able to see at least two AP's.
  - We require that the STA be able to see at least one AP at one time.
  - We need to define what it means to be tangential coverage.
  - It relates to whether we allow the overlapping coverage definition in the Use Case document to have a negative value.
  - We need to determine whether the mechanism for a STA to select a candidate AP for roaming is in scope.
  - Why is load balancing out of scope?
  - TGk is defining the candidate AP list and the site report and is out of scope for TGr
  - TGe is also giving hints to STA to facilitate roaming
  - It is out-of-scope for TGr to define the algorithm for the decision to roam.
  - The cause for the BSS-Transition is out of scope.
  - We are trying to solve the "how", not the "why" of BSS-Transition.
  - A STA could hint about an impending move to another AP.
  - TGk may not need to address the TGr requirements in a timely manner.
  - We are focused on Fast Handoff and we are ignoring the most timely component of Fast Handoff.

- Why is BSS-Transition determination out of scope?
- Different applications need to use different algorithms to make roaming determinations.
- There has to be enough information so that the STA can make a roaming determination.
- The roaming decision is a STA decision unlike the Cellular network. The AP provides information.
- TGk and WNM provide information to the STA in order for it to make roaming decisions.
- There have been proposals made to push the scanning process before the roam.
- Any scheme for fast BSS-Transition should indicate when the scanning occurs. These elements should be part of the solution proposals.
- The scan could be a continuous long-term process could take minutes and not interrupt data transmission.
- We should add the reasons for our conclusions that are described in the scope document.
- We may want to bring the discussion up again on Thursday.

- Discussion on the Selection Procedure:
  - The procedure discusses partial solution versus complete.
  - There could be complementary proposals, which could be combined into a single complete solution.
  - There are comparison criteria in the process – should we put comparison criteria together?
  - If we don't know exactly know what we're trying to solve, how are we going to define the comparison criteria.
  - The criteria could be that we want to have fast BSS-Transition occur within the time budget.
  - Delaying proposals by putting more structure in place would be counter productive.
  - Less formal is a good thing to do. However we need to do a minimum amount of work to define the problem.
- Recess until the next session.

# Tuesday July 13

10:30am

- Meeting is called to order.
- This is a joint session between WIEN and TGr.
- The following presentation present the issues to be discussed at this forum.
- Presentation by Jon Edney on Anonymous MAC Address – Document 11-04/780:
  - The number of packets in the proposed exchange stays the same.
  - The delay budget is only increased by the time it takes for the Access Point to confirm that the address is unique.
  - What information do you compromise if someone knows your MAC address?
  - Different companies bind user information to the MAC address.
  - The Service Provider doesn't really know the real identity of the user.
  - How is this different from credit card transactions? Credit card information is encrypted and not available to the transitions.
  - The IETF tried to solve this problem in 1996 and classified it as a business problem.
  - There are $2^{23}$ MAC addresses that are possible, why does the AP need to determine uniqueness.
  - If you give the Service Provider your username and password, how does changing the MAC guarantee better identification?
  - The WAVE study group is interested in MAC address randomisation. It's not a good idea to tie 802.11 to the assumption that the IP layer is secure.
  - The goal of this proposal was to completely disconnect the MAC address from the user.
  - Some Service Providers do billing by MAC address. This proposal would break these business plans.
  - This proposal sounds more like a nice-to-have rather than a hard requirement.
  - There is a lot of public resentment to the potential of being tracked by MAC address.
  - It would be better for WAVE to adopt an anonymous authentication scheme rather than MAC address manipulation.
  - The sequence of generating a MAC address takes up time in a roaming budget. However this procedure on is done on the first Association with an Access Point.
  - There is a negative use case where the MAC address expires in the middle of the roam. This would force a new Association.

STRAW POLL: Is Anonymous MAC addressing a concept that should be addressed by the 802.11 working group?

a) Yes
b) No

Discussion:

- Should this be re-worded to ask whether this should be pursued as a standardization activity? No that changes the intention.

Result: a – 26; b – 22.

- Presentation by Eleanor Hepworth on Network Selection – Document 11-04/691r1:
  - NAI is at least 72 bytes, not up to 72 bytes.
  - The scope for this work is looking at Network Selection over the wireless network.
  - It would be interesting to have Network Selection on both wired and wireless networks.
  - You need to know that when you discover an Access Point, you can identify the services that are available.

STRAW POLL: Is Network Selection information introduced in Document 11-04/691r1 a concept that should be addressed by the 802.11 working group?

a) Yes
b) No

Discussion: None.

Result: a – 55; b – 0.

STRAW POLL: In which Task Group or Study Group should this concept be pursued?

a) WIEN
b) TGr
c) Other

Discussion: None.

Result: a – 50; b – 0; c – 1.

- Presentation on access router identification by Daniel Park - Document 11-04/710r0:
  - Why would this work not be included with the work on network selection?
  - This work can be applied to TGr to advertise a mobility domain.
  - If you have to change your IP address you won't get fast roaming. The term Access Router is misleading.
  - If you change the IP address, the session ends.
  - This problem is larger than just subnet domains. The identifier defines the logical connectivity between to the Access Point and the Access Router.
  - We need to distinguish between a layer 2 handoff and a layer 3 handoff.
  - This problem does not exist if an ESS can only span one subnet.
  - Advertisement of networks is part of TGk's scope. There may be pieces that go in different groups.
  - This problem hasn't been defined sufficiently to decide who should solve it.
  - WIEN will examine this problem further.
- Recess until the next session

# Tuesday July 13

1:30pm

- Call to order.
- Joint session with TGs and 802.21.
- Presentation on "What is an ESS?" from Jon Edney – Document 11-04/614r1
  - 802.21 use the concept of a bridged LAN. Layer 2 transitions are part of 802.11. Layer 3 transitions are part of 802.21.
  - It would be useful for 802.21 to see each mobility group of 802.11 Access Points as a single entity.
  - The definition of an ESS has a single SSID as an identifier. However there is no restriction on two ESS's have a common SSID.
  - The ESS, BSS, and SSID should be defined as part of the Layer 2 technology.
  - Mobility domains would be a useful concept in defining how roaming works.
  - You could include introduce another identifier to define a group of AP's as an alternative to SSID. You could deprecate SSID entirely.
- Presentation on "Definition of an ESS" from Darwin Engwer – Document 11-04/629r1
  - The ESS Distribution system could include the Router or could be constructed without including the Router.
  - The SSID is a means of defining the ESS, not a means of defining the network infrastructure that you are connecting to.
  - Layer 2 signalling could be used to improve Mobile IP inter-working.
  - The usage and definition of SSID should be changed to facilitate its usage.
- Presentation on "Cross-domain handover" from Michael Williams – Document 21-04/100r0
  - 802.21 is looking to define an event which the mobile node will send to the infrastructure to indicate that it is going to move.
  - The Domain is defined as an administrative domain. There are a number of different definitions of the domain depending on the topology.
  - The 802.21 signalling needs to work inside existing security models. 802.21 is not looking to define this security model.
- Presentation on Service Definitions by Steve Conner – Document 11-04/785r0
  - No discussion.

STRAWPOLL: Should one joint TGr/TGs session at each 802.11 meeting to be the default?

a) In favour
b) Opposed

Discussion: None.

Result: a – 48; b – 5.

- Recess until 4pm on Thursday.

# Thursday July 15

4:00pm

- Call to order.
- The goal for this week is to issue a "call for proposals". If we miss the call for proposals at this session; it will slip another two months.
- The Requirements document needs to be agreed on before we can issue the call for proposals.
- We have stated that partial proposals may be submitted.
- Jim Wendt has posted a revised Requirements document as 11-04/805r0
- Any objections to going through the Requirements document after Jeremy's presentation?
- We will need to make a motion to approve the Requirements document – does it need to be on the server for four hours?
- Presentation by Jeremy Spilman on Roaming Test Methodology – Document 11-04/748r0
  - There are other conditions other than RF that could cause a roaming condition. RF would still play a large role in the roam.
  - The traffic was bi-directional.
  - The roaming times were measured from last data packet to new data packet.
  - The STA does not decide to roam at the same time that it fails to receive a data packet.
  - If the STA does a DHCP request, the value for $t_{data}$ was substantially larger.
  - Having a controlled environment is really good.
  - As mentioned in Document 11-04/086r3, the HUB should be replaced by a switch.
  - Uplink only traffic would yield much more reliable results versus downlink traffic.
  - It would be good to know what the $t_{associate}$ times – the information will be updated as a separate submission.
  - The attenuation rate should be reported in the results.
  - How would you evaluate a proposal that did roaming process in a different order? You can control the coverage overlap and you could modify the test set-up to accommodate other solution proposals.
  - This presentation was also given at one of the WPP SG sessions.
- Discussion on the Requirements Document, Jim Wendt – Document 11-04/805r0:
  - The Requirements Document will be edited during the discussion and updated as 11-04/805r1.
  - This captures the minimum requirements for a Fast BSS-Transition solution.
  - A DS is a logical concept, so that logical does not needed.
  - Why can't you roam from a TKIP-enabled AP to an AES-enabled AP?
  - An adhoc group will determine and propose security requirements for Fast BSS-Transition.
  - The definition of Fast BSS-Transition time is theoretical, it is not measurable. You can use periodic data to get an approximate measurement of this metric.
  - The problem with DHCP can be solved. However for the purpose of defining the Fast BSS-Transition requirements, a proposed solution may address this issue.

STRAW-POLL: How do we want to handle requirement PHYMAC.4?

a) Remove the text.
b) Change "does not have to" to "shall"

Discussion:

Result: a – 22; b – 15;

- This is not decisive enough to edit the text. We will re-work the text.
- Recess until the 7:00pm session.

# Thursday July 15

7:30pm

- Call to order.
- There is a willingness to issue the call for proposals for TGr before the end of this meeting.
- Although we are not finished working through the requirements, we should still issue the call for proposals for the November session.
- We can use the September session to finalize the requirements, scope, use cases, etc.
- There are still concerns that the Requirements are not finalized before the call for proposals. Something requirements might change in September? This will reduce the overall quality of the proposals.
- If there are significant changes to the Requirements, the call for proposals could be extended.
- November seems like a reasonable amount of time to get agreement on the requirements. We will be tinkering with requirements anyways.
- Could we accept proposals November and January?
- We did do a straw poll earlier.

STRAW POLL: How many people intend to submit proposals for fast roaming?

a) Count

Result: a – 5;

STRAW POLL: How many people would have a proposal ready by October 15?

a) Count

Result: a – 4;

Motion: Publish a call for proposals for IEEE 802.11 TGr, proposals will be presented starting at the November 2004 plenary; presentations must be available on the IEEE 802.11 document server by October 15, 2004, and intent to submit a proposal must be sent to Stuart Kerry, Clint Chaplin, and Harry Worstell by August 17, 2004.

By: Michael Montemurro

Second: Jesse Walker

Discussion:

- This is a good process to follow.
- The intention to submit will only include the name of the people.
- The letter of intention is not binding.

Result: Yes – 16; No – 1; Abstain – 9. Motion Passes.

- Suggestion to keep moving forward for continuing conference calls.
- Are conference calls really necessary? No.
- We should get through the entire Requirements document before the end of the September meeting.
- We can set a hurdle but it would not be very high.
- Given that we have passed a motion for a call for proposals, and the requirements are not complete. What do you expect the content for proposals to be?
- The requirements are hard enough that people can begin working on proposals.
- The current revision of the requirements does not include security.
- Continue on the Requirements document discussion:
  - Document is being edited as part of the discussion.

  - We should create an adhoc group to define metrics for fast-BSS transition.
  - We should make the proposals mention the differential between the pre fast-BSS transition solution and the BSS-transition solution.
  - We need to supply the measurement methodology and the metric as part of our PAR.
  - The PAR doesn't state which order we need to do things.
  - How should we address dependencies on standards which are currently under development?
  - The proposal should mention its dependencies in order to be a complete submission.
  - This document will be updated as Document 11-04/805r1
  - Document 11-04/086r3 should be listed as a reference.
- Jesse Walker has volunteered to co-ordinate the Security Adhoc group.
- We still need a volunteer to co-ordinate the Test Methodology Group. Clint will issue a call for volunteers at the Closing Plenary.
- Presentation by Nancy Cam-Winget on Establishing PTK Liveness - Document 11-04/707r0
  - This proposal is different from the one in Document 11-03/241, which was a merge of the optimisation and the TGi structure. This is a completely new construction based on the 4-way handshake.
  - The maximum size of the EAPoL-key message is 256 bytes.
  - Why weren't the EAPoL-key messages moved into the Authenticate messages? You have to do this kind of handshake at re-association because the authentication messages can occur long in advance before the re-association.
  - The QoS reservation request should be requested. This proposal does not address this case.
  - You need a path for the AP to reject the optimisation. The AP will reject the re-association.
  - Pre-computing information is really useful.
  - The proposal is too focused on security; it does not address QoS as well.
  - The QoS negotiation could occur within the re-associate transaction as well.
  - The goal of this proposal is to maintain compatibility with IEEE 802.11i.
- We are out of time.
- The next meeting will be in Berlin.
- Adjourn for this session.

# IEEE P802.11
# Wireless LAN
# Task Group S ESS Mesh
# Meeting Minutes for July 2004

**Date:** July 20, 2004

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## Abstract

Minutes of the Meeting of the IEEE 802.11 Task Group S ESS Mesh held in Portland, Oregan, USA, from July 12 to July 16, 2004 under the TG Chairmanship of Donald Eastlake 3rd of Motorola Laboratories. Minutes taken by Tyan-Shu Jou and edited by Donald Eastlake. An extended agenda for the meeting is at 11-04/663r6.

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# Significant Actions

(For the detailed minutes, including these actions, see the next section of this document.)

## Monday Afternoon Session (Monday, 12 July, 2004, 4:00PM-6:00PM)

1. **Audience unanimously approved the previous (Grove Garden, California) meeting minutes (11-04/652r1) and the June 30th teleconference meeting minutes (11-04/683r1).**
2. **Due to the lack of volunteers, the SG secretary Tyan-Shu Jou of Janusys Networks continued to take the Recording Secretary position for TGs.**
3. **There were two candidates ran for the Permanent TGs Technical Editor position. W. Steven Conner of Intel Corp. won the election and took the position.**
4. **Presentation #1: "Draft Terms and Definitions for 802.11s" (IEEE 802.11-04/730r1) Tricci So presented for the definition subgroup**

## Monday Evening Session (Monday, 12 July, 2004, 4:00PM-6:00PM)

1. **Presentation #2: "802.11s Security Proposal" (IEEE 802.11-04/777r0) Robert Moskowitz, ICSA Labs**
2. **Presentation #3: "802.11s Routing Sub-Group Discussion on May '04 Report" (IEEE 802.11-04/765r0) Tyan-Shu Jou, Janusys Networks**
3. **Presentation #4: "A View on 802.11s Routing, A Framework for a Discussion" (IEEE 802.11-04/778r0) Robert Moskowitz, ICSALabs**

## Tuesday Afternoon Joint Session of TGs, TGr, and 802.21 (Tuesday, 13 May, 2004, 1:30PM-3:00PM)

1. **Presentation #5: "What is an ESS?" (IEEE 802.11-04/614r1), Jon Edney, Nokia**
2. **Presentation #6: "The Nature of an ESS" (IEEE 802.11-04/629r1), Darwin Engwer and Bob O'Hara**
3. **Presentation #7: "Cross Domain Trigger and Handover Talking Points" (IEEE 802.21-04/100) Michael G. Williams**

## Tuesday Afternoon Joint Session of TGs and TGr (Tuesday, 13 May, 2004, 3:00PM-3:30PM)

1. **Presentation #8: "Interpretations of the Distribution System Service Based on the 802.11 Specification" (IEEE 802.11-04/785r1), W. Steven Conner, Tricci So, Tyan-Shu Jou**

2. **Straw poll: Should one joint TGr/TGs session at each 802.11 meeting be the default? Result: Favor: 48 Against: 5. Chairperson of each group will work on the arrangement.**

## Tuesday Late Afternoon Session (Tuesday, 13 May, 2004, 4:00PM-6:00PM)

1. **Presentation #9: "WLAN Mesh Usage Model and Considerations for Hot Spot Service" (IEEE 802.11-04/680r0), Taejin Lee (Broadwave), Jongtaek Oh (Hansung Univ.), Sukhee Bae (RRL), Jaewoo Lim (RRL)**

2. **Presentation #10: "Defining Comparable Usage Models for 802.11s" (IEEE 802.11-04/764r1, 662/r7), W. Steven Conner**

3. **Presentation #11: "Suggested Major Functional Components for 802.11s" (IEEE 802.11-04/749r0) W. Steven Conner, Koji Omae**

## Tuesday Evening Session (Tuesday, 13 May, 2004, 4:00PM-6:00PM)

1. **Presentation #12: "Outdoor 802.11 Mesh Links RF Impacts Considerations" (IEEE 802.11-04/731r0) Tricci So**
2. **Task Group Process initial discussion (11-04/800r1, by Donald Eastlake 3rd ). A heads-up for the audience on this topic.**

## Thursday Early Morning Session (Thursday, 15 May, 2004, 8:00AM – 10:00AM)

1. **Presentation #13: "MAC Considerations for 11s" (IEEE 802.11-04/760r0), L. Lily Yang, Akira Yamada**
2. **Presentation #14: "802.11s Security Ad Hoc" (IEEE 802.11-04/826r0), Robert Moskowitz, ICSALabs**
3. **Presentation #15: "Outdoor 802.11 Mesh MAC Problems" (IEEE 802.11-04/732r0), Tricci So**

## Thursday Late Morning Session (Thursday, 15 May, 2004, 10:30AM – 12:30AM)

1. **Presentation #16: "Multi-hop Connections Using 802.11" (IEEE 802.11-04/709r0), Guido R. Hiertz, Yunpeng Zang, Jorg habetha**
2. **Presentation #17: "Additional Draft terms & Terminology for 802.11s" (IEEE 802.11-04/0822r0) Jonathan Agre**
3. **Task Group Process discussion (11-04/800r3)**

    a. **Straw poll**
    **If a TGs call for proposals was issued right after the September meeting with a deadline shortly before the November meeting, how many would submit a proposal?**
    **Result:**
    **Reasonably certain to submit a proposal: 4**
    **50/50 chance: 10**
    **Might but probably not: a few people**

    b. **Straw poll**
    **If a TGs call for proposals was issued right after the November meeting with a deadline shortly before the January meeting, how many would submit a proposal?**
    **Result:**
    **Reasonably certain to submit a proposal: 13**
    **50/50 chance: 4**
    **Might but probably not: 4**

    c. **Straw poll**
    **Is documenting Usage Cases important?**
    **Result:**
    **Yes: 48**
    **No: 0**

    d. **Straw poll**
    **Is each category in document important?**
    - **Residential: 36**
    - **Office: 43**

- **Campus/Community/Public Access: 42**
- **Public Safety: 34**
- **Car to Car: 7**

**e. Straw poll on Informal Group Submissions Status**
**What should be the status of relevant submissions from informal groups if a majority of TGs agrees with the submission?**

- **Strongly included as part of call for proposals: 12**
- **Adopted as internal working documents: 29**
- **Included on a TGs recommended reading list: 3**
- **No special status: 2**

**f. Straw poll**
**What is the current feeling of TGs as to when we should call for proposals?**

- **July 2004: Favor: 3. Against: 31**
- **September 2004: Favor: 10. Against: 28**
- **November 2004: Favor: 16. Against: 10**
- **January 2005: Favor: 8. Against: 1**

**g. Straw poll**
**Should any call for proposals require that proposals be "complete"?**
**Result:**
**Yes: 18**
**Not: 19**

**h. Straw poll**
**How long should be the call for proposal window?**
**2 months: 2**
**4 months: 17**
**6 months: 10**

**i. Motion: One teleconference 15 August, 3PM PDT.**
**Moved: Peter**
**Second: W. Steven Conner**
**Result:**
**In Favor: 18**
**Against: 2**

# Full Minutes

## Monday Afternoon Session:

Date & Time: Monday, 12 July, 2004, 4:00PM-6:00PM
Location: Ballroom II-IV Hilton Hotel Executive Tower, Portland, Oregan, USA.
Officer presiding: Donald Eastlake 3rd

Meeting was called to order at 4:00PM by Donald Eastlake 3rd, ESS Mesh SG Chair.

The initial slides used by the SG Chair are 802.11-04/663r4

Reviewed policies and procedures of IEEE:

The Chairperson went through the IEEE-SA Standards Board Bylaws on Patents in standards and Inappropriate Topics for IEEE WG meetings.

On-line attendance recording reminded.

Audience unanimously approved the previous (Grove Garden, California) meeting minutes (11-04/652r1)
Audience unanimously approved the minutes of the teleconference meeting held on June 30, 2004 (11-04/683r0)

Agenda Discussion based on IEEE 802.11-04/663r4

**Permanent TGs Recording Secretary Position election**:

No volunteers hence SG secretary Tyan-Shu Jou of Janusys Networks will continue to serve the position.

**Permanent TGs Technical Editor election**:

**Candidates**:

- **W. Steven Conner** (Intel): Current SG Editor; started working on this group even before ESS Mesh SG was formed; has full support from the employer for the position.
- **Thomas Maufer** (Nvidia): 20 years of experience on networking; author for 3 networking books, the latest one is on wireless LAN; also has full support from his employer for the position.

**Voting Result**: W. Steven Conner: **22**; Thomas Maufer: **4**.
**W. Steven Conner of Intel was elected to serve as the IEEE802.11s Technical Editor**.

**Presentation #1:**

"Draft Terms and Definitions for 802.11s"
(IEEE 802.11-04/730r1)
Tricci So presented for the contributors to this submission

- This document is a joint work from many members of this group to define the core terms for ESS Mesh as a discuss base. It is intended to be put into a motion to make the task group to adopt it as a working document on Thursday.
- A question raised on the figure which shows the existence of multiple Mesh Points in a mesh network. The response from the audience is that figure just shows one possibility of that scenario. The task group has not decided whether that scenario will be in the scope of the task group of not.
- A question was raised whether a laptop PC can be a Mesh Point. The response from the audience was the PAR limits ESS mesh to use infrastructure mode hence ad-hoc mode has been excluded. With that limit, any entity/device that matches the Mesh Point function description can be called a Mesh Point.
- A discussion on the definition of Mesh Point STA
- A suggestion to add "Link Metric", "Mesh Neighbor Discovery", and some other necessary terms. The response was this will be a working document. There had been a long list of terms that yet to be defined. We will re-visit this issue on Thursday.
- A question on "Mesh Topology", whether it contains end STAs or not. The response was no.
- There were questions on Mesh Unicast and Mesh Broadcast definitions. A scenario that a broadcast/multicast frame to multiple STAs associated with the same Mesh AP appears as a unicast frame to the Mesh network should be counted as Mesh Unicast or Mesh Broadcast. The response was that would be Mesh Unicast—all the terms focus on the network consists of Mesh Points only. End STAs behaviour is not included.
- One suggestion was the definition for a probing mechanism will be needed since neighbour discovery will be necessary for Mesh Path Selection.
- Tricci plans to work out a list of supplementary terms and will show them to the audience on Thursday.

Session recessed at 5:30PM until 7:30PM

## Monday Evening Session:

Date & Time: Monday, 12 July, 2004, 4:00PM-6:00PM
Location: Ballroom II-IV Hilton Hotel Executive Tower, Portland, Oregan, USA.
Officer presiding: Donald Eastlake 3rd

Session called to order at 7:40PM by Donald Eastlake 3rd, TGs Chair.

**Presentation #2:**

"802.11s Security Proposal"
(IEEE 802.11-04/777r0)
Robert Moskowitz, ICSALabs

- The author presented two possible security models both utilize connectivity association and secure channel concept based on the on-going 802.1ae and 802.1af works.
- A question was raised that maybe we can focus on the security among Mesh Points only. Furthermore, we only need to consider directly linked Mesh Points. Considering end STAs can make the security issue very complicated. The response was that's possible although the security issue of STA roaming within the mesh then will have to be solved by TGi or TGr. Predefining/Building Secured Connectivity Associations and keys to all other Mesh Points at Mesh Point initialization time may in fact easier than to dynamically build up SCA to a Mesh Point that just comes up.
- A suggestion was there may be a balancing point between Model 1 and 2. Depending on the needed security level requirement, we can choose a solution more scalable.
- A question was raised on whether this proposal is centralized or decentralized. The response was that will depend on implementation. For example, key refresh without traffic is possible.
- It is raised to audience's attention that there are many issues yet to be solved if we pursue either of the models. And 802.1af is still working on some proposals on device rejoining issues.
- A notice came from the audience mentioned in the proposed models any unsecured traffic will waste bandwidth along the path until being rejected at the destination.

**Presentation #3:**

"802.11s Routing Sub-Group Discussion on May '04 Report"
(IEEE 802.11-04/765r0)
Tyan-Shu Jou, Janusys Networks

- This was a report of the 2-hour informal meeting held in May on routing issues of ESS mesh. One of the purposes was to attract audience's attention on this issue and to solicit more participants to discuss this subject.
- There were some comments from the audience on the pros and cons on using Spanning Tree Protocol on mesh. The response was this topic has been discussed in a presentation in previous meeting but no conclusive decision has been made so far.
- There was a comment on using broadcast mechanism to build unicast routing path that the wireless broadcast may not be reliable hence may affect the reliability of the routing result.
- There was a suggestion to refer to a paper using IS-IS on wireless network which may provide some hints on this subject.
- There was an opinion that this discussion was not effective and should be replaced by calling for proposals. The task group should either define better requirements or just use the PAR as the requirement to call for proposals rather than discussing solutions. The response was the members of this task group need more knowledge on this subject for all the foundation work, such as terminologies definitions. Without basic understanding and knowledge, this task group will not be able to evaluate the routing proposals.

**Presentation #4:**

"A View on 802.11s Routing, A Framework for a Discussion"
(IEEE 802.11-04/778r0)
Robert Moskowitz, ICSALabs

- In the short presentation, the author emphasized there will be no 802.1D bridge in a mesh; hence no STP should be running on the ESS mesh. Current 802.1 LAN model does not fit a mesh.
- A question was raised that 802.11 spec mentioned ESS has to be like a LAN to the higher layer.
- There was disagreement from the audience on the sentence of "mesh is ill defined," especially given the Internet is basically a mesh.

Session adjourned at 9:20PM

## Tuesday Afternoon Joint Session of TGs, TGr, and 802.21

Date & Time: Tuesday, 13 May, 2004, 1:30PM-3:00PM
Location: Ballroom II-IV Hilton Hotel Executive Tower, Portland, Oregan, USA.
Officers presiding: Donald Eastlake 3rd (TGs), Clint Chaplin (TGr), Ajay Rajkumar (802.21)

Session called to order at 1:30pm

**Presentation #5:**

"What is an ESS?"
(IEEE 802.11-04/614r1)
Jon Edney, Nokia

- The presentation explained the meaning of ESS from the 802.11 spec. As a conclusion, the presenter argued ESS is not a useful definition for standards.
- A question was asked shouldn't all BSS of the ESS share the same SSID in one ESS? The response was yes. But the reverse was not necessarily true, that is, different ESS's can have the same SSID.
- There was a question on the suggestion of "Tie group definition information into 802.21."
- Current 802.21 thinking has dependency on using SSID for station to learn it has crossed the ESS boundary. If that's not always true, a different attribute will be needed.
- A comment from the audience mentioned the topology can be hidden from the network.

**Presentation #6:**

"The Nature of an ESS"
(IEEE 802.11-04/629r1)
Darwin Engwer and Bob O'Hara

- The authors agreed with the previous presentation (11-04/614) which had strictly interpreted the definitions of ESS, DS, and SSID. But argued there were other possible interpretations of the definitions that don't violate the 802.11 spec.
- A question from the audience on Slide 16 which included a router in between two BSS, was on whether the router should be included in the DS shadow or not. The response was the router can be part of the DS, and the slide just shows one example.
- There were comments on seeing the same SSID not identifying whether the APs are in the same ESS means there will be more work on identifying ESS migration.
- One comment pointed out unfortunately people had mistakenly using SSIDs for a while. Hence to ask the whole world to take the "correct" definitions can cause problems to the real world.

**Presentation #7:**

"Cross Domain Trigger and Handover Talking Points"
(IEEE 802.21-04/100)
Michael G. Williams

- The presentation talked about BSS, ESS, DS, triggers and handover from 802.21 perspectives.
- A question was asked on what can be the trigger on APs for domain transition.
- STA triggers the transition and the associated AP can let the new AP to know the event.
- A question raised from the audience was on cross domain messages, how AP can talk across domains since there will be different policies.
- A question was asked saying the between domain message may have security issues. The response was the slide shows an example, it doesn't necessarily suggest the real implementation.

Session recessed for 5 min at 2:55PM. 802.21 will resemble in a different location

## Tuesday Afternoon Joint Session of TGs and TGr:

Date & Time: Tuesday, 13 May, 2004, 3:00PM-3:30PM
Location: Ballroom II-IV Hilton Hotel Executive Tower, Portland, Oregan, USA.
Officers presiding: Donald Eastlake 3rd (TGs), Clint Chaplin (TGr)

**Presentation #8:**

"Interpretations of the Distribution System Service Based on the 802.11 Specification"
(IEEE 802.11-04/785r1)
W. Steven Conner, Tricci So, Tyan-Shu Jou

- This presentation pointed out the DS (distribution system) is logically defined by DSS and is not defined by the physical network which is used to implement the DS.
- (Due to the lack of time no discussion time is given on this presentation)

**Straw poll**:

Should one joint TGr/TGs session at each 802.11 meeting be the default?
**Result:**
Favor: 48
Against: 5
The chairperson of each group will work on the arrangement.

Session adjourned at 3:30PM

## Tuesday Late Afternoon Session:

Date & Time: Tuesday, 13 May, 2004, 4:00PM-6:00PM
Location: Ballroom II-IV Hilton Hotel Executive Tower, Portland, Oregan, USA.
Officer presiding: Donald Eastlake 3rd (TGs)

Session called to order at 4PM

Comments for Presentation #8 above were invited but no response from the audience.

**Presentation #9:**

"WLAN Mesh Usage Model and Considerations for Hot Spot Service",
(IEEE 802.11-04/680r0)
Taejin Lee (Broadwave), Jongtaek Oh (Hansung Univ.), Sukhee Bae (RRL), Jaewoo Lim (RRL)

- The presentation introduced the characteristic of hot spots in Korea and suggested a few examples of WLAN mesh usage models.

**Presentation #10:**

"Defining Comparable Usage Models for 802.11s",
(IEEE 802.11-04/764r1, 662/r7)
W. Steven Conner

- It's the summary report resulting from the study of usage models. The document described all the submitted usage models and categorized them into five categories.
- One suggestion based on 802.11n experience was TGs has gone very rapidly and far at this stage, and should be more focus rather than support all usage models. The other comment from the same person was the task group should construct simulation scenarios and keep them simple.
- One comment was functional requirements eventually will be very much like what is in the PAR. So it is suggested to avoid taking a long time effort to reach there.
- A different opinion was TGs is building a network. We'd better be careful and cautious along the way and not to skip any necessary efforts.
- One opinion was from the experience of working in IETF MANET, just one usage model can create all kinds of simulation scenarios. The task group should come up with common and useful scenarios and focus on them.

- A person with 802.15 experience asked whether APs can be mesh nodes. The response was yes, and TGs is focused on infrastructure mode only.
- One audience suggested collecting a set of common attributes. Response was hopefully the scope of TGs defined in the PAR has been smaller than that of IETF MANET and can be used to derive the requirement. Hopefully the convergence time of our proposals can be shorter.
- One comment on evaluation criterion: don't spend too much time to create evaluation criteria.
- Steve Conner invited people to send him additional usage case material for possible inclusion in the presented document.
- One suggestion: TGs should create Functional requirements as soon as possible.

**Presentation #11:**

"Suggested Major Functional Components for 802.11s",
(IEEE 802.11-04/749r0)
W. Steven Conner, Koji Omae

- The presentation describes proposed major functional components for TGs and suggest this group to work toward these functions:
  - Routing and Forwarding
  - Mesh security
  - MAC/MLME Enhancements for 802.11s Mesh
  - Mesh network measurement
  - Interfaces for Configuration / Management & internetworking
- One comment was in Slide3, a "Service Integration" box should be added there to provide the existing DS services. The response was the slide was created to emphasize the new functions hence the existing functions are not included.
- A question was whether 11s is going to take care of all mesh related issues or 11s should be work with other groups. The response from Steve Conner was we should work together with other groups to avoid duplicate work.
- One comment was the "MAC/MLME enhancement" may cause some inconsistency if the scale is large.
- The other opinion was we do need to do some enhancement on the MAC to build a useful WLAN mesh. Current MAC may not be sufficient for WLAN mesh network. The response was TGs is going to make amendments to 802.l1, and many other works are being done before us.
- One comment was it might be too early to take AC enhancements out from the table at this table.
- One caution from the audience was to be careful on doing "necessary enhancement" on the MAC, but not much more than that. Otherwise, the process will be lengthy and the resistance will be high.
- A question was how the functional blocks were derived. The response was they are high-level requirement mainly coming from the PAR.

Session recessed at 5:50PM

## Tuesday Evening Session:

Date & Time: Tuesday, 13 May, 2004, 4:00PM-6:00PM
Location: Ballroom II-IV Hilton Hotel Executive Tower, Portland, Oregan, USA.
Officer presiding: Donald Eastlake 3rd (TGs)

**Presentation #12:**

"Outdoor 802.11 Mesh Links RF Impacts Considerations",
(IEEE 802.11-04/731r0)
Tricci So

- This presentation introduced a few RF related issues on deploying outdoor mesh networks.

**Task Group Process, Take 1**

- The discussion was based on "Mesh Networking Task Group Process", IEEE 11-04/800r1, by Donald Eastlake 3rd.
- This topic will be discussed again on Thursday. The fundamental question was "How should we proceed toward a Draft?"
- According to the average working length time from other 802.11 groups, we should expect to have the first letter ballot approved at the May or July 2005 802.11 meeting.
- There were discussions on process, schedule, and informal subgroups. No conclusive decision was made.

- Some subgroup announced their ad-hoc discussion gathering time and place.

## Thursday Early Morning Session:

Date & Time: Thursday, 15 May, 2004, 8:00AM – 10:00AM
Location: Ballroom II-IV Hilton Hotel Executive Tower, Portland, Oregan, USA.
Officer presiding: Donald Eastlake 3rd (TGs)

Session called to order at 8AM

**Presentation #13:**

"MAC Considerations for 11s",
(IEEE 802.11-04/760r0)
L. Lily Yang, Akira Yamada

- This was a preliminary analysis on 802.11e for TGs to draw the attention and interests from the audience. Those who are interested in working with Lily Yang on MA C enhancement are welcome to contact her at lily.l.yang@intel.com
- A question was raised on Slide 16. In 11e, the mesh coordination function may have some interference on HCF. Also, the mesh coordination function should not be based atop DCF.
- An opinion from the audience mentioned HCCA is very important in mesh network. Mesh Coordination Function can utilize it.
- On comment: we possibly can treat QoS issues from a network point of view. The routing protocol should be able to help traffic engineering hence is related to overall QoS. Some mechanisms suggested in 11e may not be efficient to be implemented in the MAC layer.
- One comment: in Slide 7, the most important function Mesh Coordination Function has to do is to share the information among the mesh nodes.

**Presentation #14:**

"802.11s Security Ad Hoc",
(IEEE 802.11-04/826r0)
Robert Moskowitz, ICSALabs

- This was the discussion result of the Security ad-hoc group
- Those who are interested in working with Robert on the security issues for TGs can email him at rgm@trusecure.com

**Presentation #15:**

"Outdoor 802.11 Mesh MAC Problems"
(IEEE 802.11-04/732r0)
Tricci So

- This presentation highlighted MAC issues for outdoor mesh networks to raise people's awareness on large scale long-distance deployment.
- A question was TGs wasn't charted to change the 802.11 MAC behaviours. Is this work in the scope of our task group? Tricci's response was tuning timing parameters should not be a problem.
- Another comment was CTS/RTS problem is a common problem for 802.11 networks. Those problems might be solved outside TGs.
- Comments on the timers: There are only two PHY related timers – SIFS and aSlot. They depend on the PHY technology since they are related to Transceiver turnaround time, sensing time and so on. Therefore the audience didn't see the relationship to TGs. The other comment was there should be no need of changing the parameters of 802.11. These timers are independent of TGs since TGs does not define a new PHY mode. However, there are some other parameters that can be changed, e.g. CWmin etc.

Session recessed at 10:00AM

## Thursday Late Morning Session:

Date & Time: Thursday, 15 May, 2004, 10:30AM – 12:30AM
Location: Ballroom II-IV Hilton Hotel Executive Tower, Portland, Oregan, USA.
Officer presiding: Donald Eastlake 3rd (TGs)

**Presentation #16:**

"Multi-hop Connections Using 802.11",
(IEEE 802.11-04/709r0)
Guido R. Hiertz, Yunpeng Zang, Jorg habetha

- This presentation raised the awareness of the audience that 802.11 MAC may not fit multi-hop network requirement. Modification will be needed to make WLAN mesh works better.

**Presentation #17:**

"Additional Draft terms & Terminology for 802.11s",
(IEEE 802.11-04/0822r0)
Jonathan Agre

- This presentation reported the result of an ad-hoc discussion on additional terms of TGs. This is intended to be a working document.

**Task Group Process Discussion**

The discussion is based on the slides in IEEE 802.11-04/800r3

Information on some groups working on submissions can be found at the following URL:
http://ieee.comnets.rwth-aachen.de/cgi-bin/wiki.pl?AdHocGroups

- On the slide 12 "Possible liaison to 802.15.5", one suggestion was to have two liaisons to report to the other meeting since the two groups usually meet at the same timeframe.
- No volunteer to be the above liaison, so the chair persons may have to report to each other group.

**Straw poll**

If a TGs call for proposals was issued right after the September meeting with a deadline shortly before the November meeting, how many would submit a proposal?

**Result:**

Reasonably certain to submit a proposal: 4
50/50 chance: 10
Might but probably not: a few people

**Straw poll**

If a TGs call for proposals was issued right after the November meeting with a deadline shortly before the January meeting, how many would submit a proposal?

**Result:**

Reasonably certain to submit a proposal: 13
50/50 chance: 4
Might but probably not: 4

**Straw poll**

Is documenting Usage Cases important?

**Result:**

Yes: 48
No: 0

**Straw poll**

Is each category important?

- Residential: **36**

- Office: **43**
- Campus/Community/Public Access: **42**
- Public Safety: **34**
- Car to Car: **7**

**Straw poll on Informal Group Submissions Status**

What should be the status of relevant submissions from informal groups if a majority of TGs agrees with the submission?

- Strongly included as part of call for proposals: **12**
- Adopted as internal working documents: **29**
- Included on a TGs recommended reading list: **3**
- No special status: **2**

**Discussion on group submissions and the TG process:**

- To answer the question on whether informal group submissions will be merged, the Chair mentioned there is no strong need to merge all the documents. We can use them to generate requirements
- One comment was we should make case by case decisions. We can also make call for proposals for individual functionality.
- One comment was to advise audience not to underestimate the complexity of the task we are working on.
- One comment was this group should not create solutions but should evaluate existing ones. No partial proposal should be considered. Do not spend too much time working on the formal process or requirements.
- There is a question challenge the usefulness of the above straw pool results.
- Some people expressed that if we take every partial proposal, we may end up with a large number of proposals. We should limit to full proposal only, which can encourage people to work together. We then can get the task done as soon as possible.
- On the contrary, a few people suggested the call for proposal should allow partial proposals to include all good ideas. One of the opinions mentioned partial proposal will naturally get less support in evaluation, but we should not put limitation on it when call for proposals.
- One suggested we need to spend a bounded period of time to discuss the requirements so we can know how to evaluate proposals.
- One opinion was we cannot use the PAR to evaluate the proposal yet. How much time other groups spent on their proposal is irrelevant to the time used in this group?
- One opinion was we cannot have a procedure for invention. We can call for complete proposals first, and maybe partial proposals for some areas to improve the best proposal. We can even ask for proposals now, and use 6 months to evaluate them.

**Straw poll**

What is the current feeling of TGs as to when we should call for proposals?

- July 2004: **Favor: 3. Against: 31**
- September 2004: **Favor: 10. Against: 28**
- November 2004: **Favor: 16. Against: 10**
- January 2005: **Favor: 8. Against: 1**

**Straw poll**

Should any call for proposals require that proposals be “complete”?

**Result:**

Yes: **18**

Not: **19**

- A few comments were the definition of “completeness” is not clear hence the straw poll result may not make much sense since people have different ideas.
- Another comment was completeness will naturally be reflected in the evaluation process. We should not put that limitation at the call.

**Straw poll**

How long should be the call for proposal window:

2 month : **2**

4 month: **17**

6 month: **10**

**Motion** To hold a TGs teleconference 15 August, 3PM PDT.
Moved: Peter
Second: W. Steven Conner
**Result**:
In Favor: **18**
Against: **2**

Audience was advised by the Chair to check for 11-04/800r3 for the latest information.

Meeting adjourned at 12:30PM.

# IEEE P802.11
# Wireless LANs

## Wireless Performance Prediction Study Group Meeting Minutes

**Date:** July 15, 2004

**Authors:** Tom Alexander
VeriWave, Inc.
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## Abstract

Minutes and attendance of the meetings of the IEEE 802.11 Wireless Performance Prediction Study Group held in Portland, Oregon, USA on Tuesday, Wednesday and Thursday, July 13, 14 and 15, 2004 under the SG Chairmanship of Charles Wright.

# Session Proceedings

## Meeting 1:

Date: 13 July 2004

Location: Studio Suite

Meeting called to order at 4.00 PM Pacific Time Monday May 10th by Charles Wright, WPP SG Chair. Tom Alexander was recording Secretary.

Charles opened meeting at 4 PM PST. He welcomed the participants to the meeting and introduced the Chair and Secretary. He began by setting the meeting tone with the customary opening slide. He then reviewed the policies and procedures of the SG, noting that while all 802 and 802.11 procedures applied, as this was a Study Group, everyone gets to vote; 75% consensus was required, however, regardless of whether it was a technical or procedural vote. He also read out, verbatim, the IEEE Bylaws on patents in standards to the SG. He then covered inappropriate topics for discussions, such as pricing or litigation. Charles also mentioned that the general policy was to discuss technical topics and not the persons proposing them, and personal attacks were not going to be tolerated. He passed around a signup sheet, noting that SGs are required to take attendance, but also stated that participants were only required to sign in once for the week.

Charles then brought the proposed agenda for the week before the group, and opened up discussion of the agenda. He said that he was going to do a call for technical presentations, and noted that Rick Denker had sent in a submission. He also noted that Larry Green had uploaded a presentation. He then noted that he would review the progress in the teleconferences. He said that there was a good bit of time allotted to review comments from 802; however, as of 20 minutes ago, there were no comments, and it was doubtful that there would be any. He would check at 6 PM for comments; if there were none, then he could collapse the time allotted to discuss comments, and devote it to presentations and discussions instead.

Question from Paul: I have a technical presentation wrapping up some of the discussion and discussing what went on in the teleconferences. What do you suggest? In response, Charles asked him if he would like to make that presentation. Answer: Yes.

Charles then asked Paul what the document number was. Paul said that it was document #674r2, titled “WPP Development Milestones Roadmap Proposal”. Charles amended the agenda with this presentation.

Charles then asked if the order of items in the agenda (technical presentations, followed by a discussion of how to proceed, followed by more technical presentations) worked for people. He noted that Rick could not present today, but could present either tomorrow morning or afternoon. Larry also requested time on the agenda for his presentation, document #729 r3, titled “WPP Baseline Metrics”, and said that about 30-40 minutes would suffice. Charles assigned him about 35 minutes.

Charles then called for any additional presentations from people. Bob Mandeville volunteered to present on the template at some point during the week. The document did not have a number as yet, but would be titled "Test Specification Template Overview and Proposal"; Bob felt that it would take about 40 minutes to present. Niels said that he had a presentation as well, but he had some time limitations (he would prefer tomorrow morning); his presentation was document #346r0, titled "Proposal for how to measure Receiver Sensitivity".

Tom suggested that perhaps Bob Mandeville could walk us through RFC 2285, as an introduction. Bob and Charles thought this was a good idea; Bob felt that it would take about 40 minutes. Charles put him on the agenda for a presentation titled "RFC 2285 / 2889 Walkthrough". No document number was assigned.

Charles then asked if there were any objections to accepting the agenda as shown. There were no objections, so the agenda was duly accepted.

The next item of business was approval of the minutes. Charles asked if there were any objections to accepting the minutes from the Garden Grove meeting. There were no objections, so the minutes were accepted. He further asked if there were any objections to accepting the minutes from the last teleconference (July 8) as well; there were no objections, so the teleconference minutes were approved as well.

The timeline going forward was brought up. Charles noted that at the May meeting, there had been a vote before the full WG to forward the PAR & 5 criteria to the 802 Executive Committee; due to quorum issues, however, the WG decided to use a full letter ballot instead of settling the issue at the meeting itself. The letter ballot passed, and so we are now in the position of resolving the comments from the 802 WGs and ExCom, and also requesting 802.11 to extend the life of the SG to do the work of the TG (for eventual reaffirmation as and when the TG is formed). In August NesCom would vote on the PAR, and if all went well by September we would begin work as a formal TG.

Charles then went over the presentations during the teleconferences. He noted that Paul Canaan had presented document #674r0, and Mike Foegelle had presented document #675r1. He noted also that we could not take any actual decisions during the teleconferences, but certainly the presentation gave rise to much discussion. He then opened the floor to any comments on the teleconferences; there were none.

The initial business being over, Charles then invited Paul Canaan to come forward and present his roadmap.

Presentation titled “WPP Development Milestones Roadmap Proposal” by Paul Canaan (document #674r2)

Paul began by noting that this presentation was originally given during the teleconferences. The purpose of the presentation was to outline the key deliverables for WPP per the scope and purpose. He noted that one of the reasons for the presentation was to ask two fundamental questions: where do we go from here, and what time frame will that be in? He also remarked that this presentation grew out of work done in the measurement methodologies ad-hoc.

He started off by reviewing the concept of "performance" as a function of components, applications and environment, and briefly reviewed all three areas. However, he noted, there was still a lot of discussion about this in the teleconferences, and it was all not very clear. He therefore wanted to go off on a different take on this.

Paul then went to the next slide (#5). He said that wireless performance is a function of multiple things. For instance, there is the environment: whether LOS, NLOS, or conducted. He said that there was nothing to measure out of that. The second aspect is device configurations, which was called "components" before this. The notion was: what are we doing? We are always going to have pieces; what we are really concerned about here was how these pieces were set up and configured. The last piece of the puzzle would be applications. He noted that the target was to measure device performance in a given environment with a given traffic stream representing some application. He then asked for questions to this point.

Question from Bob: What does "traffic pattern" mean to you? Answer: The issue with application level was that it was too dependent on the specific application. Let's get away from this and focus on traffic patterns; in terms of traffic patterns, we should specify a tool down the road to measure wireless performance.

Paul then noted that the biggest idea was that wireless performance is a function of multiple things. He had originally proposed that there be three ad-hoc teams to focus on three buckets: component, application, environment. However, this is

still very nebulous, and this was what he was going to talk about today. For example, we talked about the “environment” ad-hoc team. What would the people in this ad-hoc do? They would focus on defining the diagram of the test setup for NLOS environments (LOS and conductive environments would be scheduled later). He gave an example of a diagram for a test setup for a laptop testing. He also covered a concept presented in a previous contribution, namely that of the simple, multi-client, and complex environments of clients/APs. He then summarized this as the recommended environments for getting your test results.

To give an example, Paul then went back to slide #5, and asked the question: what environment would be important to a user? That would clearly be NLOS. However, going to slide #6, what would be the test setup? He gave some examples of various parameters in the environment that could be used in the test setup.

The next topic Paul covered was the device configuration for the wireless ecosystem. We have APs, encryption, power settings, etc. For different combinations of APs and clients, therefore, the group would give guidelines on the settings that were required for the APs and clients involved in the test. Again, to provide an example, Paul went back to slide #5, and discussed how the devices would be configured for a given test.

The final aspect that Paul discussed was the applications. He noted that the ad-hoc group should focus on defining the traffic patterns and the key variables underlying these traffic patterns that should be used in the performance characterization.

Question from Joe: Were you planning on uploading this revision of the presentation to the server? Answer: Yes.

Paul then went on to the development proposal. He suggested that we should get something in 6 months, focused entirely on measurement methodologies. We should develop the guidelines and publish them when the 6 months was up, and then turn the attention to prediction.

Question from Tom: did you actually say that we could publish in 6 months, and then turn to prediction? Answer: Yes. This is aggressive, but there is no reason why it cannot be done.

Question: could you clarify what you mean by “performance”? Answer: After we measure all the stuff out, in time there could be mathematical guidelines developed on how to predict performance once we get all the measurements in place. The idea is that performance is represented by an equation, and thus can be defined and then predicted.

Paul finally presented his development roadmap proposal (#13). He suggested that the separate groups would work separately on these topics, and then reconvene in 6 months.

Question from Larry: Paul, could you map the new standards (WPA, etc.) into the three buckets? Answer: OK, that's the encryption protocol. I'm glad you brought up that one. You notice I have on the bottom an “encryption” topic, this would really go into device configuration. If you have an AP that does only 802.11b, it's 3 years old, then it probably can't do WPA and this doesn't do you any good at all. However, the encryption stuff should probably go in the device configuration bucket.

Paul noted that the term "components” was too nebulous, and didn't make sense. Instead, he proposed, let's focus on configuration.

Comment from Larry: in one of your slides (#14) you mentioned authentication. This is very good; we're seeing as much as 1 second to authenticate, this is a significant problem in a real system.

Question from Bob: On slide 13, I'm very much attached to the concept of a metric. In my view, this group's task is to define metrics. Packaging the definition of a metric will involve the discussion about components and configurations. However, there is no discussion in this presentation about defining metrics; there is something that touches on it later, but not really. Are we going to have metrics for environment, applications, components? Answer from Paul: On slide 10, for example, we would have metrics defined from different applications. Bob rejoined: I would say to that: no. A metric is a metric, it is not a function of an application. The objective is not to derive a metric for jitter from a voice application, it is to define the metric for jitter and then see how this applies to the voice applications.

There was some complaint from the back of the room that they couldn't hear Bob; Charles therefore handed him the mike and requested Bob to repeat. Bob said that he was essentially saying that the fundamental task of the group, which was defining metrics, was missing from the presentation. He said that he believed that metrics would be applied to applications and not defined by applications.

Comment from Don Berry: if you exchange the words “measurements” and “metrics” on slide 4, that may address your concerns. Paul clarified that slide #5 grew out of his dissatisfaction with slide #4, and was his attempt to restructure it to better match what we needed to do.

Question from Bob: What do the arrows on slide #5 mean? Answer: For example, a hotspot designer might need to look at environments first, then look at device configuration, then the applications that were to be supported. These three things determined wireless performance.

Comment from Tom: I think what Paul has done here is to define setup parameters. RFC 2889 has the concept of setup parameters; the actual metrics are well-understood, but the setup parameters are very different for wireless as compared to wired LANs.

Question from Joe: Something that Tom just said makes me think of setup parameters. There are APs, for instance, that don't allow you to configure certain setup parameters. For instance, a home AP may not allow you to configure the link rate, but an enterprise AP will; how do we allow compare apples and oranges in this case? Answer from Paul: This work is more of a project management sort of thing; the corporate vs. the consumer market is certainly something we have to figure out.

Comment from Charles: The link rate could be another configuration parameter, so that this becomes part of the conditions under which the test was taken.

Question from Larry: Paul, I'd like to understand this concept of a management tool to guide our thinking. Let's take contention window maximum and minimum. I'm a little mixed up on where contention window settings would go in the test setup and process. Answer from Paul: My thoughts on a lot of stuff like this is that a lot of these variables impact the performance metrics. For streaming media, for example, packet error ratio would be a metric. Things such as noise would impact performance on the very far right.

Comment from Charles: I can point out that for example, WME has some settings for the AP for CWmin, etc. These fall into device configuration; it's a knob on the AP. Also, I agree with Tom that the big difference between wired and wireless is that there are so many things that should be adjusted - it's not just wires hooking into a switch, even people walking in the hallway will affect it. Also, I don't like the bucket below the three boxes. Encryption should be in device configuration, interference and signal strength is in environment, and so on.

Comment from Tom: The topic of “protocol” might fall in the application bucket. For example, VoIP or RTP.

Question from Niels: In this whole exercise, what's the value of reproducibility? You have a lot of variables there you can't control at all. How can you, as a vendor, reproduce results somewhere else? Answer from Paul: Unfortunately that's going to be a difficult challenge; if a customer calls up and says that my wireless doesn't work, what do we do? This is the million dollar question. You can start dissecting the problem piece by piece, but you can't really start reproducing the problem until you get to defining it.

Comment from Niels: I think 802.11k will help with that. You do radio measurements and metrics at the radio, and if you have a way to quantify the interference environment you can come to some predictions eventually. Paul replied, however, that one of the drawbacks with this is that you still have to go to the customers to get your measurements. Niels rejoined that you can get it automatically from the end-user equipment. Charles noted, however, that this was not the domain of WPP; it belonged to 802.11k, and it could help in an install situation. He remarked that it’s the old business about on-line vs. off-line measurements; 802.11k deals with on-line measurements, WPP needs to characterize it in a test bench environment.

Question from Niels: You want to have reproducibility, so how do you guarantee that? Answer from Charles: That's not our job, we're not here to say "make air go away". In a test environment, however, you have a lot of liberties to constrain stuff.

Comment from Paul: The only way to reproduce it is to constrain it completely. Therefore, guidelines are called for.

Question from Charles: Guidelines are another possible thing we could write, but that was not checked off in the PAR. Do you view that guidelines should be an output of WPP? Answer from Paul: Yes.

Larry commented that 802 people did not look at guidelines, and so he much preferred a Recommended Practice.

Tom said that he had three comments. Firstly, on the topic of setup parameters, the RFCs typically test in the following way: first, they establish a baseline configuration for the DUT and the setup against which all devices must be tested, as a kind of lowest common denominator. Then they vary different configuration parameters and repeat the tests to get an idea of how the performance depends on these parameters. Secondly, the definition of “repeatability” may be different for wired versus wireless LANs. In the case of wired LANs, the error rates and the statistical variations were very low, on the order or parts per billion, so we could have absolute repeatability. However, for wireless LANs, error rates are measured in percentage points, and so we may have to accept that repeatability may be true only in the statistical sense. Finally, he noted that 802.11k and WPP are two sides of the same coin; correlating WPP measurements with 802.11k measurements may enable people to truly figure out what’s going on in the field, and compare it with what they thought would happen (i.e., prediction).

Question from Joe: The purpose of WPP is to do something similar to cellular, where they make metrics that actual users can then use to make measurements that tell them whether something can work in their own environment (each users sets his or her own bar). Answer from Charles: Yes, this is correct. Users and magazine people would set their own bars, but use our measurement methodologies to make the measurements.

Question from Niels: Can you make conducted measurements and then use that measurement for prediction? Answer from Charles: Yes. Conducted measurements are the best way to get repeatable measurements with the smallest sigma, and while they are not real life they can give us a baseline. As soon as you put it in the real world, we know that the device would do worse.

Question from Niels: It's all about making it predictable, right? You can do X, Y and Z measurements conducted, and then you say that you are done? Answer from Charles: Yes, if X, Y and Z measurements can lead you to performance prediction.

Comment from Taylor Salman: This may be a problem with the way you are defining applications. For example, I can take an e-mail application traffic pattern, but when my environment changes, the offered load to the MAC layer changes. I can't define my offered load to the MAC layer as an “e-mail application” because of this. Paul replied that he was more focused on what the traffic pattern would look like. Taylor then said that he would caution us against labeling that as an "e-mail application". Paul replied that he didn't mean to clarify that this was what e-mail looks like, it was put there to spur discussion.

Comment from Charles: We like to define things that make applications perform well. When it gets down to brass tacks, we're going to measure the big four - forwarding rate, latency, loss, jitter. These are very familiar metrics from the wired world, and these are used as indicators of performance. We've got the same thing here with wireless, but there's more. We have other application-related performance. For example, roaming performance and privacy are factors that impact usability. I exhort you to think of other application kinds of stuff and what the impact to performance is; perhaps there's a metric there. If application performance is impacted, we should think about turning it into a metric.

Comment from Taylor: The term “application” has a very specific meaning in the IP world. I would change this to "traffic pattern". However, I would almost go the other way and say that a generic traffic pattern is somewhat meaningless.

Comment from Charles: I think the RFCs address it. In RFC 2889, for example, there are a whole lot of ways of referring to traffic patterns - mesh, full mesh, etc. - and they let you stress the switch in different ways. There are also bridge learning characteristics in 802.3, and we have an analog in 802.11 like association. Perhaps we should change “applications” to “traffic patterns”.

Comment from Mark: On this topic, both of these two comments do make sense. One says something about the traffic pattern being offered, and it also says something about what metrics we need to define. I think it's both.

Comment from Charles: I think we should look to what we have in the 802.11 protocol - for instance, roaming comes to mind - to figure out the protocol features that are offered to support applications. That would be a lot easier that saying "let's see, we want to simulate NetMeeting, with white boarding, and so on".

Question from Bob: Paul, is this sort of discussion contained in your 6 month schedule? Answer: The 6 month schedule is very aggressive, even for my own labs, but it can be done. In order for WPP to really deliver on its purpose and scope, it needs some boundary conditions, as it can easily get off track.

Charles began to speak, but Paul interrupted, stating that this was his ending speech, and not to spoil it. (Laughter.)

Charles then asked whether Paul had a motion to make, or if he was just done with his presentation. Paul was somewhat undecided.

Question from Larry: Paul, do you plan to make some changes to your titles and the document? Answer: I plan to change the colors.

Question from Tom: Should we have another group that looks at metrics? Answer: This was supposed to be under applications. However, applications has changed to traffic patterns, so maybe we should have another on metrics. Charles said that we should keep this in mind. He noted that the TGn folks created Special Committees within the group to agree on what channel models should be used to describe MIMO channels and so on. They also had usage model committees. Once the Special Committees were formed, they had a special charter; they had no power per-se, but went off, did work, and brought it back for approval by the TG. I clarified this with Bruce Kraemer. We can form these groups now, but we have to re-affirm them when we become a TG.

Comment from Mark: I was wondering whether it would be better to hear all the other tech presentations, and see if this makes sense after that. I'd like a straw poll.

Question from Paul: Mark, do you think any of the other presentations were orthogonal to mine? Should we wait before deciding on the ad-hocs? Answer: Maybe or not, I would still like to have more information before you make a decision. It's not going to hurt us to wait and see what other people have to say before you make a decision.

Charles then ran a straw poll for Mark's question. He said that if the straw poll came up positive, we could add an agenda item for discussing the formation of Special Committees later.

**Straw Poll #1:**

Question:

Is it the will of the group to hear technical presentations on the agenda before further discussion of formation of Special Committees?

Results:

In favor: 17
Opposed: 0

Question from Larry: Tom, coming back to a question you had earlier, could you elaborate on the metrics ad-hocs? Answer: We need to have the metrics ad-hocs because there are more metrics here than what's defined by wired metrics. We can't simply lift the metrics from the RFCs.

Larry then formally requested that the group consider the formation of a fourth ad-hoc to discuss metrics.

Question: Is there a difference between ad-hocs and special committees? Answer from Charles: Let's consider all of these special committees.

Fanny then requested a presentation slot to discuss a roaming metric. Charles duly modified the agenda to cover Fanny's presentation, and also the discussion on the formation of Special Committees.

Question from Bob: Shouldn't it be terminology and metrics? Don chimed in and asked if terminology should be also part of the metrics group. There was some discussion on this topic. Finally, Charles directed that the minutes should show that the title of the metrics group should indicate that terminology should be part of the metrics group. This was duly recorded. Don also requested time on the agenda for a presentation on "Terminology Definitions". Tom noted that we have a document like this; Charles said that we should add these terms to the terminology document.

Question from Fanny: Bob, you mentioned terminology, isn't this something the whole committee should do? Answer: Terminology is broader than attaching it to one of the sub-groups. By this I mean that terminology should not be part of any single sub-group.

Charles said that we should postpone this discussion to 8 PM, under the "Terminology Definitions" discussion. He then asked for suggestions on what to do with the remaining time. Tom suggested, tongue-in-cheek, that we recess until tomorrow. Charles looked incredulous. After some discussion and joviality, Don proposed that we should discuss the terminology after the break on Tuesday. Charles then presented the modified agenda to the group, and asked for approval. Larry requested Charles to describe the meeting times of the group for the week. Fanny read out the meeting times, and Bob clarified that the presentations were listed out of order. With that, there were no objections to accepting the agenda.

Charles recessed the meeting until 7.30 PM.

## Meeting 2:

Date: 13 July 2004

Location: Studio Suite

Charles opened the meeting at 7.35 PM PST. He noted that Don Berry had agreed to collect a list of items for terminology. This would be a good thing in order to start solidifying these things, and also these would be a good source of material for the "Terminology and Definitions" section of the recommended practice. Charles then turned it over to Don.

Don started with a blank slide on which he proposed to free-form the terms that needed to be defined, and then define them. The document was titled "WPP Terminology Definitions". He noted that this was no more than a working document; we can decide to categorize terms, throw them away, etc.

Bob, Larry, Charles, Paul, Mark, etc. proposed a number of terms to be defined. There was a lively discussion. Tom suggested that all terms in RFC 1242 and RFC 2285 should be included by reference; these RFCs were added to the slide. The topic of a "client" came up: namely, what's a client? This also sparked a lively debate. Charles brought up the notion of defining an “STA”. The topic of repeatability was discussed.

Charles noted that he had checked Stuart Kerry's mailbox, and there were no comments from the other 802 WGs on the WPP PAR. There was happiness and jubilation all around. Charles gave a short rundown on the process going forward, culminating with a NesCom decision in August.

Question from Larry: There are a number of terms in the 802.11 standard that probably don't need to be redefined here. What should we do about that? Answer from Charles: Things like “station” might be well understood by all, but something like "authentication" could be construed by different people to mean different things. Tom noted that something IEEE 802.17 used with good effect was an extensive list of definitions in the draft standards; many of these definitions were simply pointers to good definitions already present in other standards. The presence of the pointer stopped further debate on the definitions. Charles also discussed the issue of defining roaming in conflict with 802.11r. The topic of 802.21 was also brought up.

After a page full of words to be defined was created as a result of the lively discussion, the issue of what to do with them was brought up. Various schemes were proposed to palm off the work of actually filling out the definitions on to various people, which led to much back-and-forth repartee between the group members. The possibility of putting the definition task on hold, until the Special Committees got under way, was raised. There was some agreement on the notion of doing this. Finally, the group decided to identify some definitions that would be universally needed, i.e., required for the general work of the group, and leave the rest to be defined by a Special Committee or committees. These general definitions would be identified by bold font in the slide.

Tom brought up the notion of referencing IEEE STD 100, which was the compendium of all terms and definitions taken from all IEEE standards, and suggested looking at IEEE STD 100 before settling on our own definitions. He volunteered to approach the IEEE editorial staff to see if we could get hold of a copy for standards development purposes. Paul echoed that this was true, we should not repeat the definitions. It was further suggested that the definitions be categorized (which, Paul remarked, would be a big job for “someone”). Also, Bob suggested that we should italicize the metrics to distinguish them from other words, and underline measurement conditions. Bob and Don worked to do this.

There was considerable discussion about whether different words were conditions, metrics, etc. Asterisks were then added to indicate terms over which there was contention. “SNR”, “BER” and “signal strength” were specially flagged as combinations of conditions, metrics and contentious issues. "Quality" was also brought up and discussed; Charles terminated the discussion with a reference to "Zen and the Art of Motorcycle Maintenance". The discussion continued apace. The definitions for "link" and "connection" came up as well. References were made to the autonegotiation done by 802.3 interfaces. The terms "trial", "duration", "test set", "test case", "test suite", "benchmark" and "real-world" were also added. Eventually, the list was completely categorized.

At 8.45, Charles stopped the free-form discussion on the list, and asked what people would like to do next. Bob suggested that we should now decide which ones we wanted to define and which ones were already defined. Don suggested that we should take these definitions, sort them by their loose categorization, and then post the document. Charles suggested instead that we should take the words and put them into document #673r2. Tom volunteered to copy and paste the words into document #673 and post that as revision 3.

There being only about 15 minutes left, Charles asked Larry if he wanted to present at this time, or whether he wanted to present later. Larry elected to present on Wednesday, as he felt there was not enough time. Charles then informed him that he would be presenting after Rick Denker. A short discussion took place on the sequence of presentations.

All business until the start of the presentations being complete, Charles then asked for a motion to recess.

**Motion #1:**

Move to recess until 8.00AM Wednesday.

Moved: Larry Green

Seconded: Mark Kobayashi

The motion passed by acclamation.

Charles declared the meeting in recess until 8.00 AM Wednesday.

## Meeting 3:

Date: 14 July 2004

Location: Forum Suite

Charles started the meeting at 8.10 AM PST. He reminded people to sign in on the attendance sheet as well as the 802 attendance server. He then confirmed that we had officially not received any comments from 802, and therefore could go directly to technical presentations. The first presentation was by Rick Denker; Charles turned the floor over to Rick.

Presentation titled "Wireless Performance Prediction and Environments" by Rick Denker (document #770)

Rick remarked that this presentation was sparked by the proceedings at the previous teleconferences. He said that as he was the VP of Marketing at VeriWave, he'd be approaching it from the customer rather than the technical perspective. He started by noting that a key difference between wireless and wired LAN testing was that there was a tremendous variation in customer environments in wireless LANs, vs. the typical cubicle farm view in wired LANs. There was a significant interaction of the interference and the attenuation with the wireless network. For example, he sees WLANs set up in factories and hospitals, with lots of metal objects (a "room full of wheelchairs") to cause problems with propagation. These issues did not exist in wired LANs.

Rick then noted that there was a huge difference in the two environments of interest, namely the test environment and the customer environment. The test environment is set up with a high degree of control and isolation, whereas a customer environment is completely uncontrolled, and there was a huge variation. The four basic types of test environments were: open-air, cabled, test boxes and Faraday cages. All the developers he'd talked to were using some combination of these environments; nobody was using just one. Rick then went on to describe the characteristics of the four different test environments.

Question: By open air, do you mean "in the open" or "inside"? Answer: Both. However, this is a good question; there may be a need for a fifth environment. Note from the audience that "open-air" may mean different things to different people. For example, "open-air" in the RF context generally refers to an outside antenna range or other uncluttered outside scenario.

Question from Rick: Is there a better term? Answer: How about "greenfield" or "free space"? Group did not like either proposal. Some debate. Charles pointed out that the term "open-air" is overloaded and we need to get a different term. "Over the air" was suggested, and met with some approval, but still a mixed reaction. Rick noted that what he was really getting at was that there are two classes here: the "test environment" which could be controlled, and the "customer use" model where there could be 10 or 20 different configurations.

Fanny: When you talk about "open-air" do you mean that there would be different configurations for the different test conditions, such as the conditions for a hospital, the condition for a steel mill, etc.? Answer: Typically we would have to define the base conditions for each customer use model environment. And yes, this could include hospitals and steel mills.

Rick then went on to the cabled environment. After the previous debate over customer use environments, he stated that he hoped this was a fairly consistent and non-controversial term. He briefly described the strengths and weaknesses of this type of test environment.

Question: On the test setup you are using, you can simulate some of the interference that you see on the air, right? Answer: Yes, this is possible, but you need to get a bunch of interactions there to simulate the actual behavior in a real network.

Question: When you say "cabled", are you talking about shielding the NIC and the AP as well? Answer: Generally, no. However, we might have to have two sub-categories to cover "cabled with shielded DUTs" and "cabled without shielded DUTs".

Fanny noted that a cabled environment might have to be both controlled and shielded, because NICs have a high sensitivity (on the order of -80 dBm) and need to be put into a shielded chamber in order prevent stray pickup. Charles also underlined this. Tom suggested that we might want to wait for the next slide before continuing with this debate. Rick then stated that his goal was really to put a structure to the environments, something we can use for discussion rather than a definite proposal.

Rick then went on to cover shielded chambers and Faraday cages. He noted that Faraday cages were expensive and normally regarded as shared resources.

Comment from Colin: You have to be careful in mixing Faraday cages and anechoic chambers. Anechoic chambers are good for antenna testing. Faraday cages have so much multipath in them that they really don't do very well for antenna testing.

Question: How do you differentiate between a Faraday cage and a shielded chamber? Answer: Size, basically. Tom noted that the difference could be quantified by whether the walls of the chamber were within the near field or not.

Question: Are the test boxes cabled together or is the whole device in the test box? Answer: That's a good way of looking at the difference between the cabled and the shielded chamber / Faraday cage environments. However, one can see both situations in the industry; we see people cable up chambers, and we see people put the whole test system into one chamber.

Rick then presented a summary of the test setups. He then went on to the customer use environment.

Question: How about multipath effects – how do you account for them in the customer use environment? Answer: Perhaps we can lump all of this into one box, under the noise category. Tom suggested that we could simply express this as an addition to the PER, because the multipath causes smearing at the symbol level and shows up as bit errors above the RF level.

Comment from Fanny: The throughput and so on can be highly affected by the multipath effects, so we need to make sure that when these types of measurements are made they are accounted for or eliminated.

Comment from Charles: If you are going to characterize the customer environment, you need to characterize the multipath delay spread. You can compress it all into a noise effect, but then you need to map that into a standard model for the RF layer. Rick then agreed and said that we might need a fourth category for this sort of approach.

Comment from Fanny: Characterizing in terms of CRC errors in terms of bit errors per frame is not a smooth distributed effect. This may not be sufficient.

Comment from Colin: These kinds of things are statistical, and you could characterize these by a statistical model. Tom further noted that this in fact underlined the notion that repeatability in wireless may be expressed in a statistical rather than an absolute sense.

Comment from Niels: This also brings up the concept of the averaging time; the averaging time could have a big impact on the measurements. The group discussed this. It was noted by Colin that statistical effects might also raise their head as more than just CRC errors. For example, by affecting the CCA. Rick agreed that Layer 1 effects might start interacting with Layer 2 protocols. He stated that we should try to quantify this separately, and see what the effect on CRC errors was.

Comment from Colin: There is a really important point about the CCA, if there is a low-level noise effect you don't get CRC errors but you don't even get access to the media. The PHY may see this but the MAC doesn't. I would claim that the CCA issue is a high-order problem, CRC errors are 1 level down in comparison. Some discussion of this topic followed.

Rick went on to discuss the issues of overlap of wireless traffic. He viewed the nature of the background traffic as being important. After this he moved on to the signal strength issues, displaying as an example a graphic from a Wireless Valley site survey tool, and noted that this was the most common thing that people would do when installing a network. (Veera Anantha from Wireless Valley clarified that the picture on Rick's slide was actually a signal strength plot and not a site survey plot. The correction was duly noted.)

Question: How different is the prediction from the actual site survey? Answer from Veera: There is a considerable difference. Different environments have different characteristics that cannot be deduced by simply doing a site survey. There was a general discussion on site surveys vs. prediction. Rick ended up by stating that there was clearly a need for site surveys.

In his final slide, Rick covered the issue of setting good expectations for the customer site; he said that we should try to get to a framework where we separate out the test environments and then see how the variables that affect the customer use environment can be factored into the test environment. With this, he concluded the presentation.

Charles called for a round of applause for Rick's presentation. He then noted that we are going to be forming a standing committee on environments, and this would be a great first crack at the basis for the work on the committee. With this, he threw the floor open to questions and comments.

Question from Colin: Let's look at a hypothetical situation, like a hospital. In this case, we have two different usage processes to cover it - low use, which were things like monitors reporting infrequently, versus high use, like VoIP calls. How was this covered? Rick said (referring to Paul's presentation previously) that there were three categories: applications, components and environment, and this could be part of the environment. Fanny said that the test setup implies an environment, and while there may be merit in defining an environment out of context, we don't need to do this for testing (i.e., test the environment). Colin noted that we still need to make a distinction between range, multipath, etc. and things like load and traffic patterns. Charles stated that we had already had this discussion on Tuesday, where we explained that there was a difference between the terminology relating to propagation, and the terminology relating to traffic. Colin noted that network traffic load can include things like latency, jitter, etc. that were environmental. The discussion continued for some time.

Question from Charles: Were you proposing that we need to identify the needs for those applications, or just provide metrics that could be used by applications? Answer from Colin: Both. The success of the user's experience depends not only on the environment, but also on the types of applications that they are trying to impose on the environment. A guy who is trying to ram video through the environment would have a different result from a guy who would be simply doing e-mail transfers. Charles then noted that our PAR had in scope the definitions and methodologies for the specific applications.

Question from Colin: Don't you need the traffic models for the different types of applications? Answer: I would appreciate people who have input on traffic models to provide their input.

Comment from Mark: I think what Colin brought up is really important; we need to include the load, multipath channel, etc. in the environment.

With this, Charles closed the discussion on Rick's presentation. He then turned the floor over to Niels, to give his presentation.

Presentation titled "Proposal how to Measure RF Sensitivity for WPP" by Niels van Erven (document #346)

Niels presented document #346, which was basically a proposal on how RF sensitivity could be measured. He started by saying as an equipment manufacturer that he would like to bring up one small issue, namely, how to measure sensitivity. Sensitivity is key in that it affects throughput and QoS and so on. He noted that we have talked about conducted and radiated measurements, but in his view a "true" sensitivity measurement was valuable, and he felt that a "true" sensitivity measurement could not be done with a conducted or radiated measurement.

Niels then identified the problem as follows: receiver test measurements with cables cannot guarantee a true sensitivity, as it does not take into account the radiated characteristics of the device. He therefore presented a diagram of a measurement setup to identify the radiation pattern (depicted on slide #4 of his presentation). He also showed a picture of the anechoic chamber he was using, which he said was basically a large wooden box lined with foam absorption material.

Question from Fanny: How big is this chamber? Answer: I'll cover this later.

Niels then described the characterization of the chamber itself, and presented some guidelines on how to set up a test situation using this approach. He then presented some radiation patterns from actual measurements, followed by a graph between measured bandwidth in KB/s versus receiver sensitivity. He noted that when you do a conducted sensitivity measurement, you get a discrepancy of about 8 dB or more versus that of the radiated measurements. He attributed this to the high noise levels generated by the processor, which desensitized the receiver.

Question: Are these averages, or one-shot measurements? Answer: These were done with FTP transfers; the transfer length was a sort of average, plus you had to do multiple measurements because of the uncertainties there. Bob noted that his hackles rose whenever people mentioned using FTP to do measurements, because there are lots of issues with using application layer programs to do Layer 2 measurements.

Niels then concluded that in order to get a true RF measurement, you would like to do at least a radiated sensitivity measurement in the open air, and not a conducted measurement. When you do radiated measurements you get a significant difference.

Question from Tom: Would you expect to see significant differences between measurements such as CCA and rate adaptation that are influenced by receiver sensitivity effects such as you show? Answer: The conducted vs. radiated measurements are clear on this issue.

Question from Fanny: With this radiated measurement, you see value in terms of a full picture. However, do you see value in a conducted measurement as well, as it is a lot easier to do? Answer: If you have the time, then yes, definitely.

Comment from Colin: To Tom's point earlier, I find this graph eye opening.

Question from Tom: Does this suggests that measuring rate adaptation in open-air vs. conducted won't give you much benefit in terms of a final measurement? Some discussion ensued on this topic.

Question: How do you improve this? Answer: An 8 dB difference is huge, you try to eliminate it by shielding.

Question from Charles: FTP is a TCP algorithm, and TCP has well-known problems over wireless. Did you try with UDP? Answer: You also try to do this with radio control software. However, with UDP you have other issues. There is a piece of SW to get this kind of measurements. (A discussion followed on the "piece of software".)

Joe: Your wired measurements, are they also inside the chamber? Answer: Yes, we did it inside the chamber; if you do it outside the chamber you can get lots of issues. Also, the door of the chamber gets very leaky after a couple of years, and 90 dB isolation can drop down to 50 to 60 dB.

Charles thanked Niels for his presentation. He then turned the floor over to Larry for his presentation (#729r3).

Presentation titled "WPP Baseline Metrics" by Larry Green (Document #729r3)

Larry started by apologizing in advance if anyone's favorite metrics were not present in his slides. He reminded the audience about the definition of the STAs and APs in the 802.11 standard. He also suggested that we stick to the standard, in terms of vocabulary and processes. He reviewed the standards that were in development, among them 802.11i, 802.11k and 802.11n. He also mentioned that some of us are living every day with the vagaries of the air interface, and noted that, while conducted environments provide nicely repeatable results, the test environment did not represent the real world which installers and IT managers had to live in.

He then hoped that we ended up with one set of metrics for all the different environments; we should not have a complete set of metrics for Faraday cages, and a whole different set of metrics for the air interface - this is not a good thing. He felt that we should look for commonality between the metrics used in the different environment. With that, Larry proceeded to cover the specific metrics categories, beginning with STA management counters: authentications, associations, etc.

Question: Are these measured per unit time? Answer: Yes, hopefully to something like microsecond or even nanosecond accuracy. Clarification: these are not cumulative, but over some period of time, right? Answer: yes.

Larry went on to metrics for signal quality, such as RSSI,

Question from Tom: Why distinguish between ACK signal strength and RX signal strength? Answer: Some of us like to dig deeper and characterize them differently.

Question from Don: Perhaps this can be used to distinguish between the AGC characteristics imposed by short packets vs. long packets? Answer: Probably.

Question from Colin: Why specifically ACKs? Answer: Because we lose ACKs frequently.

Question from Bob: Would you distinguish between diagnostics and performance? Some of these are diagnostic in nature. Answer: Yes, good point.

Comment from Carl: To answer the question of why ACKs, those are the closest packets to any other packets. Measurements on ACKs would determine things such as settling time and so on, which in turn would show up as lost ACKs.

Question from Fanny: Would the power level have any effect? Answer: Yes, this could determine whether the stations pick up the ACKs or not.

Larry then went on to cover things like MSDU performance and receive errors, reiterating Bob's point about diagnostics vs. performance. He then moved on to cover APs as well, decomposing the various metrics in the same way as the client metrics. Finally, he showed a summary slide showing 31 metrics dealing with the MAC layer. He also noted that these did not include any of the RF layer measurements, saying that he was leaving this up to people like Niels to describe. Further, on looking at the other 802.11 standards, for example, you would have about 16 or so additional metrics to deal with WPA. Also, the QoS and fast roaming work, plus the dynamic frequency selection stuff would apply, leading to still more metrics.

Comment from Bob: Could I suggest that three or four really key metrics - loss, delay and jitter - are not in your list. Answer: Yes, you get to do this! (Laughter)

Bob commented that by sticking to counters, you run the risk of not picking up some of the fundamental metrics that the standard needs.

Question from Fanny: There are metrics and there's diagnostic info. If you simply report counters, what can a network admin do with this? Is this really useful? Answer: I could classify this as a diagnostic metric, not strictly performance. Charles noted that the group's name is "wireless performance prediction", so this might not be in scope.

Charles: Would you recommend that specific implementations make these counters available? Very many of what you mentioned are not accessible by Over The Air (OTA) passive measurements. Are you suggesting that we should propose changes to the management base? Answer: Perhaps.

Question from Tom: Charles, why would you say that these are not available OTA? Answer: Things like RX CRC errors are not available, for example.

Comment from Bob: If you distinguish diagnostics from performance, then this list might be useful, because many of these in a second step could be escalated to performance metrics. For example, if you looked at offered load, but when you mix this with capacity, this might be useful. This is a good start, but it needs some work.

Question from Colin: If you are doing these statistics, you are assuming the presence of Layer 3 and up to do this. Once you have an assumption of offered load, for example, one can make these statistical measurements. Could we say that we should "ram" a certain type of traffic pattern through the device under test and then measure these metrics? Answer: Yes.

Charles then thanked Larry for his presentation. He noted that this would get us all thinking. He then noted that he would like to have the group thinking about the difference between diagnostics and performance metrics.

Question from Fanny: Is this a list of statistics to be used in the metrics? Answer: Agreed.

Comment from Colin: But you need to couple that with the methodology. For instance, what methodology are you going to use to "ram" traffic through the device? It is silly to expect random traffic coming through the network to produce the traffic you want. Instead, we should use special processes to generate the traffic, and then relate the traffic to the actual traffic seen in the network.

Question: Regarding the scope of the work here, how does prediction really fit into the scope of the work? I was reading the PAR and it wasn't clear to me. Is it only measurement and metrics that we are concerned about here? Answer: I'll tell you after this Microsoft moment ends ... (pause for PC to reboot) We want to define measurements and methodologies to enable people to make predictions. This is another discussion we need to have, and we should have it in the Task Group: what do we mean when we say prediction? Some people might want to say that prediction includes measurement of the antenna pattern plus a conducted measurement of the device, and then put them together and say something about the radiated performance. Other people might say that prediction implies knowing the future. (Laughter, and comments about crystal balls.) The discussion also brought up the topic that estimates of performance could be other interpretations of "prediction".

Question: Item 12 in our PAR says that the development of prediction algorithms do not fall within the scope of the project. Can you explain how we can even discuss prediction? Charles: We are talking about *enabling* prediction and not *doing* it. Looking at TGe as an example, 802.11i was spun out of that group because their scope became too large. This is an example of how we should choose to scope our work very carefully.

Comment from Bob: I would rather have called the group "wireless benchmarking", but it would have resulted in a very rough ride in the IEEE with that name. "Wireless prediction" is a much nicer name.

Comment from Fanny: I'd like to dissent from that. A lot of people are used to working with prediction models, so this is a confusing name – it would imply that we need to do prediction. I think the name should be more like "wireless performance modeling" or "wireless performance benchmarking".

Comment from Colin: You have the opportunity to change your name during the formation of the TG, if you want to do that.

Charles stated that he would take that under advisement; he noted to the group that it would be possible to do this by means of a motion.

Comment from Tom: I would prefer to have the name "wireless performance prediction" to remind people that the metrics and measurements that we come up with are to be actually useful to end-users when they are using/installing equipment, as opposed to benchmarking for its own sake.

There were no further comments. The business on the agenda for this meeting being completed, Charles declared the group to be in recess until 1.30 PM on the same day.

## Meeting 4:

Date: 14 July 2004

Location: Council

Charles opened the meeting at 1.30 PM, noting that we had more technical presentations to cover. He said that the first presentation would be on RFC2285 by Bob Mandeville. Bob did not upload a contribution, as RFC 2285 was a publicly available document and freely available on the Web; instead, he would provide instructions on how to download it from the Web, by simply typing "RFC 2285" into Google and clicking on "I feel lucky". Charles then turned the floor over to Bob.

Presentation on "Review of RFC 2285 and RFC 2889" by Bob Mandeville

Bob started by repeating how RFC 2285 could be downloaded from the Web. He then asked how familiar the group was with the RFC process and the BMWG; some members of the group were familiar with this, others were not. He then briefly talked about how the wired Ethernet benchmarking process had started, with RFC 1244 and RFC 2544 (formerly 1944) from Scott Bradner. He noted that RFCs in the BMWG come in couples: generally, a terminology document comes first, followed later by a methodology document. The two RFCs that he had authored were the next two in the series, after RFC 1244 / RFC 2544. He had originally not followed a template; however, in later standards work, he preferred to use a template, because it gave a structure and forced you to get the work done.

Bob noted that one fundamental rule in the BMWG was the notion of "black box" testing. Another fundamental principle was that the BMWG results were never "good" or "bad"; it was merely some number, with a defined reporting format, but no value judgement as to whether the device was good or bad. Yet another principle was to enable testing of one variable at time. Yet another tenet of the BMWG was to test a device completely, but only at the layer at which it was designed; so, for instance, you don't use Layer 7 traffic to test a Layer 2 switch. You would instead design tests to test each characteristic at a specific layer. The BMWG would frown upon doing an FTP transfer to determine the performance characteristics of an L2 switch, for instance.

Yet another aspect of the approach taken by the BMWG is that the experience of the largest possible community of testers should be used as fundamental input into the terminology and methodology documents. For example, his lab had been doing Ethernet switch testing for about 4 years before he started working on the RFCs; thus their lab already knew what mattered in the user environment and what did not. In a sense, they pretty much knew where they wanted to go before starting the testing. He noted that this wasn't really the case in WLAN today. Bob also mentioned that the IETF doesn't really require implementations of the test methodology before publishing an RFC any more, but this was definitely a good idea.

Before the discussion of the RFC itself, Bob stated that his objective was to go through the RFC page by page and then determine what was applicable and what was not. He then started reviewing the RFC from beginning to end, from the table of contents onwards. While doing this, he pointed out that one of the great challenges for Ethernet switches in 1998 and onwards was to support fully-meshed traffic patterns. In fact, this testing helped drive the development of ASICs and off-the-shelf components that makes all Ethernet switches wire speed today.

Question from Charles: When you went into this process, did you have any notion of "meshing" at all? Answer: I was very much familiar with the notion of meshing. The very first test that I did was named X-stream and it was considered by many vendors to be a very challenging test.

Bob went on. He stated that the concept was to first define a limit of a given parameter - e.g., wire-rate forwarding, or wire-rate address learning - and then to drive towards test equipment that could exercise to that limit. It was only time to write an RFC after 2-3 years of getting test equipment to drive to this limit. He also pointed out that there was no talk about delay or jitter capability in this document; this was because, in 1998, no tester had any form of time stamping capability, apart from a custom setup that Scott Bradner had in his lab. Time stamping came along after the RFC was written, and thus one thing missing was a definition of latency.

Question from Tom: In a WLAN, what is a "SUT"? Does it include the environment? Answer from Larry: The SUT would include the DS, but my "opinion light" is flashing. Charles stated that in his case the environment would be specified, but not necessarily included as part of the SUT. Discussion ensued, and there was considerable debate. Finally, Charles recorded an action to put the term "SUT" on to the list for terms to be defined. Bob further noted that in the wired world, a DUT was an Ethernet switch, and a SUT was an Ethernet switch that was connected to other Ethernet switches. Charles felt that one could treat the DUT as a device in isolation, and it had been done.

Comment from Tom: You can't consider the DUT in isolation, you have to take the surroundings along with it. Response: It's getting complicated. Tom replied that testing a Gigabit Ethernet switch that required Cat-5 interconnections to the tester with Cat-3 voice grade cables instead would be an invalid; in the same way, regarding a WiFi SUT without including the environment and the antennas was invalid. Bob retorted that testing an Ethernet switch with the power turned off was invalid too, so what was Tom's point? The discussion continued in this vein for a short time.

Bob then proceeded to the actual definitions of the terminology. He noted that Scott's RFC had the concept of "modifiers", which may be applicable to wireless. He went on to talk about traffic orientation (unidirectional/bidirectional).

Comment from Charles: There are analogies that apply to wireless: an AP acts more like a hub, because of the shared medium, while the switched side still applies because of the Ethernet port. Response from Bob: The reason why "unidirectional" and "bidirectional" tests were designed was because in 1998 a lot of switches were half duplex and so would not give more than 60% capacity.

Bob went on to traffic meshing patterns (i.e., traffic distributions). He said that he wondered if these applied to WLANs.

Question from Bob: Are we comfortable with non-meshed, partially-meshed and fully-meshed traffic patterns? Answer from Charles: I'm uncomfortable with it; we can't just take these definitions and drop them in. We need to find out what really matters to an AP and come up with our own traffic distribution.

Bob then said that after figuring out the direction and patterns, the next step was to determine out what sort of traffic was going to be used to stimulate the device or system under test. The first requirement for Ethernet was to figure out what a burst was; in 1998, some devices would buckle when the burst lengths became larger, and forwarding rates could plummet from 90% to 20% at the longer burst lengths. He noted that one of the things that the group would have to settle on is to just make decisions; for instance, RFC 1242 arbitrarily decided that frame sizes would be 64, 128, etc., and everyone followed this. Similarly, burst lengths were decided on as well. WPP would have to do something like this.

Bob then noted that someone in the morning had mentioned "cheating" on the IFS. He noted that while informational RFCs are not allowed to put in "musts", this was one exception: the RFC had to ensure that the interframe gap was being adhered to, and require the tester to note in the test results when it wasn't. He noted that this was especially true for contention - if the protocol requires contention, and the DUT cheats, then it makes the entire benchmarking exercise worthless.

Bob discussed the "intended load" (Iload) and the "offered load" (Oload). He said that there may be a difference between the two, especially in half-duplex cases. In addition, this was also a result of testers that could not actually drive the rate up to the maximum possible. As a result, this difference had to be reported, as a precaution against people using lousy testers. In many cases, it might be easier to assume that with a hardware tester your offered load is equal to your intended load.

Comment from Tom: WLAN protocols have backoff. The backoff time is random, hence we need to have a long averaging time, and the behavior over a short time would be different. Also, for WLANs, there is a significant proportion of bit errors, and this can cause retries and resulting long backoff periods.

Question from Charles: Do we only count the goodput of the tester, or do we count everything? Answer: We should only count goodput.

Question from Tom: Well, then if a device retries, and gets through on the second try, should we count both packets or only the second packet? Answer: Only the second packet. Tom: You see why this is an interesting problem; what is the throughput? Is it half that of the effective throughput? Answer: Yes, it’s half.

Bob noted that the difference between “throughput” and “forwarding rate”, as defined by Scott Bradner. Throughput is defined at the rate below which not a single packet is dropped. Throughput hence does not allow you to characterize how the device behaves after it drops the first packet. For instance, after dropping that first packet, no more packets might be dropped; in this case, this is actually a good device, and this should be characterized. He felt that throughput was something that grew out of the simple measurement technology that Scott Bradner had available. Forwarding rate, however, does not take loss into account; it simply injects traffic and counts the number of packets received at the far end.

Question from Larry: Do you count SNMP packets in the throughput? Answer: No. Larry then went on: We have management frames, control frames, etc., which comes to a high degree of overhead. Bob felt that as a result you would have to include some level of management overhead in the tests.

Bob then continued, reviewing the definitions of maximum offered load, overloading, etc. as given in the RFC.

Question from Charles: What's "overloading"? Answer: For example, 2 ports in, 1 port out. There's another way you can overload, which is not good, which is for the tester to deliberately go below the IPG; if the DUT reports no packets lost, then you know that it's cheating.

Bob then discussed the iterative process of determining maximum forwarding rate, because a device might get confused when presented with a huge amount of traffic beyond its capacity, while the iterative process won't confuse the device in this manner. These days, however, this was not a problem; ASICs no longer got confused.

Question from Charles: Is this likely to be a problem with WLAN devices, though? Answer: Yes, very likely.

Bob talked about congestion control and forward pressure. He characterized "forward pressure" as "cheating". If you reduce your IFG every time, then you can always win, and you can get the medium every time.

Question from Charles: In half-duplex Ethernet, there was a backoff algorithm; did anyone cheat? Answer from Tom: Yes, I did that. However, by the time the equipment got to the point where this can be tested, half-duplex had gone away and nobody cared. Hence it did not become an issue, really.

Charles noted that this would be different in WiFi; WME for example builds it into the system, that's how they get priority of service. We might want to test this sort of stuff.

Bob moved on through the RFC. He covered head-of-line blocking; he noted that devices that suffered from head-of-line blocking would have to do a complete and total redesign in order to get over this issue. This was an important test in the Ethernet world. He noted that a DEC switch in particular had to be totally re-architected to pass this test. He then went on to address tests, such as capacity and learning rate. The process was to start with the capacity test, and determine how many addresses it could learn, and then use that for the address learning rate test. The definition of "flood count" came up as well.

Bob proposed that the term "behavior" be added to the list of terms to be defined, in the context of the "behavior of the device" under different error conditions. He then went on to discuss error conditions and broadcast as well.

Question from Charles: Regarding broadcast forwarding rate: if there is a difference between uplink and downlink broadcast forwarding rates, then this test would be useful, right? Answer: Yes.

Bob concluded the discussion of RFC 2285 and went on to RFC 2889, the methodology document. Rather than covering all of the tests, which was quite laborious, he went to a single test (fully meshed traffic throughput) and discussed it in detail. He started with the setup parameter section first, and then moved progressively down the test.

Question from Tom: Why was the maximum burst size set at 930 packets, specifically? I've always wondered why this strange number was selected. Bob did not really know, but guessed that this was the point at which the medium was fully occupied. Tom did not agree; he said that you could have an inter-burst gap even with a 930 packet burst, which was only a few tens of milliseconds long with 64-byte packets. There was much discussion, but the end consensus was that this was probably something that was limited by the tester.

Bob noted the random address generation requirement for stressing the address capacity of a tester, which he asserted was the kind of qualification which could only be done if you had already done this sort of testing. He then went on to enunciate a key principle behind the methodology document: basically, tests should be defined in a sufficiently abstract way so that different kinds of test equipment could implement the tests. Bob felt that we had to be extremely mindful of this principle, and not put the cart before the horse; the only way we can overcome this, and not fall into all sorts of traps, is to keep our eye on the ball. With that, he concluded his presentation. There were no more questions.

Charles thanked Bob for his walkthrough, and then turned it over to Fanny for presenting document #748r1.

Presentation titled "Test Methodology for BSS Transition Time" by Fanny Mlinarsky (document #748r1)

Fanny gave thanks to Jeremy Spilman for creating the presentation and collecting the results, and noted that this presentation would also be given to TGr. She started by showing a view of the test setup; the idea behind the test was that there was a station that had to be roamed from AP1 and AP2, and we were interested in measuring the roaming time. She noted that one way to do this was to put the station on a cart and roll it from one end of the building to the other, which was physically challenging. The method they had used, instead, was a cabled topology that would isolate the APs and then use programmable attenuators and combiners in the test. There were variable and fixed losses that were set up such that the APs and stations could not hear each other under maximum attenuation, but could hear each other with a strong signal with minimum attenuation. As the attenuation changed, the station was forced to roam. They also analyzed the Ethernet side of the AP, to look at the traffic being generated.

Fanny then went on to slide #11 of the presentation, showing the transition process and the delays. She explained the roaming process by reference to the slide. She showed the representation in terms of the packets as well, and noted that the script extracts all these packet traces and puts the results together.

Question: Is the rate adaptation included in this roaming time? Answer: In failover roaming, the adaptation time is factored in, but in smooth roaming, the adaptation time is not counted into the results. There was much discussion on the roaming parameters. Fanny noted that there were variations in the roam, depending on the degree of overlap and the speed of roaming. Basically, there was some time where the station does not hear the AP altogether.

Comment from Bob: It would be interesting to know where it was at in the rate adaptation process. In some cases it might slow down a lot, in other cases it might not slow down at all.

Fanny then showed the measurements performed on a number of different clients; there were 40 iterations of the roaming test, and the client took about 2-10 seconds to do the roam. There was some discussion about the impact of the roaming time on things such as VoIP.

Question: Does the roaming client use Microsoft Windows zeroconfig, or does it use client-specific management software? Answer: We configured the station through NDIS. There was no reconfiguration happening during the roam.

Fanny noted that TGr would be looking at this. The largest contribution was the scanning time required by the client. A member of the group asked about the term “Cone of Silence”. Fanny clarified that the Cone of Silence referred to was the practice of putting a coffee can over the AP under test in order to persuade a station to roam; however, Charles noted that this was not a very good way to do the roam either. The advantage of the method presented was that it could be done rapidly and repeatedly.

Question from Charles: Are you proposing this as one of the methodologies for our group? Answer: Yes.

Question from Tom: Did you try this with different APs? Answer: Yes. The 802.11b APs took a lot less time than a/b/g, especially in the case of one vendor that had coordinated their APs and their client cards.

Question from Fil: Did you notice a significant difference between 802.11a/b/g and b-only? Answer: Yes, if you restrict the PHY modes used by the client, you restrict the scanning, and this speeds up the roaming.

Charles noted that, speaking for TGr, they want to have roam times on the order of 20 - 50 milliseconds, which is a small fraction of the actual roaming time measured. This is present state of the art, however. We need to coordinate with TGr to define the same metric, otherwise we will end up “hating” them and they will end up “hating” us and we don't want that.

Question: Why is Tdata so high sometimes? Answer: I'm guessing that the client lost the IP address and had to regain it.

Question: What is the "inter-roam delay"? Answer: The scripts wait for a short period of time to stabilize. The amplitude is changing during the scanning. Charles noted that we want to test with different inter-roam delays, to account for settling.

Comment from Bob: In the future, it would be necessary to figure out a way to isolate the client's contribution to the transition time, and the AP's contribution to the transition time. Fanny responded: This is not quite brought out in the diagram, but is actually done - the response times are separated. Also, this is dependent on the traffic load as well.

Charles noted that these long roaming times are what happens in devices now, but TGr is going to change that. It's hopefully going to change for the better. On that note, and seeing no other questions, Charles closed the presentation.

Charles then noted that there were 20 minutes remaining in the time until the break. He asked if anyone would like to discuss changing the name of the group. Fanny said that she would like to have such a discussion. Charles therefore opened the topic.

Bob stated that, as much as he would like to change the name, he felt that we could not do so, because the PAR did mention “prediction”. Charles recapitulated, for the benefit of the people who were not present in the morning, that a discussion on this topic had taken place on Tuesday and that there were people in the group that said that we could change our name if we so chose. Fanny said that she had spoken to a large number of people who were just confused about what the group did and the source of confusion was partially the name, which led people to confuse the charter of the group with propagation modeling and so on. Paul noted, in counterpoint, that there was a lot of ROI to be obtained on the overall purpose and scope, which was still nebulous. Until that was obtained, he did not feel that we should spend any time discussing the name. Larry, on the other hand, echoed Fanny's comment that that there was a lot of confusion around the word “prediction”, and this was also giving rise to a number of jokes. The big issue, in his mind, was: what should the new name be? He said that, to Paul’s comment, we shouldn't spend a lot of time on this.

Question: How much does it matter, and does it discourage participation? Answer from Fanny: I feel that a bad name could definitely discourage participation.

Bob noted that if we are going to change the name, we should change it now, and he would like to see it changed to “Wireless Performance Metrics”. Fanny concurred, saying that she liked that name. Charles said that we should do it right now or not at all, and preferably with a motion.

Bob brought up the issue of "now" vs. "right now". He preferred that "now" equals "in this session", rather than “now” equals "in the next 10 minutes". (Laughter).

Paul then asked about the agenda for tomorrow. Charles replied that there was one more presentation on the agenda, and then there was a discussion about special committees. At that point, Fil stated that he would like to give the name change some more thought before deciding on whether to change it and what to change the name to. Charles concurred, and said that he would put it on the agenda at the very bottom, after the formation of Special Committees. He then declared the meeting in recess until 4 PM tomorrow.

## Meeting 5:

Date: 15 July 2004

Location: Parlor C

Charles opened the meeting at 4.00 PM. The group was entranced during the first few minutes by a pink spot on the screen (generated by a defective VGA projector) that gradually shrank and eventually disappeared, to the accompaniment of a countdown by Tom. The projector having returned to (somewhat) normal, Charles started the official business of the group by reviewing the agenda and the plans for the remainder of the meeting. He said that we had one presentation from Bob Mandeville on the subject of a test template, followed by a general discussion on the formation of Special Committees, the charter of the group, the deliverables and the lifetime of the group, plus some procedural work. He also noted that there was some discussion on the name of the group that could be dispensed with right away: the title of the document, from the PAR, was "Recommended Practice on Wireless Performance", and would not change, and so changing the name of the group was a moot point. He also announced that two motions would be coming up later: a teleconference motion, and also a motion to extend the life of the SG until the TG is formally approved. He stated that he would like to go back to the terms document that was started Tuesday night as well, and start working on some of the terms. He felt that this would keep us busy until 9.30 PM. Charles then passed around a signup sheet for the newcomers to the session to sign in, and reminded everyone to sign in to the attendance server as well.

With that, he turned it over to Bob for his presentation. After a bit of fiddling with the video projector and the screen, the presentation began.

Presentation titled “Wireless Performance Test Template Proposal” by Bob Mandeville (document #832)

Bob began by noting that he wanted to start the entire process by looking at the end point. The end point is a document that describes tests. If we are going to do this, then we need to think about how we are going to describe tests. The way to do this was within the confines of templates. To this end, he said that he would present a template that is unlike anything else he had ever seen. He wanted to do this early because the structure should be in place as soon as possible.

Bob noted that it was important to build a structure to all of the work that the group would be undertaking, and this was hence an ambitious proposal. He would therefore go through the template item by item and describe how each item should be dealt with. He forthwith plunged into the description of the template.

The first item in the template was the title, which should be the test name, with each word capitalized. He then went on to the test definition ID, which should be a number. He stated that he would not want a hierarchical numbering scheme; only one single number should be used to identify a test. A significant amount of discussion ensued about the numbering scheme to be used.

Khaled Amer asked if it would not be useful to have subtests with a hierarchical numbering scheme. Bob disagreed with this; he would prefer to have a single level of numbering because it would be easier to maintain. Charles noted that, as editor of the WSM test plan, he was all for simplicity, and was all for one level himself. Don noted that one thing that might be helpful is to work backwards, and then see what we would like to produce as a working group. His idea was that there would be a certain number of metrics - one or two dozen at the most - so that we can compare products and develop profiles for those. We should consider a limited number of very specific test scenarios, very controlled, and very limited. Thus we didn’t need an extensive numbering scheme.

Question from Joe: Do we want to relate this to what some of the other bodies do? You are discussing various configuration changes (modifiers) to take a different metric in the same device. In the case of the WiFi Alliance, are they changing the numbering scheme? Answer Charles: The WiFi Alliance does something different with each test plan, so that’s not a good example. Don further pointed out that in terms of reducing the amount of numbering, a single test layer without modifiers is best.

Bob then noted that you could have tests that supersede older tests; in this case, you could have the older test number in brackets next to the new test number.

Question from Mark: Are there categories of tests? Answer: Yes, that's coming up.

Question from Don: Are you talking about revisions of tests in this? Answer: Yes. Don then continued: I would support revisions of tests rather than a single test.

Comment from Tom: I suggest postponing all the format stuff until we have a draft, the IEEE Standards Style Manual says what can be done and what cannot.

Bob therefore continued with the presentation. He talked about the reference document source entry.

Question from Charles: The “source of the test”? Answer: This refers to some IEEE 802.11 document that is the underlying specification.

Bob went on to discuss the “test type” field. He noted that the TG had to maintain a number of lists, which would be definitions. He felt that it was the duty of the group to create the list of tests.

Question from Mark: did you intend this as part of the numbering scheme, such as "FRP1"? Answer: No, we would have "Test 1", "Test 2", "Test 3", etc. for the numbering. The specific test would be some type of test.

Bob noted that he had added "baseline performance tests should be conducted in a fully shielded environment" for controversy, and looked archly at Tom while saying this. He noted that he wanted to characterize the particular test as being either a baseline test, or a test with modifiers. He then went on to talk about the test purpose, which would talk about why a test would be useful, how it would be useful, and to whom it would be useful.

Question from Mark: Do you see a separate document, such as an RFC, that would be kept by the group? Answer from Charles: I don't think the test purpose should be separated into another document. The intention was to have a very brief definition here. Mark then continued, stating that the RFC was very well described. Charles asked whether there was another document in the IEEE standards collection that could serve as a model for this work. Tom brought up IEEE 1802.3, which was an 802.3 test document; however, he noted that it was probably not a very good example of our work.

Question from Gerard: Should the “purpose” of the test be the specific subclause in 802.11? Answer: No, that's in the reference document source. The “purpose” explains why the test is useful.

Bob proceeded to discuss the description of the DUT/SUT. In general, you would be required to indicate the device type, which would be pulled from a list maintained by the TG.

Comment from Charles: I would suggest that the definitions be drawn from the existing device types. Rebuttal from Don: That becomes muddier in some cases, such as when the AP is part of a switch or is a thin AP. Bob noted that in all of RFC2285, there was no definition for an "Ethernet switch". The group may in fact come up with a definition for a device type that is not in the standard. Gerard then commented that he would make a friendly amendment: we should talk about the STA, which includes several of these items.

Question from Larry: Are we defining the list right now, or are we talking about a template? Answer: We are talking about the template. Larry then reiterated that we should agree on the template first, and leave the specific items for later.

Charles then noted that he was hoping that this presentation would take no more than an hour, but given the amount of discussion, suddenly the 3 hours and 15 minutes remaining to WPP didn't seem like a lot. Larry noted that we should hurry up. Bob therefore proceeded apace.

Question from Gerard: If this were a station, would you want to describe whether this was a Pentium 4 or whatever? Answer: Yes, you do want this.

Question from Tom: What happens if the make and model number of the device hosting the DUT is no longer available at the time of the test? Answer: I don't know, what do you want me to do about it? Gerard then clarified that this information might be necessary in order to determine the test conditions, so that equivalent equipment could be found to reproduce them.

Bob noted that he added the “test result range” field because this seemed to be very significant for wireless performance testing. He said that, for example, you don't get 54 Mb/s out of 802.11a, and people reading the reports should be fully aware of that. He then went on to test environment, noting that he'd taken a crack at it. He stated that he wasn't necessarily an expert in this type of environment; this would have to include all sorts of effects, such as cables, areas, camels passing by in the hallway, etc.

Comment from Don: I think the test environment would be a definite requirement. Next! (Laughter.)

The next topic of discussion was the “test configuration” field. Bob said that the test configuration would have to be generic, not naming specific vendors or equipment. It should be described in a generic fashion.

Question from Gerard: A simple diagram of the test setup, perhaps? Answer: Yes. For instance, I used to have a simple schematic for the SUT.

Bob went on to the description of “test parameters”. He noted that the list he'd presented was not exhaustive, and would be a work order for the group. He went on to modifiers. There was considerable discussion about what the difference between a test parameter and a modifier. Tom defined the test parameters as a configuration of the traffic generator, such as the addresses used and the load. The modifiers were defined as configuration of the DUT. Charles said that he liked this definition, and paraphrased it as "parameter is a configuration of the tester, and modifier is a configuration of the tested".

Chris Polanec, in the interim, noted that he'd found a document we could use as an example for our work, which was IEEE 829, "Test Plan Outline". He said that this would be something we should look at.

Question from Don: Overall, do we have the concept of "subtests" in a test? Is that a "modifier" concept? If we have a few metrics to publish, we would need some way to aggregate those into a meaningful output. Answer from Charles: We still have to find a way to do this. For example, in the case of power consumption of a laptop, we would have a test procedure to measure the voltage and another to measure the current, and we would multiply the two.

Question from Don: We could easily define a thousand tests, would this have any value? Answer: One way would be to make it incumbent on the group to make it a pretty contained list to keep things from being an exponential explosion of stuff.

Bob stated that in the BMWG there was a definition of the frame lengths that would be used, and there were 8 of them, and this kept things fairly manageable. Don then asked how we would weight those, and distil them into one integer. Charles remarked that he did not believe that this would be in scope for the group, as there were a lot of different types of equipment that would require a number of different modifiers for tests, so that different modifiers would be applied to different categories of equipment. Don noted that he'd seen all these test plans that had hundreds of modifiers, but there was nothing that would distinguish good performance from bad. The discussion went on for some time.

Bob skipped over "test procedures" as being something that would involve the most amount of work, as an output of the TG, and went to "units", "variables" and "results". He noted that this was the item that would probably address Larry's point the most. The issue of how to present the results was significant and needed to be decided. The format would have to be fixed by the group.

Question from Fanny: Can it be generic, or would it be specific to the test? Answer: It might be hard to make it generic, so we might have 2 or 3.

Finally, Bob covered "remarks", where he said wryly that this is where we put things such as "we didn't know what we were doing, so we retired halfway through". (Laughter).

In closing, Bob exhorted the group to take this test template effort seriously, and said that we needed to work hard at it. He noted that extensive work remained to be done on the test types, device types, environments, parameters, modifiers and units section. He suggested that these six tasks may be a way to structure some of the work going forward, and may dovetail with Paul's scheme going forward (or it could be viewed as an alternative approach to how the group would go forward). He further noted that this hasn't covered a single test yet; our work was just beginning. This closed his presentation.

Charles then thanked Bob for his presentation, and said that he saw two levels of work: first, we need to agree on a template, and then we need to agree on the methodology. He therefore called for a straw poll: How many generally liked the template?

Question from Tom: Did you mean the formatting of the template, or the contents thereof?

Charles clarified: The contents, particularly the contents of the leftmost column, leaving aside the colors and so on.

**Straw Poll #2:**

Question:

How many participants like the template format?

Results:

Like it: 17
Do not like it: 1

The sole dissenter was Chris Polanec, who stated that the IEEE had some similar documents that were done in the past and we should consider the formats and structure of these documents before deciding on a template of our own. For example, the IEEE 1802.3 standard, or IEEE 890 (Chris was not quite sure of the number). He thought that perhaps we should look at these other standards first and then come back to Bob's presentation. Bob then broached the topic of another straw poll in terms of how to break up the work. Charles noted that he was hoping to use the remaining 40 minutes to discuss the work of the ad-hocs, and promised to give Bob some time later. He noted that this was a great start and we should settle on it within another couple of months.

Tom had to leave for the airport at 5.25 PM, so Bob Mandeville kindly volunteered to take over as recording secretary for the rest of the meeting time. The following are the minutes taken by Bob M.:

Charles discussed generic process of getting to letter ballot and formation of special committees to handle the tasks. Paul suggested that the revised group titles be 1. Device configuration, 2. Traffic patterns and 3. Application. After discussion, the group added another group for 4. Metrics. There was an open discussion on groups.

Mark and Don discussed how to approach tasks going forward. Fanny stated that she saw application driving the tasks which would include metrics and under that device configuration and environment. Charles noted that he did not see voice metrics as governing the process. Fanny suggested that applications should drive metrics.

Paul then reminded the group of the scope. Charles stated that the definition of tests and recommended practices is the goal of the group. Paul suggested that metrics are goal of an application driven approach. Dalfor said that variables, units and results must be defined.

Charles asked if we need to form ad hoc groups. Mark suggested that the whole group might work together. Paul wanted terminology to be defined by the ad-hoc groups. Chris suggested that the ad hoc groups can co-exist with the larger group; however, Mark preferred splitting into groups at a later stage. Charles noted that two positions are being taken on ad hoc group formation.

Charles asked who will be going to Berlin for next meeting. About half of group said that they planned on doing so.

Don suggested that the conference calls focus on topics, and then later break into smaller groups. Fanny suggested two groups: one for metrics, and one for the template.

Charles called for proposals to be posted well ahead of time. Fanny later suggested that we work first on template and then develop tests once the template is ready. Mark proposed defining a minimum set of terms and template. Paul, however, felt that most terms are defined. Dalton said that some terms may be arduous to define.

Finally, Charles suggested the order of work to be: terminology, template, environment, device set up and application. Uriel said that he wanted the template to be left to the end. Mark remarked that the template will be an iterative process, and that he was hoping that there would not be too many iterations. Gerard said that in his view terminology is an ongoing process through the life of the test definition.

No agreement was reached on this topic, but much discussion took place. Charles then declared the meeting in recess until 7.30 PM.

## Meeting 6:

Date: 15 July 2004

Location: Parlor C

The session resumed after dinner at 7.42 PM for the final meeting of the week. Fil Moreno served as recording secretary in Tom's absence. A discussion ensued on what the remaining time was to be spent on. There was some uncertainty from the group. Charles finally elected to move forward with the terminology discussion as planned, focusing on the terms that had been identified from earlier in the week as belonging to the "general" category.

Some discussion on the teleconferences also took place. Charles notified the group that he would be traveling next week and therefore no teleconference would be scheduled.

After this, the group resumed the terminology discussion. Bob provided a list of terms that need to be defined for the template. Paul expressed some concern over the direction of activity; in his view, we were diving into minutia at this point, and should be devoting our efforts to planning and structuring the overall work. On consensus from the group, therefore, the terminology definition activity ceased and the efforts of the members were directed to outline the "plan for now. Chris suggested that Rick Denker's presentation (#770r0) was a good start towards describing environments; however, he felt that we should wait until the next teleconference before starting in on this topic.

Discussion on the scope of work led to an extensive discussion on the meaning of the word "application" as applicable to WPP. After considerable debate, the group finally elected to accept a suggestion from Dalton, which enabled them to extricate themselves from the "rat hole" and move on. The suggestion was to encapsulate, within each test in Bob's template, an example of an application to which the test is most pertinent. It was also noted that this speaks to the Purpose item in the template.

This culminated the technical discussions. Charles then turned to settling the procedural matters: primarily, the continuance of the teleconferences and a request to the WG to continue the SG charter until such time as we would safely cross the threshold into becoming a formal TG. Two motions were invited by Charles to settle these matters.

**Motion #2:**

Move to hold teleconferences every Thursday at 12.00 noon ET, starting with July 29th.

Moved: Chris Polanec

Seconded: Don Berry

Voting: Yes: 16 No: 0 Abstain: 0

The motion passes.

**Motion #3:**

Move to request the 802.11 Working Group to continue the charter of the Wireless Performance Prediction Study Group through the January 2005 meeting.

Moved: Gerard Goubert

Seconded: Chris Polanec

Voting: Yes: 16 No: 0 Abstain: 0

The motion passes.

Charles then noted that he would be moving this same motion on behalf of the WPP SG before the 802.11 WG on Friday.

All business of the group being over, Charles then entertained a motion to adjourn. The motion was passed by acclamation and the group adjourned.

The WPP SG session ended at 9.30 PM PST on Thursday, July 15, 2004.

# Attendance

Abraham, Santosh
Alexander, Tom
Amer, Khaled
Anantha, Veera
Andren, Carl
Bartel, CR
Baysal, Burak
Berry, Don
Billhartz, Tom
Bowles, Mark
Canaan, Paul
Chen, Michael
Daube, Zvika
Denker, Rick
Ellis, Jason
Euscher, Christoph
Goettemoeller, Mike
Green, Larry
Hayes, Kevin
Jose, Bobby
Karcz, Kevin
Kobayashi, Mark
Kojukhov, Andrei
Lanzl, Colin
Lemberger, Uriel
Mandeville, Bob
Mlinarsky, Fanny
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Mourot, Patrick
Narasimhan, Partha
Oh, Jongtaek
Paglia, Pete
Patel, Vikas
Polanec, Chris
Polland, Joe
Rangwala, Noman
Repice, Joe
Salman, Taylor
Schreder, Brian
Sivam, Reuben
Skidmore, Roger
Slosson, Brian
Surineni, Shravan
Tokubo, Eric
van Erven, Niels
Victor, Dalton
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**IEEE P802.11**
**Wireless LANs**

# Minutes of Wireless Interworking with External Networks (WIEN) Study Group (SG) Meetings

**Date:** July 12-16, 2004

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**Abstract**

Minutes of WIEN SG meetings held during the IEEE 802 Interim meeting in Portland, OR, from July 12 - 16, 2004.

## 1. Executive Summary:

1. Background to WIEN SG presentation (04/688r1)
2. Technical Submissions:
   - Network Side Issues (04/708r0)
   - Hotspot issues (04/751r0)
   - MAC address anonymity (04/780r0)
   - Network Selection Issues (04/691r1)
   - Access Router Identifiers (04/710r0)
   - Key Management Issues (04/690r0)
   - 3GPP issues (04/733r1)
   - ARID scenarios (04/835r0)
3. Liaison Issues to external standardization bodies
4. Extension of the Study Group
5. Initial drafting of PAR and 5Criteria
6. Plans for Berlin Meeting

## Morning Session of IEEE 802.11 WIEN SG, Tuesday 13 July 08:00 – 10:00 am

## 2. Logistics

WIEN Meeting called to order by Stephen McCann (Chair) at 08:00am.

Agenda was reviewed (04/**689r2**) and it was agreed to bring the MAC address presentation forward to the joint session with TGr. Two joint sessions was scheduled for the week:

With TGr (Fast Roaming) Tuesday 1030 – 1130
With IEEE 802.21 Wednesday 0900 – 1030 (in ad-hoc mode)

The IEEE 802 & IEEE 802.11 Policies and Rules were reviewed.

Patents and By-laws read out by the chair, together with licensing terms and associated conditions.

There are 3 sessions, 2 on Tuesday 13th July between 0800 – 1230, and one on Thursday 15 July 1600 – 1800.

**3. Background (04/688r1)**

Stephen McCann (Chair) gave a short presentation about some of the background to the creation of this study group.

**4. Network Side Issues of the interworking (04/708r0) Cheng Hong**

Andrew Myles: Any example of the policy enforcement?
Cheng: e.g. the MAC addresses filtering at the Access Point (AP).

Stephen McCann: Are these functions at the AP or other network nodes?
Cheng: Could be on other nodes, if the architecture introduced in the AP functional description group (split MAC) is adapted. But these functions will be related to the MAC.
Ted Kuo: There is no need to define the physical location of the function.
Cheng: Yes. Only the functions need to be defined. Location could be left for implementation.

Chair suggested having straw polls regarding the discussed issues to decide if they are within the scope of WIEN.

Jon Edney: Are the straw polls per item or take as a package?
Chair: It could be carried out per item.
Floor: If the items address by other group, e.g. IEEE 802.21, turns out to have requirements on MAC and PHY, we may still have to deal with them in IEEE 802.11.
Chair: Yes. So, the straw poll is about whether we should ultimately deal with the issues in IEEE 802.11.

Stefan Rommer: Are we assuming a certain solution when we say it is in the scope of the group?
Chair: Not necessary to think about solution now. A future Task Group (TG) will be the place to work on detail technical problems.

Floor: User revocation relates to the WNM (Wireless Network Management). Will this straw poll decides on whether it would be dealt within WNM or WIEN?
Chair: We don't need to specify the group yet. Only need to consider if it is within IEEE 802.11's scope.

**Straw Polls:**

◊ Is the "Access Control & User revocation" in the scope?
Result: 17-0-2 (Yes-No-Abstain)

◊ Is the "Policy Enforcement" in the scope?
Result: 4-2-9

◊ Is the "QoS control and mapping" in the scope?

Result: 15-1-1

◊ Is the “Admission Control” in the scope?
Result: 13-1-5
◊ Is the “Simultaneous Access” in the scope?
Result: 6-4-8

Chair: Would like to know about the reason for the objections?
Andrew Myles: Feeling those points may not really relates to .11
Chair: Currently, cellular network made some assumptions about the WLAN, and these has to be checked in the WLAN standardization group.
Andrew Myles: Not sure about this from the presentation.
Chair: We are not yet in the stage of finding solutions. These are just a list of issues for future study.

Jon Edney: Some policy issues may be combined with the QoS issues.
Stefan Rommer: All of the items could be in the scope if we have some solutions that require changes to the MAC and PHY.
Chair: We need to list out the items, and then make some decisions in a future TG.
Ted Kuo: Maybe some contributions based on pervious work in other groups, e.g. ETSI BRAN, could help in understanding of the problems.
Chair: Yes. That is why we have started the technical discussions in the SG. The items listed are to be studied in IEEE 802.11, not necessary WIEN only.

Chair: Regarding the user revocation issues, it could be addressed in a joint session with WNM group in next meeting.

**5. Hot spot issues (04/751r0) Max Riegel**

Jon Edney: What is the anonymous authentication? Is that he authentication of the network?
Max: The network is authenticated to the user, but user is not yet known to the network. It is kind of similar to the PEAP process.

Jon: Secure web page is providing the protection to the user data.
Max: That does not provide security at the link layer, and that is the reason for the combination.

Chair: Item identified as “Secure UAM” and support of anonymous service, and user interaction/help. Would be useful to have a straw poll for these items.
Chair: Is there an equivalent term in IEEE 802.11 for the UAM which is a Wi-Fi term?

Straw Poll: Should we put secure UAM in the items in the list for WIEN group?
Jon Edney: Why this has to be done in IEEE 802.11?
Max: There is IEEE 802.11i, but not sure this could be done in IEEE 802.11i. This also touches the MAC.
Jon Edney: That is why PEAP is mentioned.
Max: PEAP does not provide the change of the sequence (of authentication). It is only contained in the authentication process. Here is trying to get the link layer key in place first, and then authenticate the user. PEAP does not allow doing IP connection before doing the authentication.
Jon Edney: Could be doing an open authentication first, and then establish another authentication. The issue is how to combine them and make them work.
Stefan Rommer: There are already proprietary solutions using the PEAP to do similar things.

◊ Straw Poll: To add this issue to the open issue list (tentative name “secure portal page”)
Result: 12-1-5

**Joint Session with TGr, Tuesday 13 July 2004, 10:30 – 11:30 am**

**6. MAC addresses (04/780r0) Jon Edney**

Floor: how many packets involved? What is the delay budget (of this scheme)?
Jon: The same as current association procedure, so same number. There may be some delay since the AP needs to check with other AP (using IAPP) for the uniqueness of the address. But it may not affect FR, since it is only for the first time the address is used in side the group. For the transition, it does not change the MAC address

Floor: what needs to be done for the DS to ensure uniqueness?
Jon: Maybe for the DS to keep a table for the bridging. It does not really bring much overhead, except a bit extra storage.

Bob: what kind of information is encrypted?
Jesse Walker: the authentication could be resolved to the user identity.
Jon: Some company will bind the MAC to the identity of the personal identity
Flo (FT): For user@homenetwork identity, the visiting network cannot know my real identity.
Floor: Fail to see the linkage of the problem. Why does it matter if your identity is known? And how the third party would get info about user identity?
Flo: 3G has not solved the problem. Would that mean it is not a big issue?
Floor: It is similar to the credit card issue, and credit card is even more serious.
Pat Calhoun: There were some efforts in IETF, and it was decided that it is a business problem. And this solution still doesn’t solve the problem.
Henry: why not just have a random address than using the protocol
Jesse: there are still possibilities of collision.
Jon: This is to reduce even the possibility of collision.
Floor: WAVE also would like to see this. The MAC address would also allow law enforcement agencies to track the user. This is a concern there.
Nehru Bhandaru: it is good, and we should have it studied in the group.
Pat Calhoun: Is it too much to do to tie the MAC to the identity?
Jon Edney: It is not so difficult now. And there is a trend to do that in the industry.
Floor: The request and ack will add extra time for the FR
Jon: It only affects first time association.
Floor: When the MAC expire, it may affect the FR

◊ **Straw poll**: “Is anonymous MAC addressing a concept that should be pursued within IEEE 802.11?”
Yes-No: 26-22

**7. Network Selection Issues (04/691r1) Eleanor Hepworth**
Flo (FT), 72 bytes in RFC2486, it could be longer. It is AT LEAST 72 bytes.

Jon Edney: Are you considering distributing the info wirelessly or in the wired network?
Eleanor: In WIEN it is wireless, in IEEE 802.21 could also be wired.
Bernard Aboba: The mobility for the EAP may not be well understood.

◊ **Straw poll**: “is network selection information as presented in 04/691 a concept that should be pursued within IEEE 802.11?

Floor: This is a specific solution. Is the straw poll about general issue, and will other solutions be considered?
Stephen: Yes. We will not concentrate on the solution but only on the issue.

Result: 55-0

◊ **Straw poll**: "Where should the network selection information as presented in 11-04-691 be pursued?
: WIEN-TGr- Other within 802.11:
Result: 50-0-1

**8. Access Router Identifier - ARID (04/710r0) Daniel Park**

Floor: Those fields are already not free. You need to put a bit somewhere else.
Jesse: Why would not include this in the discovery work?
Stephen McCann: It could be.
Pat Calhoun: It may not be the AR, could be a mobility domain.
Floor: What is the delay like if you move between ARs
Pat Calhoun: If you change IP address, there is no FR.
He HaiXiang: One AR could have multiple subnet associated, is the ID identifying the physical AR or the subnet?
Stefeno: Need to distinguish between whether we need to provide the info, and how we do it. As for how to do it, the proposed may not be the best solution.
Floor: Clint: What is the range of the ESS?

Decision: To take this back to WIEN and discuss more.

**Morning session of IEEE 802.11 WIEN SG, Tuesday 13 July 11:45 – 12:00 am**

**9. Key Management (04/690r0) Eleanor Hepworth**

Chair: Will carry out a straw poll to see if these are still in the scope.

◊ Straw Poll: "To have keying material/issue in the open issue list"
Result: 1-1-9

Needs further presentations to clarify what needs to be done for the issue.

**Joint Session with IEEE802.21, Wednesday 14 July 09:00 – 10:30 am**

**10. Stephen McCann presented WIEN scope and issue list**
Stephen: Should the scenario 3 of 3GPP interworking be covered in WIEN?
People are confused about the scenarios. Stephen will come back in Sept to present about the different scenarios.

Floor: Will also deal with 3GPP2? Or will it be dealt with in a serial manner?
Stephen: In parallel, although the questions in the slides are biased towards 3GPP.

Ajay: Any liaison has to be from the WG, so it would be an IEEE 802.11 & IEEE 802.21 joint LS instead of WIEN & IEEE 802.21

Mani: How is the network detection and selection related to interworking?
Stephen: It needs to provide info of the network behind the WLAN.
Sanjeev: When you said the IETF requires that, would it be a more generic issue than interworking or layer2?
Stephen: Yes.
Mani: Would that be more of an IEEE 802.21 issue?
Cheng: There are different levels of solution to the problem. The items at IEEE 802.11 could be solved with existing IEEE 802.11 mechanisms, and not really conflicting with IEEE 802.21
Ajay: Would this cause confusion when IEEE 802.21 produces a different architecture?
Cheng: They should co-exist

Ajay: Do you have idea of where those functions to be implemented?
Stephen: No. AP function description group could be a place to look at.

Ajay: what are layer 2 interactions?
Stephen: If IEEE 802.21 has any architecture that would have interaction with layer 2, WIEN will have to look at that in IEEE 802.11.
Stephen: WIEN is not working on these items, e.g. triggers, but expect inputs from IEEE 802.21 regarding those. WIEN will try to look at those issues.

Vivek: In what form the output from IEEE 802.21 would the WIEN expect? The final specification or just some understandings? Some model would be done by individuals that would also work in WIEN? Also how to ensure that models would conform to IEEE 802.11?
Stephen: IEEE 802.11 will have to watch the draft in IEEE 802.21, not wait for the final spec. If significant changes are needed to the IEEE 802.11 MAC, feedback would be expected earlier than late. IEEE 802.11 will take the IEEE 802.21 output and made the changes. IEEE 802.11 not expect IEEE 802.21 to specify the exact changes to the IEEE 802..11 since that is not scalable. Those would still be sort out in IEEE 802.11 groups. In the end IEEE 802.11, IEEE 802.16, etc will still try to be IEEE 802.21 compliant. They will have to make changes to achieve that.

Yogesh: When you become a TG, would WIEN carry out any changes required from IEEE 802.21 in IEEE 802.11?
Stephen: yes

Michael: Procedures questions. IEEE 802.11 people are not working on the same problems as we are. They have their market and customer demand, and they will not just wait for IEEE 802.21. Therefore, we need to work together with them, to influence them, and even cellular, since some our changes suggested would be fundamental

**11. ARID issues, Daniel Park**
Floor: How to sync the use of ID in different domains.
Daniel: needs more study

Michael: in IEEE 802.16, the IP address may not change even if the domain changes. Basically, there needs to be more information than just he AR. IETF has several drafts talking about that. Also, there needs to be input from mobile node to inform the network of its identity and its intension.

Xiayu: It is true there should be some solution to identify the mobile domain. ARID is just one solution, link identifier in the DNA group stands as another solution. ARID needs manual configuration and that may have problem.

Micheal: In IEEE 802.21, no need to have ID limited to the beacon of IEEE 802.11

**Afternoon session of IEEE802.11 WIEN, Thursday 15 July 16:00 – 18:00**

**12. Ratification of issues raised by IEEE802.21-WIEN ad hoc**

* No issue to be ratified.

**13. 3GPP Issues (04/733r1) Cheng Hong**
Stefan Rommer: What else does the IEEE 802.11 needs to do to support USIM?
Cheng: We know IEEE 802.11i could support EAP, but not sure about the USIM, and the keying stuff.

Q: (Mike, Dorothy): would the keying thing be an IETF issue?
Stephen: There is a liaison regarding the IETF to be mentioned later. And, now we are not going to the details yet. Just to get a feeling of whether the items should be in the scope.

◊ Straw Poll: USIM support
Result: 5-2-9

◊ Straw Poll: Network Sharing
It is decided that the item will be the same as the network detection and selection issue that is already in the open issue list.

◊ Straw Poll: Traffic Enforcement
Result: 8-0-8

◊ Straw Poll: Charging
Result: 12-0-5

**14. 3GPP/2 Liaison issues**

Liang Jie: Why haven't we sent something already?
Chair: We are not sure where to send?

◊ Straw poll: Is it a good idea to sent liaison (LS) to 3GPP and 3GPP2? (Not define the time)
Result: 13-0-3

Take the drafting of the LS offline.
It would contain the open issue list.

**15. ARID presentation II (04/835r0) Daniel Park**

Lang: How is the ARID are propagated to the AP?
Daniel: Not sure now.

Eleanor: What info do you need to support the FR, and it would fall into TGr's scope? And another issue is how you made that info available, which would be the network selection issue? Also, for how to make it available, it could fall into IEEE 802.21's scope.
Stephen: It is indicated that it is an issue, and we are not sure which group should deal with it. We will see Daniel to come back with the issue for Berlin meeting.

**16. Letter/Liaison to IETF (04/833r0)**

◊ Motion: Move to approve document 11-04-833r0 and request the IEEE802.11 Working Group chair to forward it to the IETF

Discussion of the motion:
Q: May doc submitted to the IETF. Does this document represent the direction? Will it just die off?
Bernard Aboba: IETF will grant high priority to contributions from other SDO. One is a WG draft. The other is an individual draft. The process could be common, but there are couples of ways to deal with the comments.

Stefan Rommer: We need to have a time estimate for the comment process.
Bernard Aboba: One has a 3GPP posed deadline. When the letter is received, you can have a discussion about when the deadline is.

Moved: Mike Moreton
Second: Eleanor Hepworth
Result: 19-0-2

**17. SG extension motion:**

Motion: "Move to request the IEEE802.11 Working Group to extend the (WIEN) Study Group for another 6 months"

Moved: Hong Cheng
Second: Takashi Aramaki
Result: 20-0-1

**18. Update of open issues list (04/834r0)**

Air Interface Issues:

AR identifier (needs further work)
MAC address anonymity (Possibly)
Network Detection and Selection (Yes)
Beacon Scalability (Yes)
Universal Access Method/11i co-existence /Secure Portal Page (Yes)
User clear down (possible)
Keying issue (Possibly)
~~USIM Based access control (Yes) 3G/cellular based access control~~

Eleanor: This may be similar to the keying material issue.

This point modified into:
"3G keying issues (possible)
- USIM based access control
- Length and entropy"

Stefan Rommer: The 3GPP SA3 may have already solved the issue

Network-Network Issues:

Policy enforcement (Not sure)

- configuring public access AP - WNM

Access control (Yes)

- user revocation - WNM

~~Simultaneous access (not sure)~~

External QoS mapping (Yes)

Admission control (Yes)

Traffic enforcement (yes)

Charging (Yes)

"Simultaneous access" is taken out.

Bernard Aboba: Comment in IEEE 802.1 thinking that not all IEEE 802.1 QoS is supported in AAA. Especially in VLAN mappings.

Insert under "External QoS mapping

- IEEE 802.1 issues
- Admission Control"

**19. Roadmap for SG/TG (04/712r0)**

◊ Straw poll: To have Teleconference to review PAR and 5 Criteria and the LS to 3GPP/3GPP2

Result: 17-0-0

Dates to be announced in the Mailing List (ML). (initially 2nd week of Aug)

◊ Straw poll: If you intend to take part, what time zone region do you prefer?

Asia: 3

US: 7

Europe: 3

Chair: The Teleconference time should be around noon central US time.

**20. PAR and 5 Criteria preparation**

- Audio conference – 2nd week of August

04/628r2

PAR Title:

"PAR for IEEE 802.11 Wireless Interworking with External Networks"

◊ Scope:

This document amends the IEEE 802.11/1999 (2003 Edition) MAC and PHY to support interworking with external networks, such as 3GPP, 3GPP2, etc.

Mike Geipel: Should we mention any one of the external networks.

Chair: No, hence remove the reference to 3GPP etc.

Mike Moreton: Should we change the IEEE 802.11/1999 to reflect the IEEE 802.11i, etc?

Chair: may come back and update these words at the Berlin meeting.

Result:
“This document amends the IEEE802.11/1999 (2003 Edition) MAC and PHY to support interworking with external networks”

◊ Purpose:
The purpose of this document is to provide an interface to using the IEEE802.11 PHY/MAC layers which enables interworking with non IEEE802 networks. This document will specifically address changes required within the IEEE802.11 PHY/MAC layers to enable interworking with external network

Mike: The “provide an interface” may cause confusion. People may think it is protocol or similar things.
Floor: suspect will not involve changes to the MAC or PHY. More of a the API
Chair: Maybe some specific changes to the MAC would be possible, e.g. Beacon.
Chair: Agree to get rid of the word “PHY”

Result:
The purpose of this document is to provide an interface to the IEEE 802.11 PHY/MAC layers which enables interworking with other networks.

This document will specifically address changes required within the IEEE 802.11 MAC layers to enable interworking with other network

◊ Additional Explanatory Notes:
The scope of this project is to develop a standard for the interworking of IEEE 802.11 with external networks. It is necessary for IEEE 802.11 to create a standard, which specifies the requirements and interfaces between IEEE 802.11 and external networks, such as those found in cellular systems.

The amendment will address specific interfaces to address external authentication, authorization and accounting, together with policy enforcement and resource management.

Such interface provides interaction method between IEEE 802.11 entities and the interworked external network to achieve required security, QoS, accounting support.

The standard also specifies how the interface works with existing IEEE 802.11 functions, e.g. IEEE 802.11i, to meet the interworking requirements

Comment: To add the open issues into the second paragraph.
Comment: Will you mention AAA or RADIUS.
Chair: AAA will be OK. RADIUS will be too specific.
Eleanor: Will mention network selection.

Result:
The scope of this project is to develop a standard for the interworking of IEEE 802.11 with external networks. It is necessary for IEEE 802.11 to create a standard, which specifies the requirements and interfaces between IEEE 802.11 and external networks, such as those found in cellular systems.

The amendment will address specific interfaces to support external authentication, authorization and accounting, together with network selection, encryption, policy enforcement and resource management.

**21. Agenda for the Berlin meeting**

To discuss the PAR and 5Criteria created by the teleconference.
Start the procedure to form a TG.

# IEEE P802.11
# Wireless LANs

## Management Study Group Minutes, Portland

**Date:** July 2004

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**Wensdeay, 8-10:**

Harry Worstell announces this is a study group

Jesse Walker volunteers to be secretary for this session.

Harry reads the intellectual patent policy.

Harry explains rules for study groups. Study group will ask for an extension if the study group does not finish PAR. 75% approval needed on any subject. Attendence list required and being circulated.

Proposed agenda presented.

Motion: Approve Agenda

First: John Klein

Second: Richard Paine.

Need secretary on Thursday.

Call for proposals.

C: .11k looked at scenarios for service provider versus enterprises deployments. Each try to control their environment.

Chair: After PAR and 5 Criteria work done, we will talk about that.

Chair: Working through teleconference on PAR and 5 criteria. Need to examine it and approve it. Work due to Richard Kennedy. He will go through PAR and 5 criteria when he arrives. Document 537r03.

Most areas of PAR are boiler plate (through item 12). Item 12 begins to define scope of project. Discussion of item 12 (project scope)

C: Should we add the word “secure” to the scope clause.

Chair: We should discuss this. Some feel it is not required, but chair thinks making it explicit.

C: Rather not have it there. Security implicit in the notion of management. Putting it in doesn’t help.

Chair: This statement says what we are allowed to do and what not.

C: But if the word is not present, that doesn’t preclude you from talking about it.

Chair: That is the question. What is in the PAR and 5 Criteria is what is allowed.

C: How does .11k deal with it?

.11k Chair: Asked .11i and they said too far along, so trying to address it. Deadlocked, so will go to first letter ballot without security.

C: If you want it to be part of the scope, you should say so.

C: Based on .11k experience, that would be an error in strategy. Stalled if there is deadlock. Put it is as a side note, but don’t make it a requirement.

Chair: Item 18 is further explanation. That may be a better place to explain this.

C: Is there value for a management interface without security?

C: The TG is to do management, and security is a separate expertise. Security is a feature of management, not the goal itself.

C: Adding security after the fact is difficult and sometimes impossible to add after the fact.

C: Don’t completely agree. If there was another group that has defined a way to secure action frames, then other groups could built on it. Want to layer secure transport. We could create a new study group to secure the management transport.

Chair: Some of the .11k discussion has moved to this group. Do we need security more than .11k? This is a pertinent topic for the PAR discussion.

C: The management group needs security more than in .11k. In .11k can impose a denial-of-service. Management issues command and control messages. These cannot be compromised.

C: Agree.

Chair: Does anyone feel security is unnecessary?

C: You need a secure transport, but does that have to be part of the work of this WG?

C: Until now .11 has build management and control explicitly in the clear.

C: Concerned about different groups building different mechanisms.

Chair: A new PAR may be appropriate. It is a broader subject than .11k. It was inappropriate to delay .11i to do this. We should ask Stuart about this.

C: Security has been mentioned in WNG, and brought up with Stuart to start advisory board 6 months ago, but nothing has happened.

C: But this belongs as part of architectural discussion. Anyone can go to WNG to propose a new SG.

Chair: Would like .11i participants to go into WNG to start a new study group. If I have to deal with security, it will lengthen time needed to complete my PAR. It will help all TGs. There is still a major need.

C: An orthogonal solution that can go across all messages. For those who live in pre-.11i days, we don't want to release something that allows command and control of network.

Chair: If they started now, then might finish sooner, because all the pieces of .11i are in place.

C: There are three cases: command and control can go its own PAR or in any TG. There are also problems like reassociation, disassociation, and deauthentication that should be handled by .11r. Finally there are corner cases, like wake up.

Chair: Seems like we are getting consensus for unified approach under separate PAR. Strawpoll: How many believe this? Vote: virtually unanimous.

C: Is there not a requirement to not break existing functions?

Chair: Yes

C: But adding new command and control degrades security.

Chair: The consensus is a unified approach is needed. We state we know it is an issue, but state it should be handled by another PAR.

C: We know security is required for this application, but it is not necessary this is required from a standards perspective. This is different than WEP, because we aren't advertising we have security.

Chair: The only concern is if we make another study group or TG, will loose many participants in Management. But narrowing scope speeds standard. Enough on plate to figure out what command and control is. Is everyone happy with item 12 without a security statement?

C: One question is it explicitly identifies MAC and PHY. Why not enhancements to DS and AP?

Chair: Let me scroll to item 18. First paragraph in Item 18 attempts to define manageability.

C: But scopes says making changes to only MAC and PHY, whereas item 18 says want to control 802.11 devices.

C: in TGk it has brought up current thinking is to put management as an application, but 802.11 has never viewed the problem this way. Say MAC, PHY, and selected application.

C: This does not apply to DS.

C: DS is part of the MAC

C: This is not my understanding of the architecture.

C: Annex C defines the DS as part of the MAC.

C: Disagree. The DS was separated from the MAC so it did not need to be specified.

Chair: Added "DS" to MAC and PHY..

C: Not sure about AP

Chair: What about the link layer?

C: The standard is nebulous so we can avoid this.

Chair: There is nothing in 802.11 PAR restricting us to the MAC and PHY.

C: If you go higher, don't you begin to imply AP architecture?

Chair: Possibly. We should stay within a delimited scope and leave hooks for the rest.

C: It is better to leave it open to cover as many entities as possible.

C: Are you asking that we change the backbone?

C: Associations happen with the DS, not to a STA or an AP. When you roam you reassociate back to the DS.

C: Are you talking about distribution service or system?

C: The Distribution System provides distribution services.

C: We need to clarify what DS means if we leave it in.

C: Need to clarify what is meant.

C: The term ESS has already cause problems. DS needs to be very well defined.

C: Current standard defines DS as distribution system and explicitly does not define it, but rather defines services it provides. These services are part of the MAC. If you want the distribution services included, it is sufficient to discuss services, so including DS goes beyond the scope of current architecture.

C: It is always useful to include layers you will be working in in PAR. If we know, we should include within our scope.

C: The problem is specifics make it harder to address what you need later.

C: In 802.11k we say MAC and PHY and also say we will define interface to upper layer. Could say MAC, PHY, and selected Upper Layers

C: Would prefer to say interfaces to upper layers than upper layers itself.

C: Like suggestion to say 802.11 devices, to maintain flexibility to improve manageability of entire device.

C: add "and selected upper layer as required, to effect a complete and coherent upper layer interface"

Chair: Everyone happy with this? No complaints, so we will go with this for the time being. Anyone want to make a motion?

C: Are we really managing network or network devices? Last sentence says "managing wireless networks" which is removed from managing 802.11 interface on the device. We are talking about an interface to manage device on the network.

C: But we want to manage entire network.

C: We will provide an interface for that function.

Chair: We are not gleaning much information out. This takes the information .11k provides and does something about it.

C: All of the work is within the device. But we won't be able to effect synchronization, etc.

C: Disagree. A lot of the work is outside the devices.

C: The facilities to do device synchronization will be above the device. Like that management of networks is the goal.

C: Say network managbility.

C: We are focused on 802.11 devices, but customers focus on APs, switches, RADIUS servers, etc. We are not going to do anything about RADIUS servers. Should say wireless network devices.

C: Upper layer interfaces

C: Upgrade of software or firmware will apply to all devices and is device specific, not radio specific.

C: Try “for managing 802.11 devices in wireless networks”

C: Over the next few years we will see lots of non-laptop devices entering the market. Are they covered?

C: There will be more such devices than attended devices.

Chair: Are people happy with this language? Hereing no objection, go to item 13, “Project Purpose”

C: What is the value of the phrase “ESS-wide management”? It enables management. Whether it is in an ESS seems irrelevant.

C: There is the physical RF medium, which may be shared among different ESSes. If you don’t tak account of this, you can degrade performance for all.

C: But that isn’t relevant.

C: TGk is attempting to improve efficiency of network operation. This Purpose statement doesn’t address this.

Chair: Believe we are providing hooks for network manager to adjust the network as he sees fit, not make it more efficient.

C: Assumption was that Management would include this.

Chair: You want to broaden scope then?

C: Yes.

Chair: The problem seems that there are “multiple definitions” for “ESS” What would you like instead of “ESS”?

C: Seems like statement about manageability of large networks already says everything needed.

C: What does local and remote management mean?

<no consensus on the meaning>

C: all of the interpretations of local and remote seem fine. We need the ambiguity.

C: Are we going to allow full management of device from the wireless interface? Or do you have to manage device by crossing distribution service? Can you get to the MIB through the 802.11 interface, or do you have to access it through the distribution system.

C: This is network management enhancements.

C: But .11k is just measurements, no command and control.

C: Need an interface to allow management to effect the command and control. Is the whole mechanism on the radio side.

C: It should not matter. It should be capable of effecting command and control from any device.

C: We don’t care where the manager should be. We want to effect flexible management.

C: Want to make sure we can access interface from a wireless device.

C: Want wireless in-band management, but don’t want it to be hacked.

Chair: We have already discussed security. Consensus is a unified proposal needed developed by a new TG coming out of WNG.

Chair: Next item is boiler plate. Disccussed SNMP issues, list groups doing similar things, but none doing within 802.11. We are trying to enhance work going on in these other groups.

C: But we just extended scope to include upper layers.

Chiar: This gives us ability to do things as upper layers if needed. Move on to item 18. Additional explanatory notes. (Reads and explains current text to membership).

C: Security is a necessary feature of the management function, but it is assumed that another group will provide a unified protection scheme for 802.11 management.

C: What do we mean by another group? 802.11 group?

Chair: yes.

C: Does this preclude us from working on this if another group does not come forward?

C: Other groups like 802.11k may be working on this already.

C: Say “will become available” instead of “another group”

Chair: Change accepted. Do we need anything else added to Item 18?

Chair: Here is a time-table.

C: Return to item 18. Change “limits” to “limit”

C: What happened to boilerplate?

Chair: This is not yet the correct form. There is no way to get your hands on correct form, because it has become a web-based form. Complained to IEEE that we con’t do business this way. Plan to cut-and-paste into the form, with no changes. Will go through the process until we get this fixed. If we can approve the text, then we have a PAR.

C: Sroll down to “manageability is defined.” Does this limit us to building upon measurement, because we need to add command and control.

Chair: These are restrictions. If you don’t like wording, change it. First sentence includes word “controlling.” Perhaps you want to add something?

C: Supposed to be controls that use the measurements. Want to be able to add other measurements as required.

C: Want to build on .11k. Don’t say anything about control in that sentence.

Chair updates the document.

Chair: Ok, we have gotten through.

C: The scope clause allows selected upper applications. Is this a legal scope?

Chair: Intent is to restrict this to interface to upper layers.

C: Put in “if required” with “upper layer applications”.

C: Wasn’t management a common concern from architecture meeting.

C: Concern that language allowing work on upper layer applications will allow groups whose goal is to misue TG extract functions from 802.11 MAC instead of enhance 802.11 MAC

C: Change “as” to “if”

C: Should include language for prediction?

Recess due to orders of the day.

End Jessie Walker Meeting Minutes

WNM Meeting

Thursday 07/15/2004 (8:00 – 3:30 pm)

Harry called the meeting to order at 8:15

Secretary for the duration of this meeting will be Victoria Poncini

Harry went over Study group voting rules – requires 75% of group to approve any person can vote regardless of voting status.

Harry opened meeting with proposed agenda and presents the agenda with leaving the discussion session open

Harry: Any objection to approve agenda unanimously?

No objections.

Harry: agenda approved unanimously

No presentations to present in the morning session.

PAR is finished.

Richard Kennedy is presenting the 5 Criteria of the WNM PAR which was finished yesterday to the group.

Doc 684-000wnm

Richard Proceeds through review of the 5 Criteria document with the group.

Broad sets of applicability

No changes.

Multiple Vendors, numerous users – no comments

Only new addition

Multiple vendors from around the world have participated in the development of this PAR and 5 Criteria. (Suggested by David DJ Johnson) to amend this section.

Balanced Costs (LAN versus affected stations)

David Johnson, explained the reasons for this section of the five criteria on balanced costs

The widespread of commoditization of 802.11 wireless LAN devices yields an environment where standardized manageability of features can be deployed cheaply and efficiently.

In large deployments standardized manageability features can reduce the currently high cost of deployment and management of the network.

Compatibility

The proposed amendment shall be (shall be) was added on review.

Distinct identity

David Johnson suggestion John Klien /Marty / Pat Calhoun/ Tim Olson: final wording follows:

There exists no WLAN network management standard for 802.11 systems enabling network-wide management of wireless device. The current 802.11 standards do not address the needs of current products, such as load balancing and virtualization.

One unique solution for the problem

Okay no changes

Removed network management and added wireless network management.

Easy for document reader to select the relevant specification

It will be obvious from the title and content of the standard that it is a standard for wireless network management within 802.11.

Technical Feasibility

Demonstrated system feasibility

Network Management systems are deployed in cellular networks and in proprietary ways in 802.11 networks therefore they are demonstrably feasible.

Proven technology reasonable testing

DJ and Marty: modified the wording under this section to read:

The main components of the technology for wireless network management have precedents proving their feasibility and testing.

Confidence in Reliability

Wireless network management implementations are widely deployed and thus are widely demonstrated to have the capacity to be reliable.

Economic Feasibility

Known cost factors, reliable data

Wireless network management is an integral part of wireless communications systems. Standardizing such behavior is likely to add costs to implementations. Any additional costs will likely be insignificant.

Reasonable cost for performance

No objections to the original wording

Considerations of installation costs

The proposed wireless network management standard will typically be directly embedded in devices and will not require additional installation costs. In addition,

A standardized network management system may serve to reduce installation costs of 802.11 networks.

Kennedy reviewed the finished 5 Criteria Document

**********

Harry discussed the timing for when WNM will be a task group. Task group will likely be awarded in November.

It was announced that WNG just voted to start a new SG for Security by Emily…to address the security issues around securiting management frames.

A vote will be taken at the WLAN WG closing.

**********

Tim Olson asked about content or transport? Not a transport but agreement over the issue is content and how it is to be used.

Harry:

Bring a motion to 802.11 working group to extend the study group for another 6 months

Motion:

Move to extend the Wireless Network Management Study Group for another 6 months

Moved: Richard Kennedy

Seconded: Roger Skidmore

No discussion on the motion

Called the question

Harry: explained that the study group must be extended every 6 months and either submit a PAR & 5 Criteria or else stop.

Results: Yes 11 No 0 Abs 0

Orders of the day called at 10:06 for break.

Any objection to approve the revised agenda.

Harry presented the new motion to bring the PAR and 5 Criteria for Wireless Network Management forward in the 802.11 Working Group session.

Motion:

Move to approve document 11-04-537-04-wnmdraft par.doc and 11-04-0648-01-0wnm-draft 5 Criteria Wireless network management.doc and forward them to the IEEE 802.11 working group for approval.

Moved by Richard Paine

Seconded by Richard Kennedy

Pat Calhoun: asked if the right version on the server?

Harry: …No it was not posted. So Harry needs to post the document to the server. Vote will not be able to be taken until after 4 hours. 802.11 WG requires documents must be posted 4 hours for review before taking a vote.

YES: NO: abs

Vote Cancelled due to document posting time on server. Vote delayed until the afternoon.

Richard Paine Presentation

Doc 11-03-270-00k

Use case scenarios for RRM advised WNM to do the same thing

Detail environments and suggestions for management

Factory floor

Airplane Environment

Home/Apartment buildings

Office Buildings

VoIP

IBSS: Jesse walker wanted to know why people would deploy IBSS?

Richard: Military example, what about software AP?

Jessie: had that in mind. But he stated that he was satisfied with the application that Richard mentioned.

Richard is presenting the additional use case for 802.11k to produce the requirements

Desire was to get more and more specific about what a use case was and what exactly the measurement were.

Richard: presented working set of scenarios

- Hot spot
- Hot Zone: airports train stations, malls what measurements needed
- Multiple dwelling units: apts, townhouses, condos
- Enterprise w/rogue access point
- Ubiquitous WLAN coverage
- Non-ubiquitous WLAN coverage
- Handheld scenario: battery levels and power consumption are important criteria
- Handheld non ubiquitous scenarios
- High speed mobile environment: even in .11k neighbor report doesn't cover very high speed, but it does cover slow speed and Bernard presented doc # which explained the mobile environment and what could be covered by the neighbor report
- Airplane environment

Any questions on how 802.11k evaluated scenarios so that they could come up with scenarios. Richard stated that 802.11WNM could use the documents to come up with scenarios to create requirements document.

Harry asking if task group K could provide the scenarios they used.

Joe Kwak and Jessie suggested that Harry call the vote in TGk for sending the PAR & 5 Criteria forward.

Harry: stated that hopefully people will come to WNM meeting this afternoon to vote on sending the proposal forward to 802.11WG

Harry: asking question whether there was general or concise proposals to bring forward, Harry wanted to know whether or not we should bring forward with a general proposal that addresses all of network management? Anyone have a complete solution for network management? No one responded affirmative.

Then Harry wants individual proposals or to use the ones like the one Richard Paine presented.

Any comments on how to bring in proposals?

Richard: will present his Network Management ideas from the one presented in .11k

Harry wants to know how we are going to run the group.

Harry: Pat Calhoun if he was going to bring forth a use case,

Pat Calhoun will bring one in?

Harry: What people envision on what they want to control and derive out of this how people are going to do it.

Harry: How many are going to Germany? How many would be putting together use case for September … results were that 5 submissions would bring use case papers at the Berlin meeting

Harry: also is going to try to get Pat Calhoun to come and present CAPWAP at the meeting.

Pat Calhoun: I will present a second paper on CAPWAP.

Harry talking about service provider campus/home environment with adaptive AP's,etc.

Harry brought up issues what you believe that WNM will control?

Harry: talked to Dorthy Stanely (?) about security (she felt that no reason to having a standing committee and a study group and the same time) Harry agreed with Dorthy to leave the standing group to later and let the study group handle the security issues.

Harry: What needs to be controlled? Where they need to be controlled from?

Marty: Are we going to tackle or change the way roaming is done?

Harry: there is a group looking at fast roaming?

Marty: the station is completely in charge of the roaming decision – kinda a scared cow in 802.11? Are We going to influence the stations' decision?

Pat: talked abut the MIB is not sufficient for today's devices, Pat not sure that having the snmp manager influence roaming

RichardPaine: stated that snmp is not being used

Marty: the MIB is not the exclusive method, but one of the methods which could be used to influence the roaming decisions

Harry: some discussions MIB is not fast enough to do this? Is the MIB the right way to do this or are there other mechanisms to do this, how we going to go about it? A lot of people are already doing it, want to have companies doing it to bring in the proposals on how they are doing it.

Harry: what happens when I roam to other technologies like cellular, other groups also looking at this but 802.11 needs hooks to move not only from the station but from the manager where there may be a lot of things that must happen before the move occurs?

Richard: spectrum management, even though I don't believe in it. As WLANs become more ubiquitious spectrum management may give you more assistance than you really want.
They will remind you of the Part 15 requirements and is quite an issue for an enterprise

Being able to select the actual spectrum and manage it equivilant to load balancing

Scenario

Also if we get into the TB frequency space and system will need to adapt and manage

Marty: there is a difference between freq agility and spectrum management

Richard: worried about RFID , and needs to address spectrum management … not sure if it is a requirement for this group.

Harry: co-existence is an issue that is now raising its head between the groups with activities in that area, and can't predict where this will go in the future?

Harry: roaming, MIbs good enough, spectrum management, how do things like handoff to cellular, triggers to know when you want to move, Network management interactions need to be initated between (mobile assisted handoff) wwan and wlan networks

J: Does this model make sense in the unlicensed band?

Marty: scope for interworking?

Harry: not in scope

Marty: do we need liason to go between 802.11

Harry: 802.11 must be ready with the mechanisms to do handoff …we may need somebody from the 3gpp group to look at this

Marty: hope that 802.21 would

Harry: if 802.21 is in Germany to come in and give presentation to WNM

Marty: what about having manufacturer of multie mode phones come in and present the issues they are dealing with?

Marty: is there a difference between enterprise, home and cellular with different requirements for management of Voice,

Jessie: public access have the same or different or overlapping requirements

Harry: you have home vs enterprise vs public

Mark: Seems like what we are talking about is different from network policy? Confused defining interface between network and administrator or other lower mechanisms

Harry: network manager managing the enterprise is one scenario that should be there, but that cellular may have similar hooks that need to be there, the hotspot may be a little different

Adaptive APs which adapt to its surroundings – we are general solution for many thing and accommodate actions

Cellular, network manager and how to best accommodate all of them within

802.11

R: the majority of devices are going to need to manage themselves, what hooks that you provide

Marty: adaptive AP rules that it adapts to, or does it sniff the air and configure itself?

Marty: this AP does adapt and all around it also adapt to it

Jessie: observation – conclusion different solution for the different problem domains, mobile AP or mobile sta must have the ability to detect and adapt to the environment and do the right thing, Solutions good for one thing may not work for another? Do we want to work on the core common to everything or specific to a solution?

Marty: device needs a discovery phase in whatever we do

Mark: confused self managed doesn't need management? One of the end points is the management station and the administrator

Marty: work out of the box what it needs to know to be deployed

Harry: need to understand tthe hooks that go into the mac and phy

Klien: sees AP needs configured by management station, load balancing needs to be done in a real-time but th e configuration of load balancing and parameters for mechanism can be configured and threshold assignments should be done by the network management.

Mark: says that real-time operation is out of scope for the group.

Marty: says that you can't have real-time mechanisms unless they are defined to facilitate

Jessie: how you read this is a closed loop mechanism,

Tim: we need to assume that we are creating some functionality there are things that need to be defined for load balancing…go to next closest AP,etc blah

Use network management looking to load some parameters to manage devices, and improve the operations of WLAN?

Jessi: do we need to change the PAR?

Tim: I just want to be able to provision the configuration and update the firmware, but not dealing with roaming and load balancing

Harry: wants the group to define where are our limits? Need more to create value add?

Klien: things that controlling and shaping the spectrum is in PAR and need to do real-time things and are not limited to just configuration? One of the broad goalls of the group so that the WLAN will work better than it does today…through some control mechanisms would work better

Marty: we don't want to define a load-balancing algorithm but want the mechanism in there so that both sides could see this

Harry PAR is R5: Harry brought up the PAR definition and asked if it covered Tim's question.

Klien: if we have requirements before .11k finishes then WNM will add measure ments when required

Harry: said that WNM do management and do measurements if we have to but won't do it as long as .11k has the ability to do it.

Harry is trying to have group have a discussion on what manageability is and how we are going to accomplish this.

Harry will compile from his notes and the meeting notes to see what applications are needed. Not writing applications, and algorithms, but what issues are so that hooks can be put in so that it is flexible and people can do what they need to over the wireless networks?

Harry: anyone have anymore scenarios enterprise scenarios, airplanes scenarios with no wireless lan experts to, load balancing –Marty, ? Any more?

Harry: good time to break for lunch? Come back after lunch to hear more ideas from other people? Think about writing some papers and bringing them in to move this forward?

H: afternoon, work on scenarios…around 3:15-3:30 will have the vote for the PAR and 5 Criteria so that we can move forward? Suggestions on how to move forward please bring forward,

Marty: moved that we recess early

Harry any objection? NO objections to adjourning early.

Harry adjourned the meeting at 12:08.

Harry: opened the afternoon session at 1:30pm by his watch.

Harry ran through the completed items on the agenda

Harry discussed the results that people are going to present case scenarios for network management for next meeting.

Harry mentioned that 802.11 does not have the hooks to do management from an external entity. Nothing from an upper layer down to manage your wireless network.

Other people want to handle roaming in fast manner, even though there is another group looking at it,

For control need to add mechanism in a timely manner

Spectrum management and have 802.21 come in and give presentation to the WNM group.

Scenarios of auto configuration of AP themselves would be an application where the AP ran this themselves, but WNM would still need to have the hooks

Marty/Richard/Harry: that finding location would this be important…FCC may put 911 regulations on companies deploying VoIP and we would need locations based activities.

Harry: More ideas? For Network Management…what does it mean to you?

Harry would consolidate these and put together some scenarios which could take advantage of this function. It shouldn't be limited to enterprise could be used in home networks and hot spots.

Victoria: sensor overlay network….and having network management system that would reconcile

It could be access port or a dedicated device. But would also like to see receive only

802.11k will not be providing this feature

Bob: can use WNM to make cognitive radio (localized intelligence) at the radio and a coordinated intelligence that would be residing at a higher level

Cognitive radio with 802.11k could provide spectrum management and then have a centralized intelligence for the coordination function.

Harry: not sure how to do this

Bob: says using the sensors can simulate cognitive radio.

Roger: Centralized intelligence can override the localized intelligence … have all the information available to the centralized

Harry: example go from autoconfiguration and then shut off for a time and go to centralized intelligence for management.

Bob: localized implies you don't corrupt the spectrum, works with FCC new view of what unlicensed, also if localized belong to group and can coordinate

Unusual that local radios can optimized global with centeralized management

Roger: there are really three levels here: localized, distributed and centralized coordination

Harry: cognitive radio: may be other frequency bands that you can be configured to use them, have the devices look around to see what available and then have the management station tell the devices to move back down to the other frequency. We currently have multi-band cards with receivers on them that can use different front end but can change to another frequency.

Roger: thinking about the roaming question, possible to set up roaming thresholds.

Harry: key to what we do is to have the ability to go in and set these thresholds.

Roger: when to begin the association and reassociation process

Harry: and Load balancing

Roger Durand: in order to do load balancing you must be able to control the client

Harry: many people feel that the client is the determining factor as to when they move others want the AP to have some control of moving, or to have both

Roger: the client does it today…you are thinking about some type of trigging mechanism

Bob: the client has to because it is in the know

Harry: having intelligence to go down and determine what it needs to know but you still need to have the ability to direct the client to where they are going, what power they are using,

Yaron: Upper layer hooks, layer 2 needs to know why don't we define upper layer hooks and the 802.11 in the management scenarios

Harry: No conclusion as to how far up we go into the upper layers that IEEE works in the MAC and PHY layer, but don't generally go up a level to do that. Given that we are in an area which is new territory, we can go ahead and there needs to be a lot of thought on this. SNMP may not be the only way of doing network management, and we may need to make other hooks to allow for the management needs required for 802.11 systems.

Harry: we can continue the teleconferences and continue the discussions need to get something down on paper, we are going to spend time understanding the scenarios and interfaces to come up with the information

Mike Pellcheck(?): wake on LAN related to network management…managers like to use wake-on lan related to laptops , but the wired wake-on-LAN doesn't totally fit the wireless requirements, but need to define the hooks and special requirement needed for 802.11 devices

Harry: says this does apply to wake-on-LAN/WLAN can be either in our discussions where an AP comes in and wakes you up.Power save is always and issue even with desk tops. Harry asked Mike to present something.

Mike: may be in Berlin and will prepare something for presentation

Harry wants to elaborate on the current list:

Load Balancing what do we need in the area of hooks within the 802.11 netowrks

Charles: need an indication from the AP to the client of what the load is rather than having the client have to guessing The QBSS element in 802.11e but has been removed and is needed, could be in the beacon but something that is on the AP

Roger: Need a common metric

Charles: that is what the work entails, defining what that load metric would be

Merman Rudoldf: Loading of the bss that was discussed in .11k

Harry: said there is overlap because the measurements .11k are doing are needed for WNM is needed here. The .11k people also want to work on the management

Harry: we will not put in new measurements in WNM unless .11k is finished .11k is looking at what measurements are needed from the mac and phy and in here what hooks do we need

Merman Rudoldf: load indication is very much needed, seemed that there was some resistance to the idea in .11k that loading is needed?

Harry: thinks that 11k is needed but didn't know how to do

Charles: It needs to be in .11k but is TBD

Harry: we will put your comments in this is a brain storming session so it will be put in for discussion in WMN

Richard: needs to be a very general mechanism that tells clients when to move (for load balancing)

Harry: where does it need to be in client AP or both

Richard: needs to be in both

Merman Rudoldf: maybe more of an admission control, AP could force certain stations to go over to another AP

Richard: the application will use it but we won't be defining the applications but we will neeed to provide the mechanisms

Harry: Marty could be associated with more than one AP at a time

Sounds like Fast Roaming

Harry: what do you do when you have time bounded traffic? This is clearly a fast roaming issue they are going to take care of it 802.11r

Merman Rudoldlf: will this be handled in 802.11r

Clint: some one doing a presentation with rebuttal this afternoon, yes this is in scope for 802.11r

Harry: what about location, Richard talks about the Boeing building locatons

Merman: mentioned about 911 requirement, location and 911 must come together

Harry: Location needs within 802.11

Richard: location is a requirement

Joe levey: now that mimo will be reality in 802.11n, location will be needed to be delt with in 802.11n. This group can float this requirement to 802.11n

Harry: it does apply to 802.11n, but doesn't mean we can't look at it here

Joe pel: training sequences in the mimo phy portions will make locations services important

Harry: .11n needs to determine platform before location

Roger: location RF Path loss information enabled in 11k, another is antenna information from 802.11n but we don't have phase control or time control

Harry: phase and time control is coming think about overlapping cells where the AP's time share

Roger: I can see a multi phased environment but not time

Harry: what if you can do your timing across the backbone using UTC

Roger: need time info

Harry: or the ability to do time offset to do your timing

Harry: Neils APs do triangulation; we could also do directional arrival, and would be good for 802.11n

Harry: there will be mimo's in regular 802.11 devices

Merman Rudoldf: should we keep the door open for certain antenna measurement techniques

Harry: what we need is someone to present how this would work and how fits into the standard, with the different antenna techniques, lets get the max in we can to accommodate the maximum scenarios, how you implement it makes your

Implementation unique…GPS is not likely indoors, but there are companies looking at GPS location within buildings, we need someone to come in and share there experiences

Yaron: Time Domain synchronizing (like a TDD) be between AP's would this be included

Harry: yes this would be SDMA

Yaron: what is SDMA
Neils: 802.11n Mimo can be used for some other arrival SDMA transmission can be at the same time but because the antennas can be transmitting out of the two separate antennae?

Harry: not mimo, but each of the antennas can share and coordinate share the transmission space

Harry: Interfaces to the upper layers should be discussed. Whether use MIB's or some other mechanism, some people think that MIB's aren't timely enough a mechanism, Yaron had brought up the interfaces what does this mean?

Yaron: start to make a decision to roam needs a lot of information (load, hook from the type of application currently running: VoIP will not roam, but doing ftp or browsing then easier to do the roaming) he does not think it should be SNMP when was the last frame, application sensitive for jitter, or roaming help make a better decision, timestamps

Harry: .11k is working on timestamps, number of clients are unresolved at this time .11k is going a little early to letter ballot.

Harry: has no metric set up to determine the quality of the data that is being reported.

Joe ?? 802.21 group will be looking at interfaces between the upper layers and talks to the example that was just mentioned…someone having a voice over IP session running and making the determination to roam.

Harry: 802.11n may be a different animal and may become a stand alone group. 802.11n will be touching the MAC and PHY

JOE: 802.21 only focusing on requirements this week, output will be an updated set of requirements and some use cases as to what it will handle in the first phase and what will happen in the next phase and they are also looking at network management

Harry: anybody is welcome to stay to vote on the PAR and 5 criteria

BoB: 802.21 was asking 802.11n what it needs of it?

Harry: looking to 802.21 to give us a framework to work to, but because they are in early phase they are looking and we need to have close cooperation and some joint meetings between the groups. Need cross fertilization between the group. Harry going to promote this? Mike is here – what do you think of the wake on wLAN, what do you envision

Mike: outlined presentation to WNG what some of the issues: main some ambiguities as how it works in wired and how those would translate into wireless, and doesn't know if could add some extra elements to handle it, or whether it could be done as a best practices type Document: was presented at Orlando

Harry or Mike will look up and send out on the reflector for the group to review document number 388-00.

Richard: stated that the documents have been up on the server for 3hours and 04 minutes

Harry:

Motion:

Move to approve document 11-04-0537-05-0wnm draftpar.doc and 11-04-0684-01-0wnm-draft 5 criteria wireless network management.doc and forward them to the IEEE 802.11 working group for approval.

Moved: Richard Kennedy

Second: Clint

Results: YES: NO: Abs

Clint offering friendly amendment.. to change the wording of the proposed motion

Move to approve document 11-04-0537-05-0wnm draftpar.doc with the following change: change all instances of 802.11k to IEEE 802.11TGk and approve and 11-04-0684-01-0wnm-draft 5 criteria wireless network management.doc and forward them to the IEEE 802.11 working group for approval.

Harry: reread the changes proposed by Clint. And asked, Is there any objection to accepting the change?

Hearing no objections

No discussion

Any objection to call question

Question called

Motion presented.

Harry read the motion:

Move to approve document 11-04-0537-05-0wnm draftpar.doc with the following change: change all instances of 802.11k to IEEE 802.11TGk and approve and 11-04-0684-01-0wnm-draft 5 criteria wireless network management.doc and forward them to the IEEE 802.11 working group for approval.

Harry: All participants of the study group can vote.

Yes: 23 No: 0 abs: 4

Henry??: In the WMN PAR references 802.11k should you mention that? Anyone who looks the PAR can't look at 802.11k and the timing of this as to where .11k is at. Had the same issue with TGr and r was postponed, the stated date is December 5, 2005 and we've stated we dependent on .11k also concerned about the time to do the work, and he is worried about the same people in .11k will be in WMN. Worried about the ability of people to do the work?

Harry: we are not dependent on .11k and Harry has the ability to ensure that the schedules do not overlap between the two groups. When work for .11k required, the study group was postponed.

The proper wording should be the TGk and does not have the appropriate reference.

Harry: said that we can put it through and then make editorial comments

Harry: a lot of it is how you plan the work and manage the meetings.

Henry: still concerned but question answered and sees your point.

Harry: stated that we've now completed the study group activities

Charles: Teleconference times?

Harry: Thursday 12:00 continue on with teleconferences? And if so when?

What is a good time?

Carry on conference calls? Wanted at most only one.

He would prefer not to have teleconferences until the next meeting period.

The group agreed that no teleconferences would be held between July and September Berlin Meeting.

Mike moved to adjourn the meeting

Joe levey seconded

Meeting adjuroned.

End Victoria Poncini Meeting minutes.

Attendance List from July 15, 2004 Morning session:

Richard Kennedy

Victoria Poncini

Roger Skidmore

Veera Anantha

Sebastien Dure

Wayne Allen

Mariko Yoshida

Jim Wendt

Burak Baysal

Patrick Mourot

David ‘DJ’ Johnson

Marty Lefkowltz

Pat Calhoun

Tim Olson

Marian Fudoy

Katsuhiko Yamada

**IEEE P802.11**
**Wireless LANs**

# Minutes of Wireless LAN Next Generation Standing Committee Meeting

**Date:** July 10th-16th, 2004

**Contact:** E Hepworth
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**Abstract**

Minutes of WNG SC meetings held during the IEEE 802 Plenary meeting in Portland, Or from July 10th-16th, 2004.

## 1. Executive Summary:

1. MMAC Briefing: providing an overview of the current work on going within this forum
2. Cooperative Transmission Schemes: summarizing the results of the Romantiq EU project
3. XG Communications Program Overview: highlighting results from a DARPA workshop in June
4. TV Spectrum Reuse: providing updates to the information presented in May
5. Access Point Functions and Behaviors: presenting possible functions and ways forward for the AP functions activity
6. Management Frame Protection Study Group Request: requesting formation of a new SG to look at management frame protection issues.

## Afternoon Session Tuesday 16:00-18:00

## 2. Logistics

WNG Meeting called to order by TK Tan (Philips) at 16:00.

The objectives of the session were reviewed.

The IEEE 802 & IEEE 802.11 Policies and Rules were reviewed.
Patents and By-laws read out by TK Tan, together with licensing terms and associated conditions.

There are 4 sessions, 2 on Tuesday 13th July 2004 and 2 on Thursday 15th July 2004.

The agenda was reviewed (**755r0**), no updates were required. It was requested that the document numbers be added to the agenda documents for information.

The minutes from the Orlando 2004 meeting (**635r0**) were reviewed. There was no discussion on the minutes and no objection to approve as presented.

Move to accept minutes: TK Tan, seconded: Bruce Kraemer, minutes approved unanimously

**3. MMAC Update July 2004: 791r1, Yasuhiko Inoue**

The presentation provided an overview of the current status of activities within MMAC, and future planned work items. Changes to the organization of MMAC (from Council to Forum) were highlighted along with an overview of the current internal structure. Future work includes allocation of new frequency bands to support the 802.11n standard.

Question from floor (slide 3): will there be a public enquiry for the allocation of new frequency band 5.470-5.725 GHz
Answer: Yes, there will be a public enquiry. The information council has recommended use, and technical requirements will be submitted to MPDHPT in October 2004, and changes may occur one year after that.

Question from floor: is there a possibility of a wider allocation?
Answer: that would be hard, and is not currently on the roadmap. This item may be in scope of a new MMAC working group.

A presentation regarding Korean Spectrum Policy Updates was scheduled on the agenda; however the speaker was unable to attend the WNG session. The slides are available on the server, document number 783r0.

**4. Cooperative Transmission Schemes for Capacity Increases in 3G and Beyond Wireless Systems: 797r0, Josep Vidal**

The presentation outlined the on-going work and results from the Romatiq project funded by the EU commission. The focus of this project was to study what gains could be made using cooperative transmission in wireless networks, where a cooperative network consists of a set of terminals that cooperate to improve quality of transmission and reduce the effects of path loss and/or shadowing i.e. by providing relaying services.

Question from floor (slide 13): Why is the value Mx2N
Answer: the 2N comes from the use of two timeslots in a TDD system.

Question from floor (slide 20): Doesn't the multi-hop relay approach drain other people's batteries?
Answer: of course, but the relay may be a laptop, in which case battery use is not so much of a concern.

Question from floor: are you assuming licensed or unlicensed bands?
Answer: assuming licensed, within framework of UMTS or WLAN TDD

Question from floor (slide 42): is synchronization an issue for cooperative schemes when using space time channels?
Answer: Synchronization is not important because you can consider the receipt of two transmissions as being the same as multi-path propagation.
Question from floor: for CDMA this in understandable, but can TDMA be recovered in this way?
Answer: if the delay is longer than one symbol then this is possible
Question from floor: In practice, would you buffer all soft decisions out of the equalizer to handle this?
Answer: Yes – this is not any different to any other communication system

Question from floor: if the relays are moving, what impacts does this have on capacity?
Answer: this was not studied within the scope of this project

Question from floor: would you expect similar improvements with other access control algorithms, e.g. FDMA
Answer: yes you can expect similar results
Question from floor: is this even true for CDMA?
Answer: it is possible but with the limitation that you cannot transmit and receive on same frequency at same time

Question from floor: (in response to previous comments that all frames are relayed regardless of whether they are corrupt or not) another method would be for relays not to forward incorrect frames.
Answer: yes, you could filter on CRC, but for some reason (that the project couldn't explain) they observed that if the number of errors is low it is good to retransmit al frames anyway.

Question from floor: 3GPP considered a similar scheme for 3G cellular systems (ODMA). Was this considered?
Answer: ODMA was dropped by 3GPP and was not considered further within the project.

Question from floor: were the issues of delay and QoS a consideration for the system design?
Answer: there was not enough time for the project to consider these issues.
Question from floor: so the decision to consider only one relay was not based on QoS considerations?
Answer: The project did not consider more that two hops, but Telenor have developed a full simulator for ODMA to consider multi-hop issues but they are only looking at best effort. With two hops it is feasible and simpler to manage QoS, it gets much harder with multiple hops.

Question from floor: did you consider security implications
Answer: no

Question from floor: Are there any delay or jitter implications from using a relay?
Answer: Up to now, every unit is only involved in relaying a single transmission, so it's not an issue yet.

Session adjourned.

**Evening Session Tuesday 19:30-21:30**

Meeting called to order at 19:35.

**5. XG Communications Program Overview: 697r1, Peter Ecclesine**
The presentation summarized the results of the DARPA workshop on June 30th. Peter began by drawing attention to the list of references at the end of the slide set, which cover the architecture, vision and policy of the next generation of DARPA communications.

The key issue is how to enable the reuse of spectrum without conflicting with primary users and their operation, and how to regulate software radios and their co-existence. One conclusion of the meeting was that it is recognized by the FCC and other regulatory bodies that there needs to be some way to trace software radio downloads and ensure that such downloads have safe behavior.

Question from the floor: how should the IEEE prepare for this?
Answer: near term need to take back to regulators and companies that there are ways forward for use of spectrum and development of new behavior that do not lock down spectrum and allocations. We need to respect licenses granted in the past, but also allow sharing of this spectrum for new uses.

Question from the floor: with regard to the "policy reasoner" (slide 6), the possible use of a clipper chip to implement this functionality implies a closed solution, but doesn't this need to be upgradeable to support for example, policy changes?
Answer: yes, this has to be future proof and this is a work in progress. We also need to persuade regulators that their current approach will not be useful in future.

**6. Wireless Network Operation in the TV Bands Update: 803r0, Barry O'Mahony**
Presented updates from the original information presented at the May meeting to reflect new rules that have been released regarding new proposal for unlicensed operation in channel not locally used by licensed TV stations, and new guidelines to prevent interference to unlicensed devices. The schedule

for providing comments on these guidelines was also highlighted, with comments due at the start of September 2004.

Session recessed.

**Morning Session Thursday 15th July 2004, 08:00-10:00**

Meeting called to order at 08:00

**7. Access Point Functions and Behaviors**

**7.1. AP functions for IP Broadcasting: 700r3, Jongtaek Oh**

Presented a new approach to support IP broadcasting services where broadcast traffic is sent to the IP address of the AP, which then broadcasts the information to all STAs in range. The AP matches incoming packets to a set of filters (destination IP address, protocol number), and if the packet is determined to be part of a broadcast service, the IP address is translated to the broadcast IP address, and the packet is broadcasted to all terminals. To prevent broadcast of information into cells with no interested STAs, a subscriber service is introduced to enhance efficiency.

The additional functions that would be required in the AP to support this service were highlighted, along with further standardization work that would be required.

Question from the floor: what are the advantages of providing this service at layer 2 instead of layer 3?
Answer: the solution is much simpler in terms of requirements on the terminal
Comment from the floor: but it does require more state in the APs. In addition, this solution only works in wireless environment, and would not be applicable to wired situations.
Response: this is only that start of this work, work needs to be done to define exact process and protocols.

Comment from the floor: still can't see the advantage of this approach over current L3 solutions.

Comment from the floor: you suggested the use of IPsec for securing this service, IPsec will not protect multicast/broadcast traffic. It was designed for unicast only.
Reply: Only suggesting the use of IPsec between server and AP where the traffic is unicast
Comment from the floor: If you want any value from the security, it has to be end-to-end.

Comment from the floor: the scenario on slide 22 looks like something the WAVE group might be interested in, perhaps you should go along and see if this is the case.

Comment from the floor: the purpose of the AP function SG is to describe existing behavior, not introduce new functions. As such, this work is not in scope.

**7.2. AP Function Classification and Requirements: 692r0, Cheng Hong**

This presented some initial thoughts on classification and grouping of AP functions, and possible approaches for how to approach this problem. It was also suggested that the ability to enable/disable functions in the AC might be useful to allow interoperability between ACs and APs that have assumed different functional splits.

Comment from the floor: please bring this work to the new study group. We need to make sure we balance describing the old functionality without defining too many new ones.

Comment from the floor: the figure on the last slide is very useful, and similar things would be useful in other groups, especially TGe.

**7.3. AP Architecture Changes: 738r0, Mike Moreton**

This presentation highlighted the changes to the AP architecture that were defined by TGi to integrate the 802.1X standard into 802.11. Changes included introducing the concept of logical ports, access to which can be controlled based on whether the STA in authenticated or not.

An issue related to how to securely fit multicast/broadcast services into the architecture was also raised, with reference to a couple of solutions that could used to secure such services.

Comment from the floor: on the issue as to how to support multicast services, prefer the first approach (where you have a single logical port for multicast/broadcast traffic) but appreciate the fact that 802.1D spanning trees and multicast addresses are alien concepts to each other. This seems to raise a more fundamental issue that should be addressed.

Comment from the floor: earlier in the presentation you raised the question as to whether an AP typically includes 802.1D bridging. The answer is yes, it usually does, but this typically falls within the logical concept of the DS.

**8. Management Frame Protection Study Group Request: 814r1/r2, Emily Qi**

This presentation raised a request to form a new Study Group to look at security for management frames, and provided justification as to why such a group would be needed. TGi defined mechanisms to secure data frames, but a need has been identified in other groups, such as TGk and WNM SG that protection of management frames is also needed. The principle reason is that having a single group to develop and co-ordinate a solution between different TGs with management frame security requirements would lead to a better and more cohesive solution, and would allow other groups to focus on the main issue they are chartered to solve without being side-tracked by the security problems.

Motion reads “Move that the WNG SC recommends that the IEEE 802.11 WG form a study group to determine how to formally describe the 802.11 management frame protection functions and behaviors, with the intent to create a PAR and five criteria to form a new task group.”

Moved: Emily Qi
Seconded: Jon Edney

Question from the floor: a couple of meetings ago we passed a motion to form a security SC, but this doesn’t seem to have materialized. Would the SC help address this problem?

Answer: haven’t checked the status of the SC, but we ought to do so. The reason or raising this motion is in direct response to a discussion within the WNM SG and from informal discussions with TGk. Both these groups want a solution, but also want to progress the work they were set up to address.

Comment from floor: As far as I can tell, the security SC cannot write standards, but could only propose text that is picked up by other groups. At the moment there is a need to develop a solution that is coordinated across multiple TGs, we need one coherent way to move forward.

Comment from floor: the SC was more of a last resort, because there didn’t seem to be any other group able to deal with these issues. It also provides a forum for security experts to work on these security issues and come up with solutions that are not last minute solutions, and also do not interfere with the progress of the other TGs.

Comment from floor: having a single group addressing these issues also allows input to be taken from other 802 groups considering security architectures and infrastructure.

Question from floor: should this run in addition to the security SC. Would rather see a single place for these issues.
Answer: need to discuss this with Stuart.

Comment from floor: are we formally saying that we want to withdraw the recommendation for a security SC? Also, what about timing issues where we can't reference a standard that hasn't been published yet. TGk would not have a security solution until TGk and any new TG completes. This is why it might be worth TGk continuing with their security discussions.

Comment from floor: TGk has a specific security requirement in measurements, there is a more general requirement that needs to be addressed.

Comment from floor: if leave TGk measurements in the clear, then the system is opened up to a few more DoS attacks, but there is no opportunity for other types of attack. The WNM group has a much clearer need for such security because they will be managing and controlling the network.

Question from floor: should control frames also be in scope?

Friendly amendment made to motion to include control frames.

Comment from floor: RTS and CTS also need to be seem by other APs, isn't this a really tricky trust model?
Answer: we've only agreed to look at it – not necessarily do anything.

Friendly amendment to motion: to determine is a bit strong, changed to examine.

Motion now reads: "Move that the WNG SC recommends that the IEEE 802.11 WG form a study group to examine how to formally describe the 802.11 management frame and control frame protection functions and behaviors, with the intent to create a PAR and five criteria to form a new task group."

Question from floor: should we also include data frames? For example to address multicast issues?
Answer: we don't want to turn this into a security maintenance group, so this should be excluded from the scope.

Results: 45, 0, 1

Motion to adjourn session, no objections.

Session adjourned.

# APPENDIX C

US007415074B2

(12) **United States Patent**
**Seto et al.**

(10) **Patent No.: US 7,415,074 B2**
(45) **Date of Patent: Aug. 19, 2008**

(54) **MIMO TRANSMISSION AND RECEPTION METHODS AND DEVICES**

(75) Inventors: **Ichiro Seto**, Fuchu (JP); **Tsuguhide Aoki**, Kawasaki (JP); **Hiroshi Yoshida**, Yokohama (JP)

(73) Assignee: **Kabushiki Kaisha Toshiba**, Tokyo (JP)

( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 647 days.

(21) Appl. No.: **11/016,808**

(22) Filed: **Dec. 21, 2004**

(65) **Prior Publication Data**

US 2005/0163244 A1 Jul. 28, 2005

(30) **Foreign Application Priority Data**

Jan. 9, 2004 (JP) ..... 2004-004848

(51) **Int. Cl.**
***H04K 1/10*** (2006.01)
***H04L 27/28*** (2006.01)
***H04L 1/02*** (2006.01)
***H04B 7/02*** (2006.01)

(52) **U.S. Cl.** ..... **375/260**; 375/267

(58) **Field of Classification Search** ..... None
See application file for complete search history.

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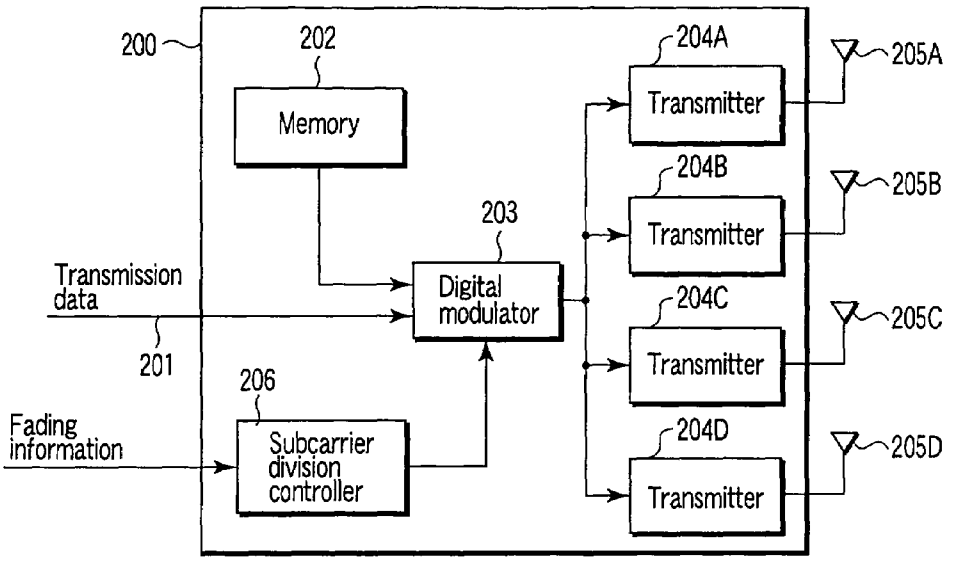
* cited by examiner

*Primary Examiner*—Shuwang Liu
*Assistant Examiner*—Gina McKie
(74) *Attorney, Agent, or Firm*—Oblon, Spivak, McClelland, Maier & Neustadt, P.C.

(57) **ABSTRACT**

In a wireless transmitting device which performs transmission by an OFDM using a plurality of subcarriers orthogonal to each other, a plurality of preambles to which a plurality of different subcarrier groups selected from a plurality of subcarriers within an OFDM signal band are allocated are transmitted by using a plurality of transmit antennas, and data is transmitted by using the antennas after the preambles are transmitted.

**4 Claims, 11 Drawing Sheets**



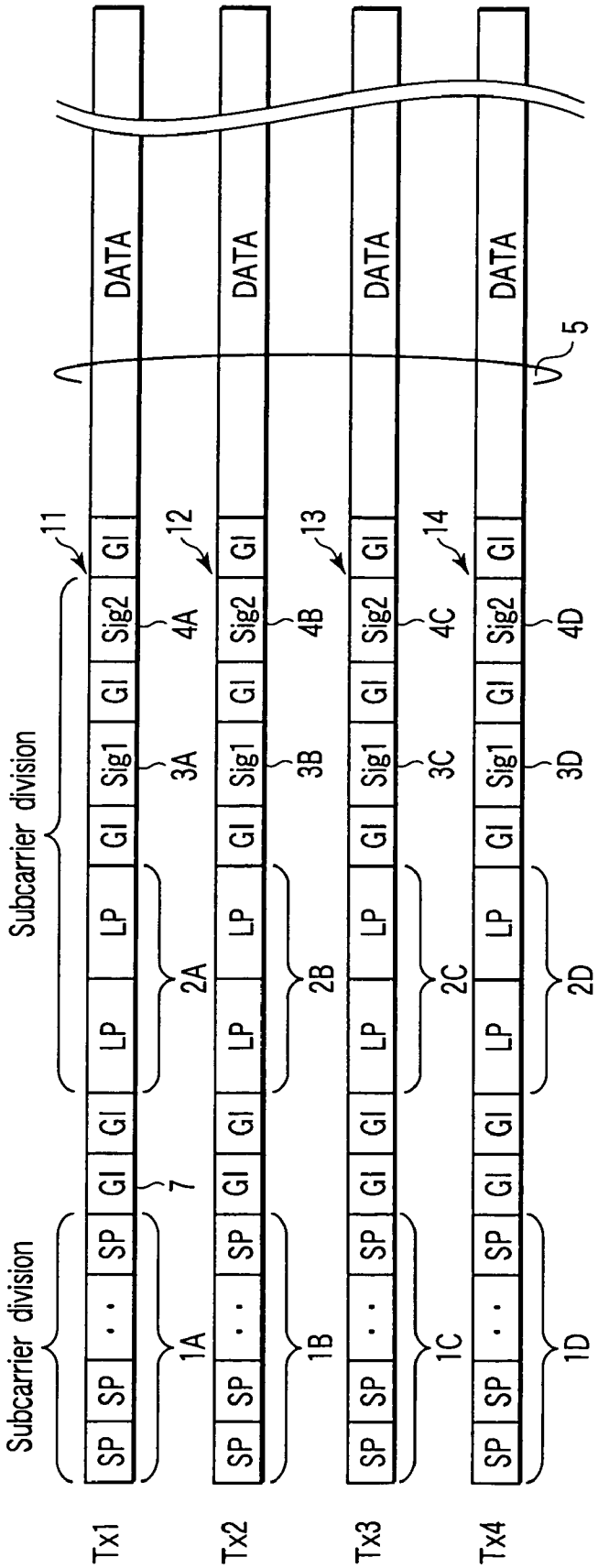

Tx1
Tx2
Tx3
Tx4
Subcarrier division
Subcarrier division
SP
GI
LP
Sig1
Sig2
DATA
1A
1B
1C
1D
2A
2B
2C
2D
3A
3B
3C
3D
4A
4B
4C
4D
5
7
11
12
13
14

FIG. 1

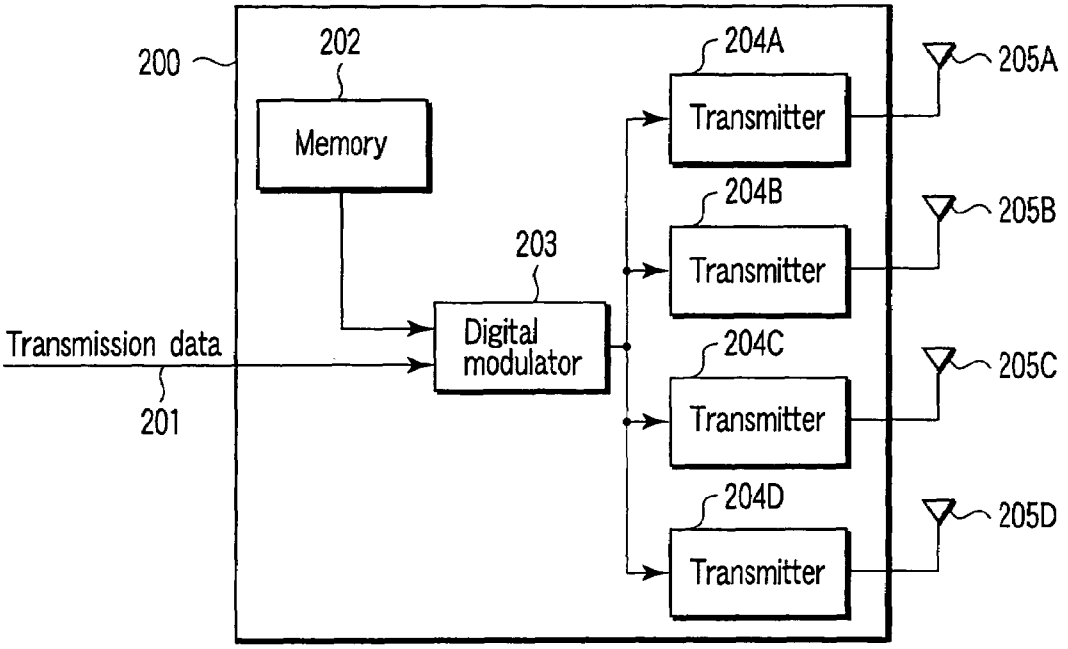

200
202
Memory
203
Digital modulator
Transmission data
201
204A
Transmitter
204B
Transmitter
204C
Transmitter
204D
Transmitter
205A
205B
205C
205D

FIG. 2

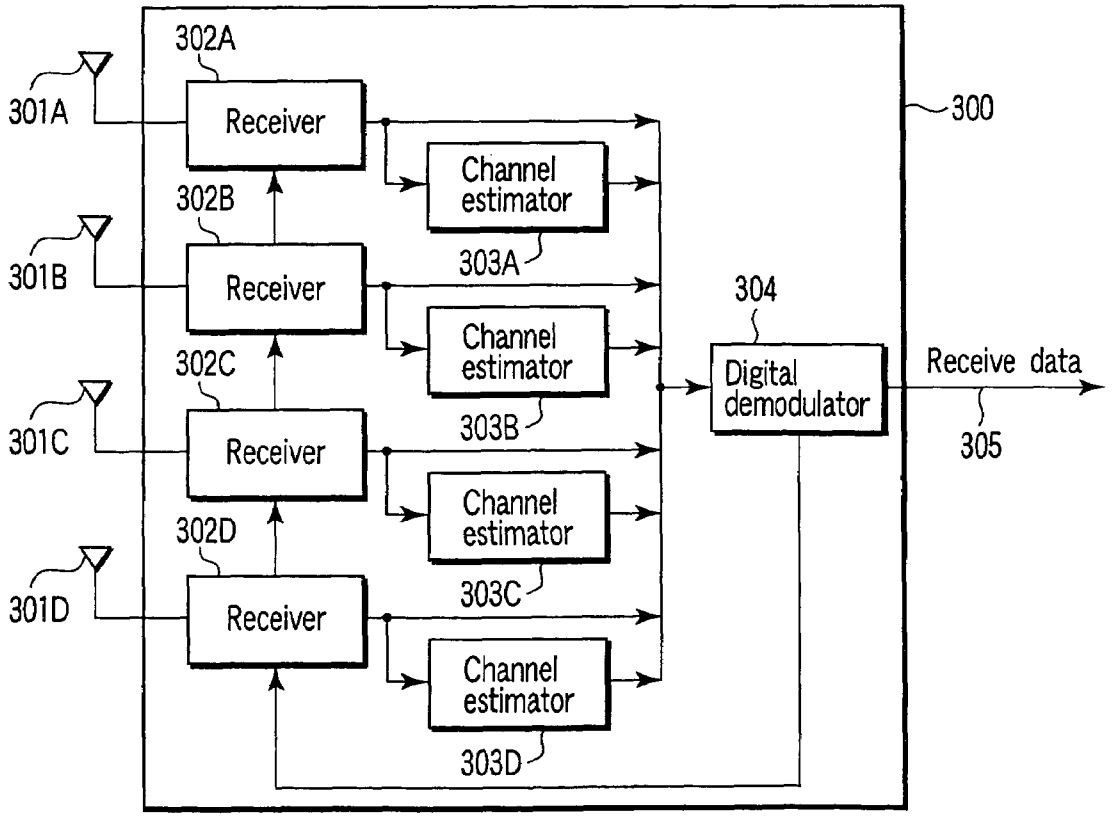

302A
301A
Receiver
Channel estimator
303A
302B
301B
Receiver
Channel estimator
303B
302C
301C
Receiver
Channel estimator
303C
302D
301D
Receiver
Channel estimator
303D
300
304
Digital demodulator
Receive data
305

FIG. 3

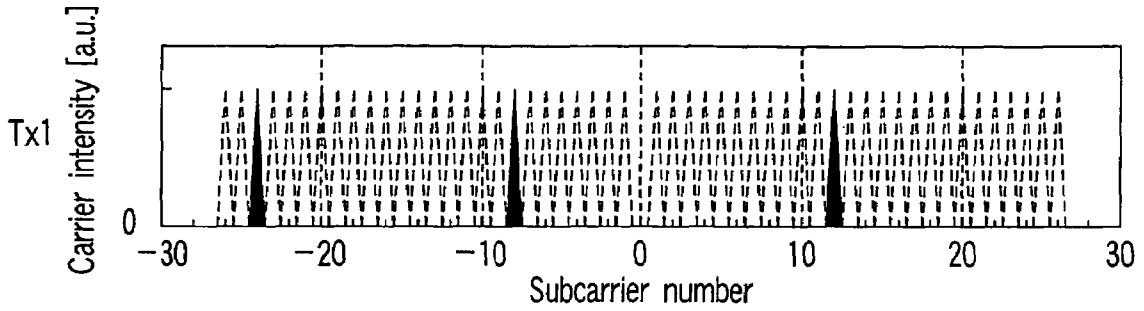



FIG. 4A

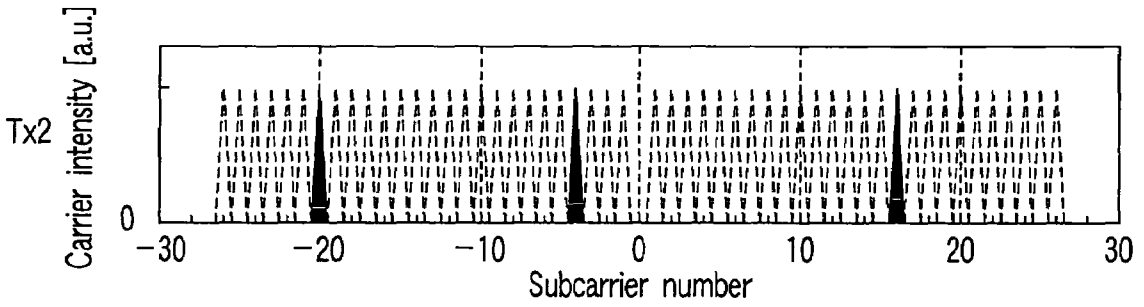



FIG. 4B

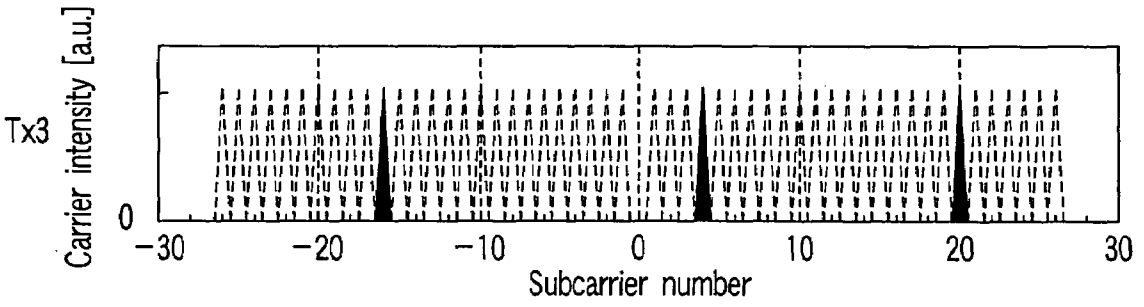



FIG. 4C

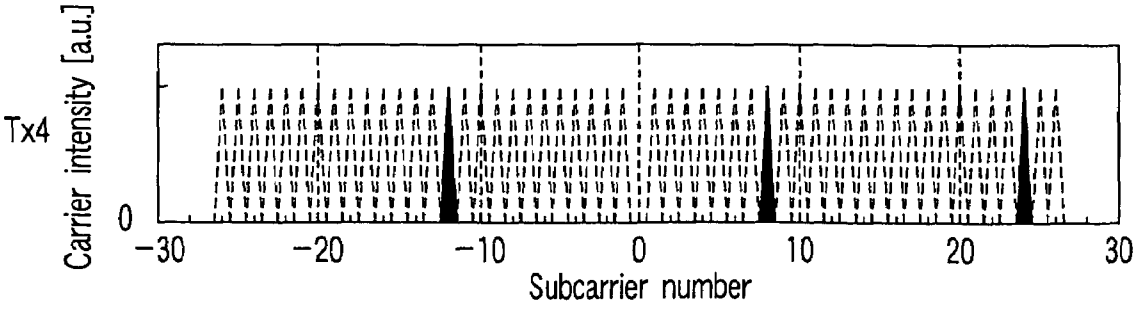



FIG. 4D

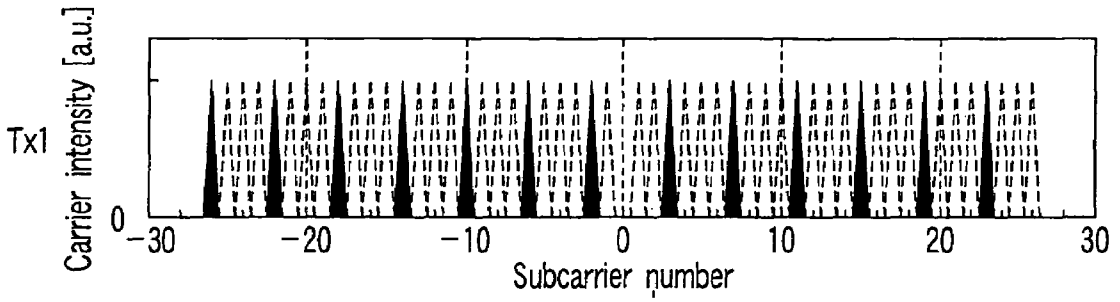



FIG. 5A

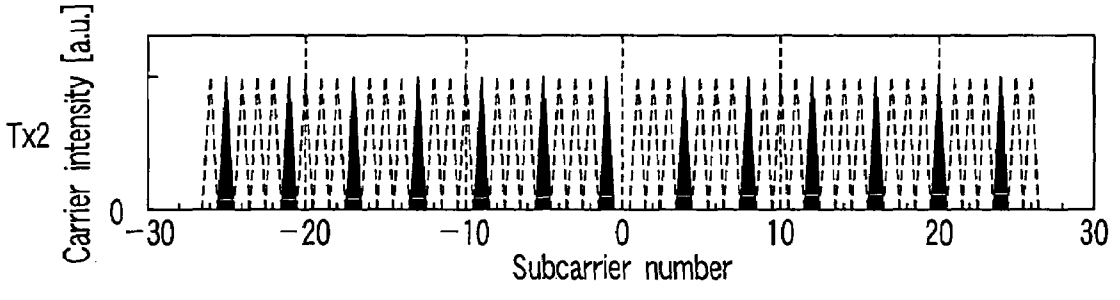



FIG. 5B

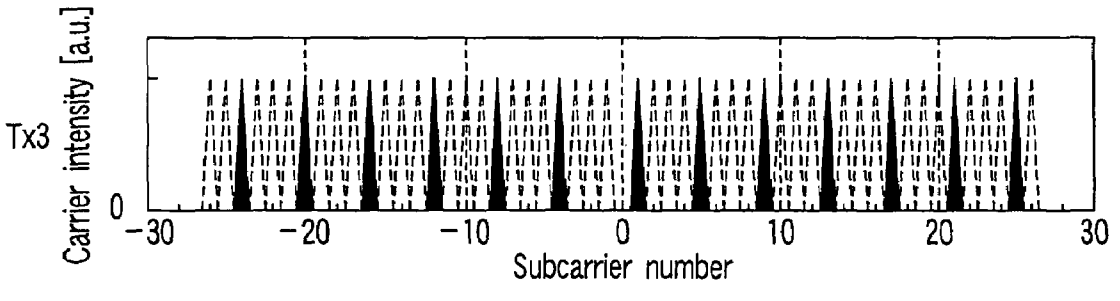



FIG. 5C

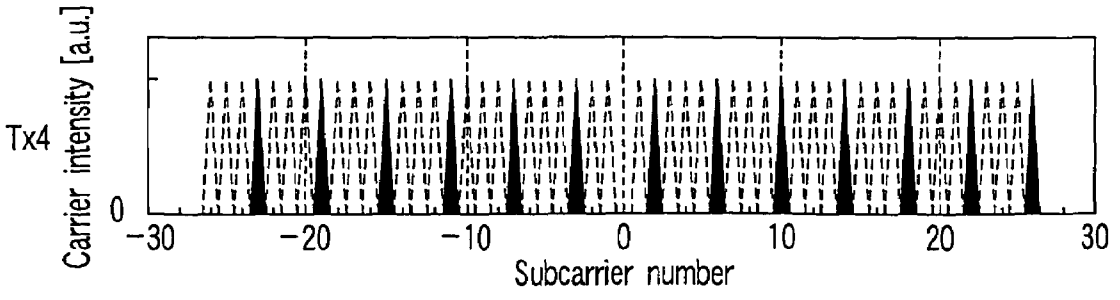



FIG. 5D

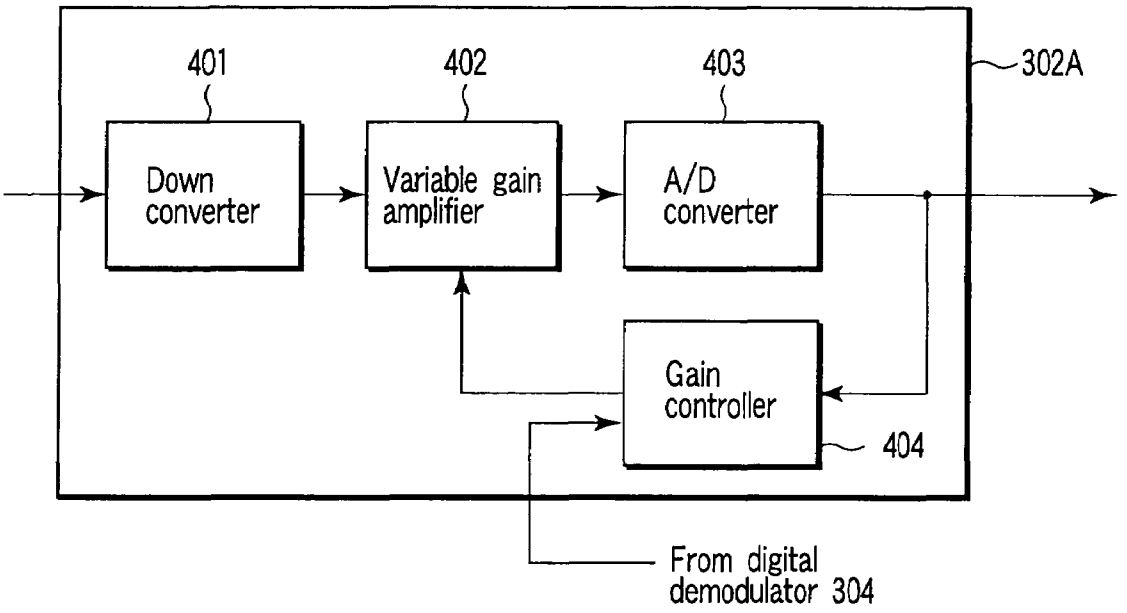

401
402
403
302A
Down converter
Variable gain amplifier
A/D converter
Gain controller
404
From digital demodulator 304

FIG. 6

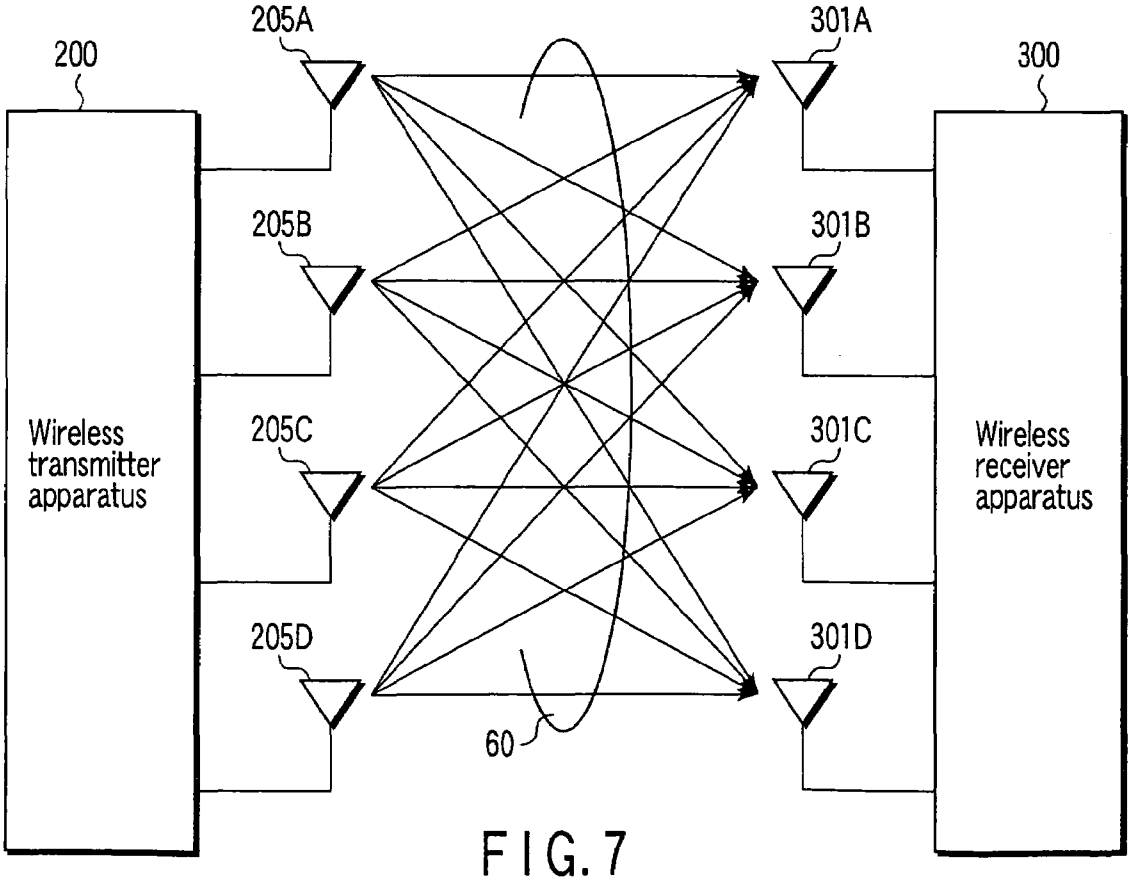

200
205A
205B
205C
205D
301A
301B
301C
301D
300
Wireless transmitter apparatus
Wireless receiver apparatus
60

FIG. 7

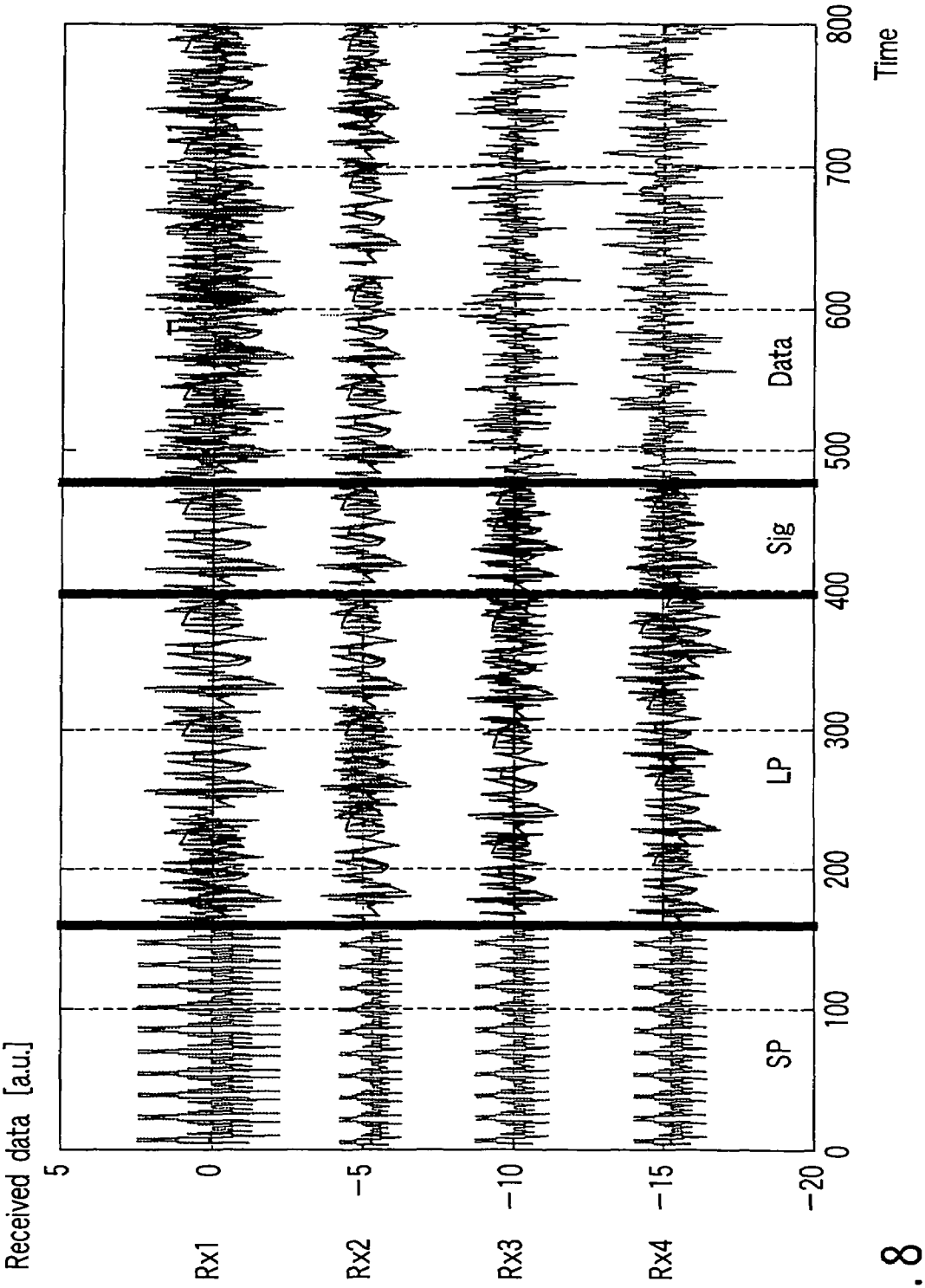

Received data [a.u.]
5
0
−5
−10
−15
−20
Rx1
Rx2
Rx3
Rx4
SP
LP
Sig
Data
0
100
200
300
400
500
600
700
800
Time

FIG. 8

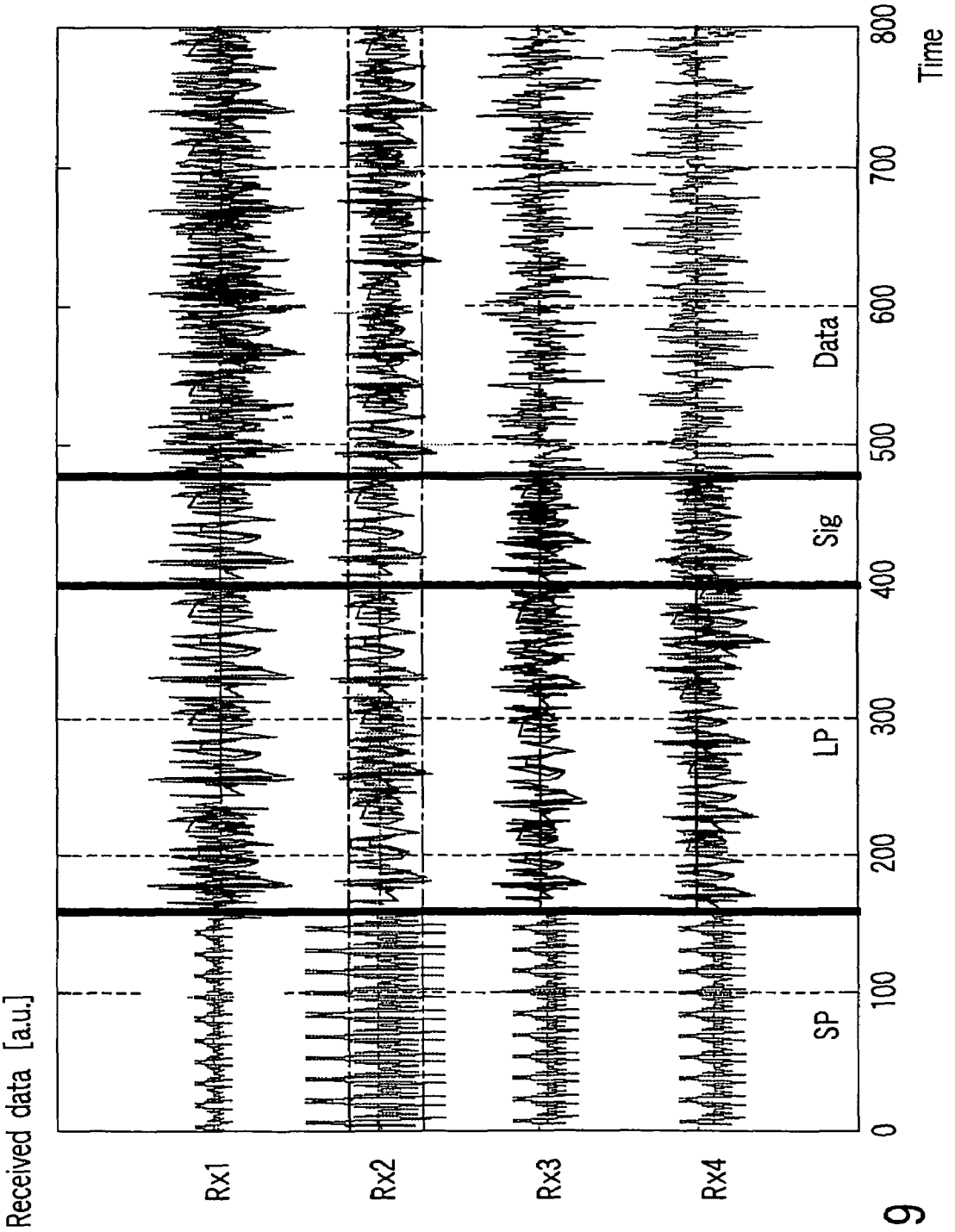

Received data [a.u.]
Rx1
Rx2
Rx3
Rx4
SP
LP
Sig
Data
0
100
200
300
400
500
600
700
800
Time

FIG. 9

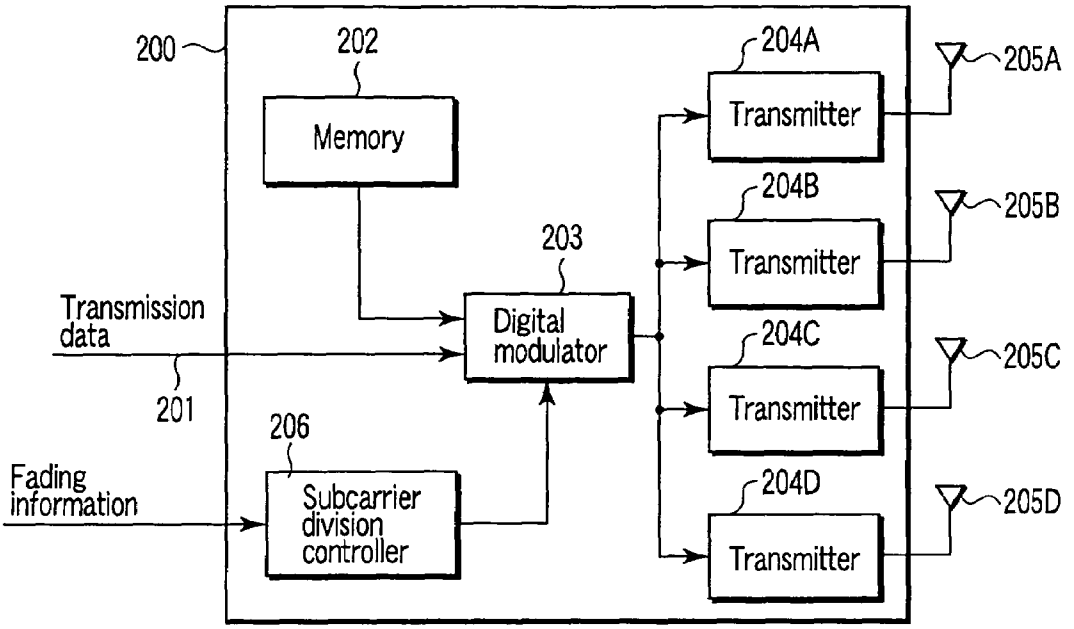



FIG. 10

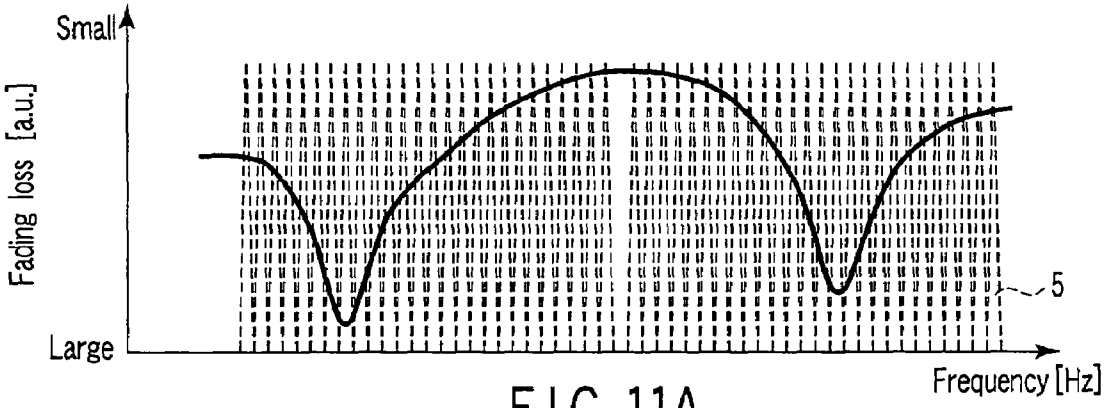



FIG. 11A

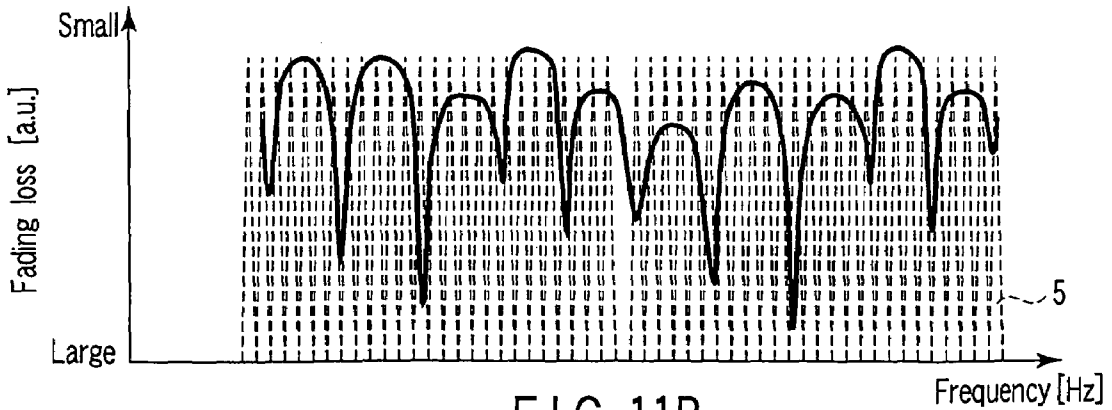



FIG. 11B

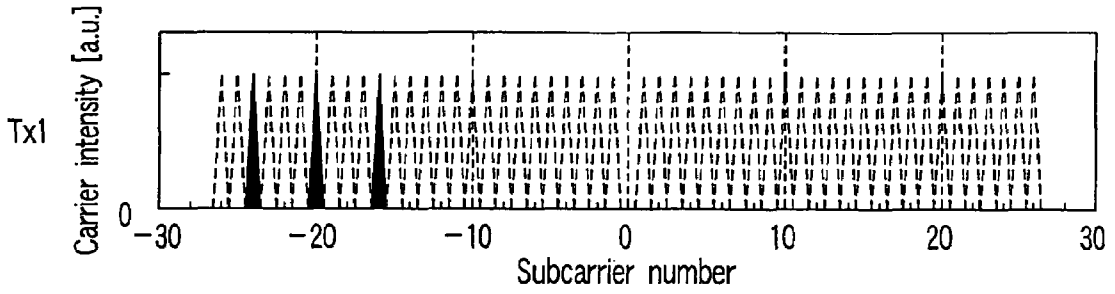



FIG. 12A

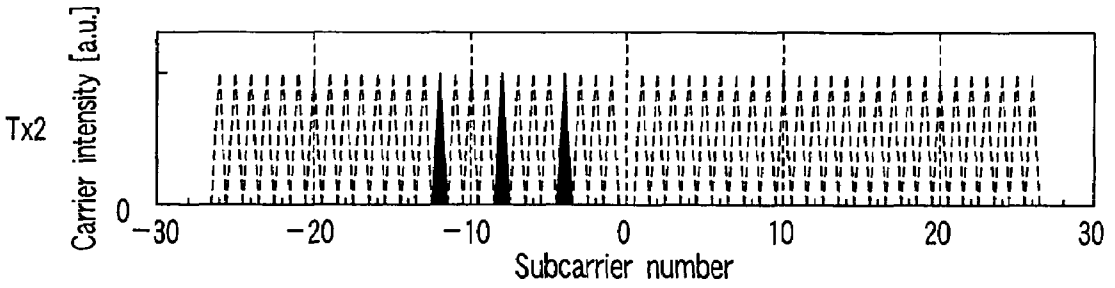



FIG. 12B

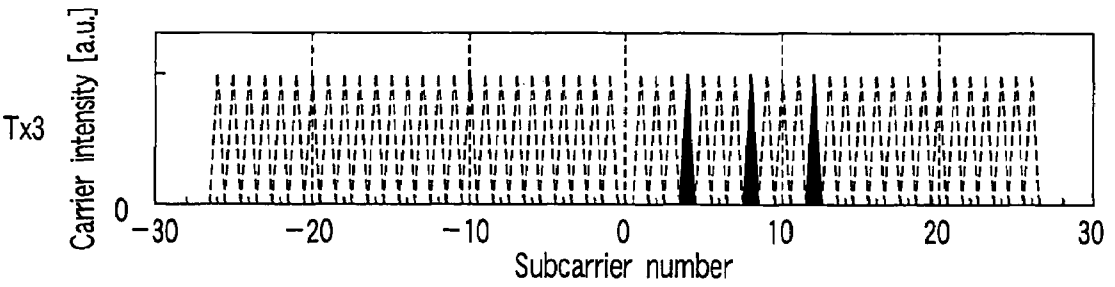



FIG. 12C

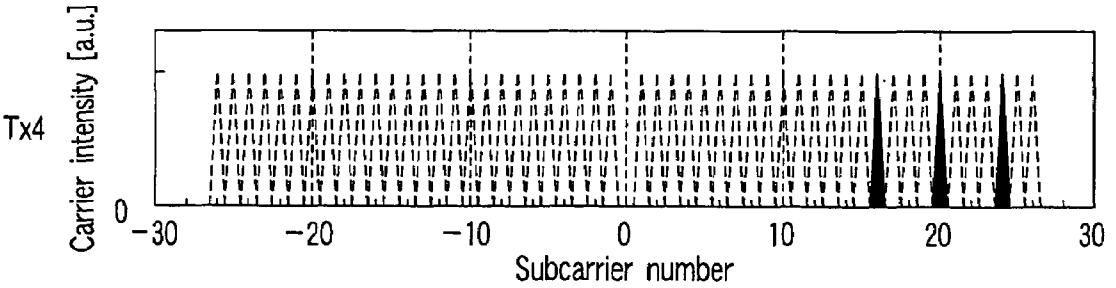



FIG. 12D

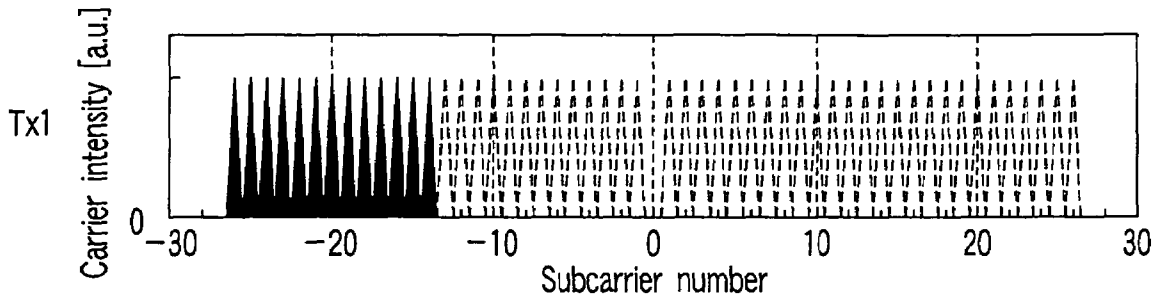



FIG. 13A

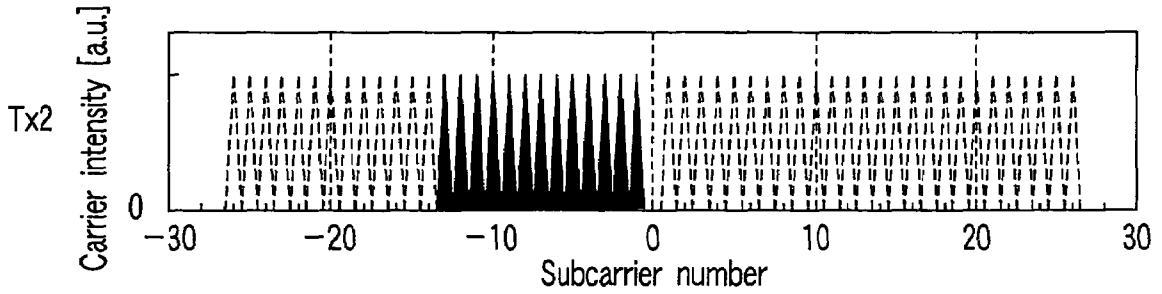



FIG. 13B

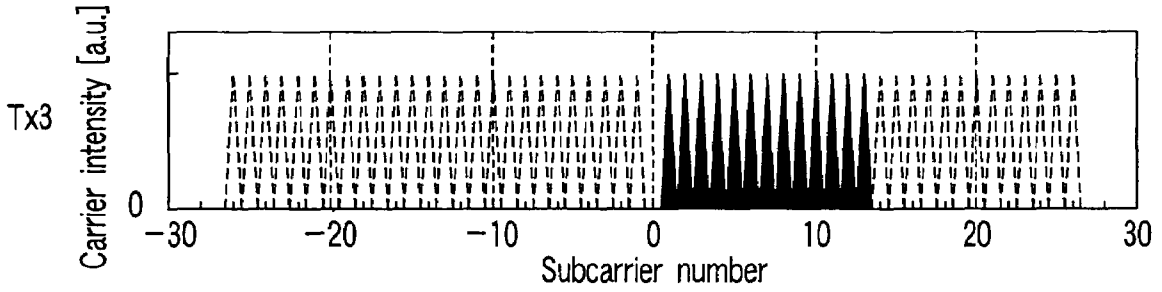



FIG. 13C

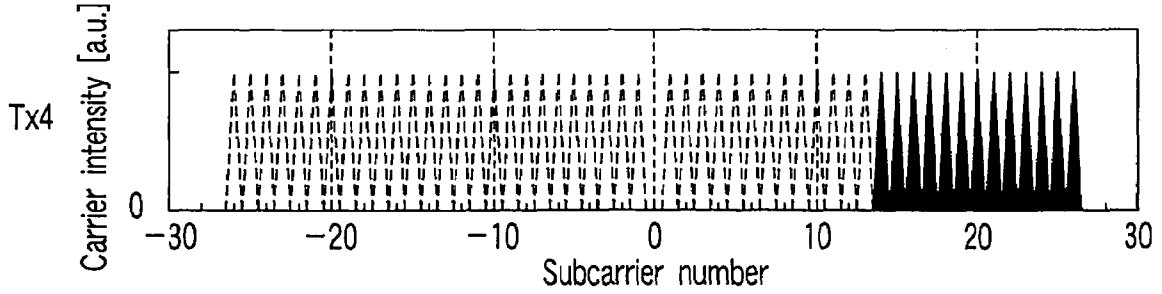



FIG. 13D

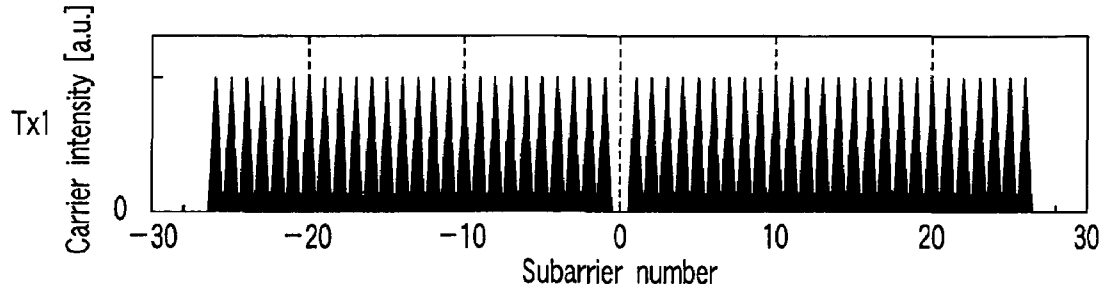



FIG. 14A

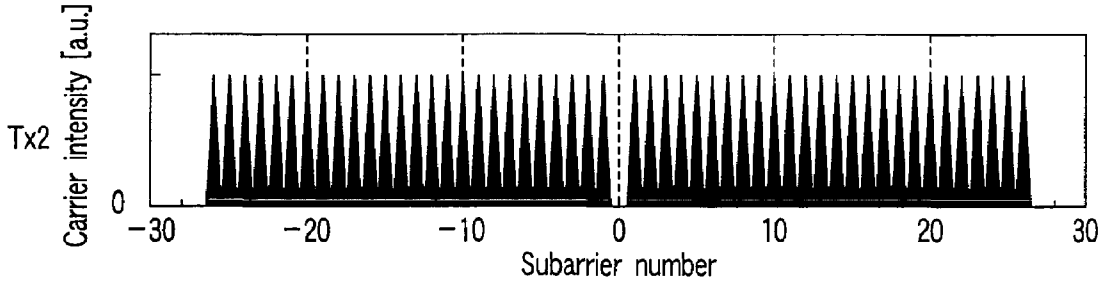



FIG. 14B

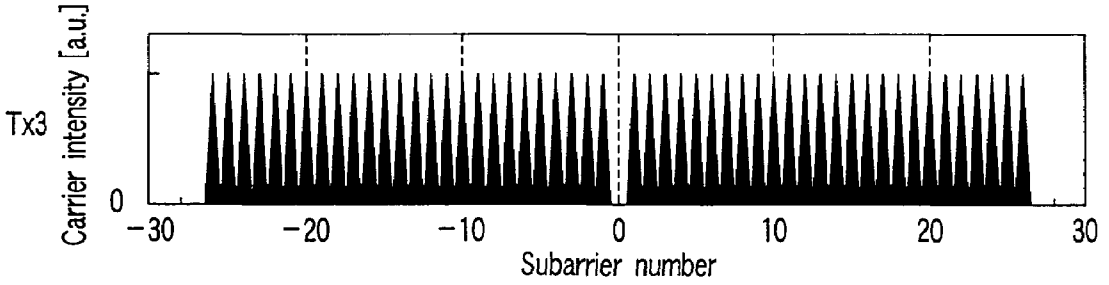



FIG. 14C

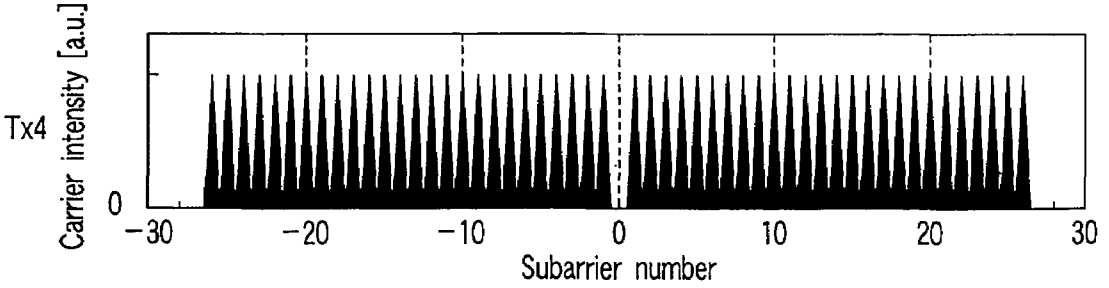



FIG. 14D

# MIMO TRANSMISSION AND RECEPTION METHODS AND DEVICES

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from prior Japanese Patent Application No. 2004-004848, filed Jan. 9, 2004, the entire contents of which are incorporated herein by reference.

## BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates particularly to a wireless transmitting device, wireless receiving device, wireless transmitting method and wireless receiving method by which preamble are transmitted before data.

2. Description of the Related Art

The institute of Electrical and Electronics Engineers (IEEE) is establishing a wireless LAN standard called IEEE 802.11n which aims at a throughput of 100 Mbps or more. In IEEE 802.11n, a technique called multi-input multi-output (MIMO) which uses a plurality of antennas at transmitters and receivers, may be adopted. IEEE 802.11n is required to coexist with the existing IEEE 802.11a. In the MIMO technique, to measure responses (called channel impulse responses) of channel impulse response from a plurality of transmit antennas to each receiving antenna, a preamble as a known sequence must be transmitted from these transmit antennas.

In a preamble proposed by Jan Boer et al. in "Backwards compatibility", IEEE 802.11-03/714r0 (Jan Boer, "Backwards compatibility", IEEE 802.11-03/714r0, Section 2, Slide 14 to 19, (URL:ftp://ieee:wireless@ftp. 802wireless-world.com/)), Paragraph 2 "Diagonally loaded preamble", a short preamble sequence for performing timing synchronization and automatic gain control (AGC) is transmitted from a single transmit antenna. After that, a long preamble sequence for estimating channel impulse response is transmitted from a plurality of transmit antennas. The receiving side performs automatic frequency control (AFC) by using the short preamble sequence and long preamble sequence, and estimates channel impulse response between the antennas. In this manner, the MIMO technique is used in transmission of data signals and the like after that. That is, after the long preamble sequence, a signal field indicating the arrangement of a data signal, e.g., the modulation coding scheme and length of a wireless packet is transmitted, and then the data signal is transmitted.

Jan Boer et al. describe only that the short preamble sequence is transmitted from one antenna and the long preamble sequence is divided into subcarriers and transmitted from a plurality of antennas, and do not describe any signal field transmission method. The preamble proposed by Jan Boer at al. is the same, in a portion from the short preamble sequence to the signal field, as the preamble of IEEE 802.11a standard based on transmission from a single antenna. Therefore, a wireless receiver based on IEEE 802.11a standard which has received the proposed preamble can recognize that the received packet is a wireless packet based on IEEE 802.11a. Accordingly, the proposed preamble allows IEEE 802.11n and IEEE 802.11a standards to coexist on a single wireless station.

The short preamble sequence is transmitted as an orthogonal frequency division multiplexing (OFDM) signal from a single antenna. The long preamble sequence is transmitted, from a plurality of antennas, as different subcarriers divided from one OFDM signal. Likewise, the signal field is transmitted, from the plurality of antennas, as subcarriers divided from one OFDM signal. Since the long preamble sequence is transmitted by dividing one OFDM signal into subcarriers as described above, the receiving side can simultaneously estimate channel impulse response.

In the OFDM receiver apparatus, a received signal is generally demodulated by digital signal processing, so an analog to digital converter is prepared to convert an analog received signal into a digital signal. This analog to digital converter has an allowable level range (called an input dynamic range) permitted to an analog signal to be converted. Therefore, AGC by which the level of a received signal falls within the input dynamic range of the analog to digital converter is essential.

In the preamble by Jan Boer et al., channel estimation is performed by using the long preamble. Since this channel estimation is done by digital signal processing, AGC must be performed by using the short preamble sequence which is a signal before the long preamble sequence. That is, the received level of the short preamble sequence is measured by a receiver connected to each receiving antenna, and the input level of the analog to digital converter is adjusted on the basis of this received level.

Unfortunately, other transmit antennas than the transmit antenna which transmits the short preamble sequence transmit nothing before the long preamble sequence. To receive the long preamble sequence, therefore, AGC must be performed by using the short preamble transmitted from the single transmit antenna. Accordingly, when the receiving side receives the long preamble sequence transmitted from the other transmission antennas or receives a data signal, the received level becomes much higher or lower than the level adjusted by AGC using the short preamble sequence transmitted from the single transmit antenna. If the received level is higher than the upper limit of the input dynamic range of the analog to digital converter, the analog to digital converter saturates. If the received level is lower than the lower limit of the input dynamic range, the analog to digital converter produces a large quantization error. In either case, the analog to digital converter cannot appropriately convert a signal, and this adversely affects processing after the conversion.

Also, since a data signal is transmitted from the plurality of transmit antennas, the changing range of the received level in the interval of the data signal further increases. Accordingly, the problems of the saturation and quantization error of the analog to digital converter described above become significant, and the receiving performance greatly deteriorates.

Generally, a wireless apparatus desirably holds the output level of a transmission signal constant. Assume that the number of transmit antennas is N, and the transmission output is $\alpha$ [watts]. In a wireless communication system obtained by combining the MIMO technique and OFDM, i.e., in a so-called MIMO-OFDM system, the transmission output of a single antenna must be $\alpha$ [watts] for the short preamble sequence because the signal is transmitted from a single antenna. In contrast, for the long preamble sequence, signal field, and data signal, the transmission output of each antenna is $\alpha/N$ [watts] because these signals are transmitted from all antennas.

Accordingly, in a path which transmits the short preamble sequence by using a single antenna, N-fold transmission output is required only to transmit the short preamble. That is, a transmission path for the short preamble produces the redundancy that the specifications of an up converter and power amplifier are required to be able to control the transmission

output α [watts] only when the short preamble sequence is transmitted. On the transmission side as described above, a plurality of transmitters corresponding to a plurality of transmit antennas cannot be given equal structures, and this complicates the whole transmitter apparatus. In addition, since the power consumption of the transmitter apparatus strongly depends on the transmission output level, this is not advantageous in achieving low power consumption.

## BRIEF SUMMARY OF THE INVENTION

The first aspect of the present invention provides a wireless transmitting method of performing transmission by an orthogonal frequency division multiplexing (OFDM) using a plurality of subcarriers orthogonal to each other, the method comprising: transmitting, by using a plurality of transmit antennas, a plurality of preambles formed of a plurality of different subcarrier groups selected from a plurality of subcarriers; and transmitting a data by using the plurality of transmit antennas after the preambles are transmitted.

The second aspect of the present invention provides a wireless receiving method for an orthogonal frequency division multiplexing (OFDM) using a plurality of subcarriers orthogonal to each other, the method comprising: receiving, via a plurality of receiving antennas, a plurality of preambles containing a plurality of short preamble sequences formed of a plurality of different subcarrier groups selected from a plurality of subcarriers, and data following the preambles; amplifying the received preambles by a variable gain amplifier having a gain; and controlling the gain in response to reception of the short preamble sequences.

The third aspect of the present invention provides a wireless transmitting method with a plurality of antennas, comprising: transmitting a plurality of preamble signals with the plurality of antennas, the preamble signals being formed of a plurality of different subcarrier groups selected from a plurality of subcarriers orthogonal to each other, using an orthogonal frequency division multiplexing (OFDM) system; and transmitting a data signal with the plurality of antennas, after transmitting the preamble signals.

The fourth aspect of the present invention provides a wireless receiver apparatus comprising: a plurality of antennas; a receiver, associated with the plurality of antennas, which receives a plurality of preamble signals containing a plurality of short preamble strings formed of a plurality of different subcarrier groups selected from the plurality of subcarriers being orthogonal to each other, and a data signal following the preamble signal, using an orthogonal frequency division multiplexing (OFDM) system; a variable gain amplifier which amplifies signals received by the receiver; and a gain controller which controls a gain of the variable gain amplifier depending upon the short preamble strings of the preamble signals.

## BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

FIG. **1** is a view showing a wireless packet format including a preamble according to an embodiment of the present invention;

FIG. **2** is a block diagram showing a wireless transmitting device according to the embodiment of the present invention;

FIG. **3** is a block diagram showing a wireless receiving device according to the embodiment of the present invention;

FIGS. **4**A to **4**D are views showing the subcarrier arrangements of short preambles shown in FIG. **1**;

FIGS. **5**A to **5**D are views showing the subcarrier arrangements of long preambles and signal fields shown in FIG. **1**;

FIG. **6** is a block diagram showing a receiver shown in FIG. **3**;

FIG. **7** is a view showing channel impulse response of an MIMO-OFDM system according to the embodiment of the present invention;

FIG. **8** is a view showing the received levels of receiving antennas for PLCP signals and data signals according to the embodiment of the present invention;

FIG. **9** is a view showing the received levels of the receiving antennas for PLCP signals and data signals based on IEEE 802.11a;

FIG. **10** is a block diagram showing a wireless transmitting device according to another embodiment of the present invention;

FIGS. **11**A and **11**B are graphs showing two typical fading characteristics used to explain the other embodiment of the present invention;

FIGS. **12**A to **12**D are views showing the subcarrier arrangements of short preambles according to the other embodiment of the present invention;

FIGS. **13**A to **13**D are views showing the subcarrier arrangements of long preambles and signal fields according to the other embodiment of the present invention; and

FIGS. **14**A to **14**D are views showing the subcarrier arrangements of data signals.

## DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the present invention will be described in detail below with reference to the accompanying drawing.

A preamble according to an embodiment of the present invention contains first to fourth physical layer convergence protocol (PLCP) signals **11** to **14** transmitted from transmit antennas Tx**1** to Tx**4**. The PLCP signals **11** to **14** includes short preamble sequences **1**A to **1**D, long preamble sequences **2**A to **2**D, first signal fields (Sig**1**) **3**A to **3**D, and second signal fields (Sig**2**) **4**A to **4**D. The transmit antenna Tx**1** transmits the short preamble sequence **1**A, long preamble sequence **2**A, first signal field **3**A, and second signal field **4**A of the first PLCP signal **11** in order. Likewise, the antenna Tx**2** transmits **1**B, **2**B, **3**B, and **4**B of the second PLCP signal **12** in order, the antenna Tx**3** transmits **1**C, **2**C, **3**C, and **4**C of the third PLCP signal **13** in order, and the antenna Tx**4** transmits **1**D, **2**D, **3**D, and **4**D of the fourth PLCP signal **14** in order.

Unit preambles SP contained in the short preamble sequences **1**A to **1**D and unit preambles LP contained in the long preamble sequences **2**A to **2**D are signal sequences having predetermined lengths. The length of LP is relatively larger than that of SP. After transmitting the PLCP signals **11** to **14**, i.e., the second long preamble sequences **4**A to **4**D, the antennas Tx**1** to Tx**4** transmit data signals (DATA) **5**.

The short preamble sequences **1**A to **1**D, long preamble sequences **2**A to **2**D, and first signal fields **3**A to **3**D are based on IEEE 802.11a standard. The second fields **4**A to **4**D are not based on IEEE 802.11a standard, but contain information such as the modulation coding scheme and data length of wireless packet for communication by MIMO technique. The second signal fields **4**A to **4**D are desirably based upon IEEE 802.11n currently being in standardization process.

Guard intervals GI are arranged between the short preamble sequences **1**A to **1**D and the long preamble sequences **2**A to **2**D, between the long preamble sequences **2**A to **2**D and the first signal fields **3**A to **3**D, between the first signal fields **3**A to **3**D and the second signal fields **4**A to **4**D, and between the second signal fields **4**A to **4**D and the data signals **5**. In the

preamble based on IEEE 802.11a, GI7 having a double length is placed before each of the long preamble sequences 2A to 2D.

The short preamble sequences 1A to 1D are mainly used in timing synchronization, AGC, and coarse adjustment of AFC for frequency synchronization. The long preamble sequences 2A to 2D are mainly used in fine adjustment of AFC, and signal processing for channel estimation. The first signal fields 3A to 3D are based on IEEE 802.11a, and transmitted as OFDM symbols. In the first signal fields 3A to 3D, the modulation coding scheme of the data signals 5 following the PLCP signals 11 to 14, the length of a wireless packet, and the like are described. Therefore, a wireless receiving device based on IEEE 802.11a can perform a normal receiving operation. During the interval of the data signals 5 following the PLCP signals 11 to 14, no other wireless transmitting device based on IEEE 802.11a starts transmission and destroys wireless packets.

The PLCP signals 11 to 14 can meet IEEE 802.11a standard during the interval from the short preamble sequences 1A to 1D to the first signal fields 3A to 3D. This makes it possible to construct an MIMO-OFDM system capable of matching both IEEE 802.11a and another wireless LAN standard (e.g., IEEE 802.11n).

In this embodiment, the second signal fields 4A to 4D describing the modulation coding scheme for communication by using MIMO and the length of a wireless packet are inserted in the endmost portions of the PLCP signals 11 to 14. The receiving side demodulates the second signal fields 4A to 4D, and recognizes, e.g., the modulation coding scheme of signals transmitted from the antennas Tx1 to Tx4, the wireless packet length, and the MIMO operation. Therefore, the receiving side can recognize that the data signals 5 following the PLCP signals 11 to 14 are wireless packets based on a wireless LAN standard (e.g., IEEE 802.11n) other than IEEE 802.11a, and perform a receiving operation as the MIMO-OFDM system.

FIGS. 2 and 3 show a wireless transmitting device 200 and wireless receiving device 300 according to this embodiment which implements the MIMO-OFDM system. The wireless transmitting device 200 shown in FIG. 2 includes transmit antennas 205A to 205D, wireless transmitters 204A to 204D, a digital modulator 203, and a memory 202. The wireless receiving device 300 shown in FIG. 3 includes receiving antennas 301A to 301D, wireless receivers 302A to 302D, channel estimators 303A to 303D for performing channel impulse response estimation (channel estimation) on the basis of information from the wireless receivers 302A to 302D, and a digital demodulator 304.

The transmit antennas 205A, 205B, 205C, and 205D shown in FIG. 2 correspond to Tx1, Tx2, Tx3, and Tx4, respectively, shown in FIG. 1. In this embodiment, the numbers of the transmit antennas and receiving antennas are four. However, the number of the transmit antennas is not limited to four and can be any plural number. The number of the receiving antennas may also be one or any plural number other than four. The numbers of the transmit antennas and receiving antennas need not be equal.

A practical operation of the wireless transmitting device 200 shown in FIG. 2 will be explained below. First, the digital modulator 203 modulates transmission data 201 and an output preamble from the memory 202 to assemble a wireless packet. The output preamble from the memory 202 corresponds to the first to fourth PLCP signals 11 to 14 shown in FIG. 1.

The assembled wireless packet undergoes processing necessary for transmission performed by the transmitters 204A to 204D, e.g., digital to analog conversion, frequency conversion (up conversion) to the radio frequency (RF) band, and power amplification. After that, the wireless packet is supplied to the transmit antennas 205A to 205D corresponding to the antennas Tx1 to Tx4 shown in FIG. 1. As a consequence, the RF signal is transmitted from the transmit antennas 205A to 205D to the wireless receiving device shown in FIG. 3. In the following explanation, the transmit antennas 205A to 205D are Tx1 to Tx4 shown in FIG. 1.

The transmitted RF signal is based on an OFDM signal, and contains a plurality of subcarriers of the OFDM signal. The first to fourth PLCP signals 11 to 14 shown in FIG. 1 are simultaneously transmitted from the transmit antennas 205A to 205D as subcarriers allocated to the transmit antennas 205A to 205D while frequency orthogonal conditions are maintained.

Generally, in the OFDM signal based on IEEE 802.11a, the short preamble sequences 1A to 1D contain 12 subcarriers, and the long preamble sequences 2A to 2D, the first signal fields 3A to 3D, second signal fields 4A to 4D, and data signals 5 contain 52 subcarriers.

As shown in FIGS. 4A to 5D, the first to fourth PLCP signals 11 to 14 are transmitted as different subcarrier groups from the transmit antennas 205A to 205D (corresponding to Tx1 to Tx5 in FIG. 1). FIGS. 4A to 4D illustrate the arrangements of 12 subcarriers in the short preamble sequences 1A to 1D shown in FIG. 1. FIGS. 5A to 5D illustrate the arrangements of 52 subcarriers in the long preamble sequences 2A to 2D and first signal fields 3A to 3D in FIG. 1. Referring to FIGS. 4A to 5D, the abscissa indicates the positions where the subcarriers are arranged, and the ordinate indicates the subcarrier numbers. The dotted lines indicate subcarrier positions where subcarriers can be arranged, and the solid portions represent that subcarriers are actually arranged.

The subcarrier numbers are 0 in the center of the signal band of the OFDM signal, negative numbers on the lower sideband side, and positive numbers on the upper sideband side. No subcarrier is placed in a position where the subcarrier number is "0", and 52 subcarriers are arranged in the positions of subcarrier numbers ±1 to ±26. For example, as shown in FIGS. 4A to 4D, 12 subcarriers of the short preamble sequences 1A to 1D are arranged in the positions of subcarrier numbers ±24, ±20, ±16, ±12, ±8, and ±4 on the basis of IEEE 802.11a.

As a subcarrier dividing method, i.e., as a method of allocating a plurality of subcarriers of the OFDM signal to the first to fourth PLCP signals 11 to 14, the embodiment of the present invention uses a method, as shown in FIGS. 4A to 5D, by which subcarriers are sequentially selected and allocated one by one to the PLCP signals 11 to 14 in order of subcarrier arrangement (order of subcarrier number).

For example, the allocation of subcarriers to the short preamble sequences 1A to 1D of the first to fourth PLCP signals 11 to 14 is as shown in FIG. 4A to 4D. That is, subcarriers having subcarrier numbers −24, −8, and +12 are allocated to the short preamble 1A. Subcarriers having subcarrier numbers −20, −4, and +16 are allocated to the short preamble sequence 1B. Subcarriers having subcarrier numbers −16, +4, and +20 are allocated to the short preamble sequence 1C. Subcarriers having subcarrier numbers −12, +8, and +24 are allocated to the short preamble sequence 1D. In this manner, the phases of subcarriers allocated to the short preambles 1A to 1D are shifted by four waves.

The allocation of subcarriers to the long preamble sequences 2A to 2D of the first to fourth PLCP signals 11 to 14 is basically the same as the allocation of subcarriers to the short preamble sequences 1A to 1D described above, except

that the phases of those subcarriers allocated to the long preambles **2**A to **2**D are shifted by one wave as shown in FIGS. **5**A to **5**D.

The PLCP signals **11** to **14** containing the subcarrier groups divided as shown in FIGS. **4**A to **5**D are transmitted from the transmit antennas **205**A to **205**D. The data signals **5** following the PLCP signals **11** to **14** are transmitted by MIMO channels. That is, the transmitters **204**A to **204**D generate different OFDM signals corresponding to the individual data signals **5**. These OFDM signals are transmitted as four RF signals, corresponding to the number of the transmitters **204**A to **204**D, from the transmit antennas **205**A to **205**D.

In the wireless transmitting device according to this embodiment as described above, the four PLCP signals **11** to **14** are transmitted, from the transmit antennas **205**A to **205**D by the transmitters **204**A to **204**D, as four subcarrier groups obtained by dividing a plurality of subcarriers of one OFDM signal. On the other hand, the four data signals **5** are transmitted as different OFDM signals generated by the transmitters **204**A to **204**D from the transmit antennas **205**A to **205**D.

When subcarriers are uniformly divided in accordance with the transmit antennas **205**A to **205**D, the PLCP signals **11** to **14** are transmitted at equal levels (transmission powers) from the transmit antennas **205**A to **205**D. Even when subcarriers are not uniformly divided, the PLCP signals **11** to **14** are transmitted at substantially equal levels. For example, when the number of the transmit antennas **205**A to **205**D is four as in this embodiment, the transmit antennas **205**A to **205**D transmit three subcarriers for each of the short preamble sequences **1**A to **1**D, and transmit 13 subcarriers for each of the long preamble sequences **2**A to **2**D and signal fields **3**A to **3**D and **4**A to **4**D. When the number of the transmit antennas is three, each transmit antenna transmits four subcarriers for each of the short preamble sequences **1**A to **1**C, and 17 or 18 subcarriers for each of the long preamble sequences **2**A to **2**C and signal fields **3**A to **3**C and **4**A to **4**C.

Since the data signals **5** are not divided into subcarriers unlike the PLCP signals **11** to **14**, the data signals **5** have a subcarrier arrangement different from the PLCP signals **11** to **14**. However, a total of 52 subcarriers are transmitted as the data signals **5** from the transmit antennas **205**A to **205**D, so the transmission level of the data signals **5** is equivalent to that of the PLCP signals **11** to **14**. As described above, the transmission levels of the transmit antennas **205**A to **205**D are equal between the PLCP signals **11** to **14** and the data signals **5**, and substantially equal between the transmit antennas **205**A to **205**D. Therefore, the transmitters **204**A to **204**D can have identical structures having the same output level. Furthermore, the output level of each of the transmitters **204**A to **204**D can be decreased in proportion to the number of antennas, against the total output level of the transmitter apparatus **200**. This makes it possible to reduce the current consumption by suppressing the output power of the power amplifiers used in the transmitters **204**A to **204**D, and alleviate the distortion characteristics. That is, it is possible to simplify the transmitter apparatus **200**, and thereby realize low power consumption.

The operation of the wireless receiving device **300** shown in FIG. **3** will be explained below. The RF signals transmitted from the wireless receiving device **200** shown in FIG. **2** are received by the receiving antennas **301**A to **301**D. The wireless receiving device **300** may also have a single receiving antenna. The RF received signals from the receiving antennas **301**A to **301**D are input to the receivers **302**A to **302**D. The receivers **302**A to **302**D perform receiving processes, e.g., frequency conversion (down conversion) from the RF band to the baseband (BB), AGC, and analog to digital conversion, thereby generating baseband signals.

These baseband signals from the receivers **302**A to **302**D are input to the channel estimators **303**A to **303**D and digital demodulator **304**. The channel estimators **303**A to **303**D estimate channel impulse responses from the wireless transmitting device **200** shown in FIG. **2** to the wireless receiving device **300** shown in FIG. **3**. The channel demodulator **304** demodulates the baseband signals in accordance with the channel impulse responses estimated by the channel estimators **303**A to **303**D, and generates received data **305** corresponding to the transmission data **201** shown in FIG. **2**.

More specifically, the digital demodulator **304** has a channel equalizer on the input stage. This channel equalizer performs equalization for removing distortion of the received signals from the channels in accordance with the estimated channel impulse responses. The digital demodulator **304** demodulates the equalized signals at an adequate demodulation timing based on the timing synchronization process described above, and reproduces the data.

The receivers **302**A to **302**D shown in FIG. **3** will be described below. FIG. **6** shows details of the receiver **302**A. Since the receivers **302**B to **302**D are the same as the receiver **302**A, only the receiver **302**A will be explained. A down converter **401** down-converts the RF received signal input from the receiving antenna **301**, and generates a baseband signal. The down converter **401** can convert the RF received signal into the baseband either directly or after converting the signal into an intermediate frequency (IF) band.

The baseband signal generated by the down converter **401** is input to a variable gain amplifier **402**, and AGC, i.e., signal level adjustment is performed. The output signal from the variable gain amplifier **402** is converted into a digital signal by an analog to digital converter **403**. The digital signal from the analog to digital converter **403** is output outside the receiver **302**, and also input to a gain controller **404**. The gain controller calculates the gain in accordance with the digital signal from the analog to digital converter **403**, and controls the gain of the variable gain amplifier **402** on the basis of the calculation. Details of AGC will be described later.

The operation performed by the wireless receiving device **300** to receive a transmission signal containing the PLCP signals **11** to **14** shown in FIG. **1** will be described below. First, the wireless receiving device **300** receives the short preamble sequences **1**A to **1**D transmitted from the transmit antennas **205**A to **205**D shown in FIG. **2**, and coarsely adjusts frame start detection, timing synchronization, AGC, and AFC by using baseband signals corresponding to the short preamble sequences **1**A to **1**D. In response to the reception of the short preamble sequences **1**A to **1**D, the digital demodulator **304** sends a command signal to the receivers **302**A to **302**D to perform AGC.

In the following description, the gain controller **404** measures the received level from the analog to digital-converted received signal and calculates the gain. However, it is also possible to measure the received level by analog detection of an RF-band or IF-band received signal, and calculate the gain. The variable gain amplifier **402** amplifies the baseband signals corresponding to the short preamble sequences **1**A to **1**D in accordance with a predetermined initial gain. The output signal from the variable gain amplifier **402** is input to the gain controller **404** via the analog to digital converter **403**. The gain controller **404** calculates the gain from the level after analog to digital conversion of the received signals corresponding to the short preamble sequences **1**A to **1**D, and controls the gain of the variable gain amplifier **402** in accordance with the calculated gain.

Letting X be the level before analog to digital conversion of the baseband signals corresponding to the short preamble sequences **1**A to **1**D. If the level X is high, the baseband signals exceed the upper limit of the input dynamic range of the analog to digital converter **403**, so a digital signal obtained by analog to digital conversion saturates. This particularly distorts high-level signals. If the level X is low, large quantization errors caused by analog to digital conversion are contained particularly in low-level signals. That is, regardless of whether the level X is high or low, the analog to digital converter **403** does not perform any adequate conversion, and this largely degrades the reception quality.

To solve this problem, the gain controller **404** controls the gain of the variable gain amplifier **402** such that a level Y after analog to digital conversion of the baseband signals corresponding to the short preamble sequences **1**A to **1**D is a predetermined target value Z. If the level of the baseband signals is very high to such an extent that all input signals to the analog to digital converter **403** saturate, or if the level is very low, it is sometimes impossible to appropriately control the gain of the variable gain amplifier **402** by one-time control. In this case, gain control is repeated. Consequently, the level of the baseband signals input to the analog to digital converter **403** can be adjusted to an adequate level falling within the input dynamic range of the analog to digital converter **403**. By thus controlling the gain of the variable gain amplifier **402** by using the baseband signals corresponding to the short preamble sequences **1**A to **1**D, appropriate analog to digital conversion can be performed, so deterioration of the reception quality can be avoided.

AGC can be either individually performed for the receivers **302**A to **302**D, or collectively performed for the receivers **302**A to **302**D by using, as a target value, a received level obtained by measuring one specific receiver or the highest received level. Although the former method will be explained in this embodiment, the latter method may also be used. Accordingly, the same AGC is individually performed for the receivers **302**A to **302**D, and the gain of the variable gain amplifier **402** is adjusted for each of the receiving antennas **301**A to **301**D.

As described previously, the short preamble sequences **1**A to **1**D are transmitted from the transmit antennas **205**A to **205**D after being divided into subcarriers, and received by the receiving antennas **301**A to **301**D. As shown in FIG. **7**, therefore, the fading statuses of all channel impulse response **60** between the transmit antennas **205**A to **205**D and the receiving antennas **301**A to **301**D are accurately transmitted to the receiver apparatus **300**. In this embodiment, the four transmit antennas **205**A to **205**D and four receiving antennas **301**A to **302**D are used, so the number of the channel **60** is **16** as shown in FIG. **7**.

The statuses of the channel **60** when the short preamble sequences **1**A to **1**D are transmitted are equal to those of the channel **60** when the long preamble sequences **2**A to **2**D, first signal fields **3**A to **3**D, second signal fields **4**A to **4**D, and data signals **5** are transmitted. Therefore, unlike in the case proposed by Jan Boer et al. in which short preamble sequences are transmitted from a single antenna, the receiver apparatus **300** can accurately recognize the fading statuses of the channel **60** when the short preamble sequences **1**A to **1**D, long preamble sequences **2**A to **2**D, first signal fields **3**A to **3**D, second signal fields **4**A to **4**D, and data signals **5** are transmitted. Accordingly, AGC can be accurately performed for each of the receivers **302**A to **302**D.

This effect will be explained below with reference to FIGS. **8** and **9**. Referring to FIGS. **8** and **9**, the abscissa indicates the reception time of the preambles and data signals, and the ordinate indicates the received levels of the receiving antennas Rx**1** to Rx**4** with respect to the preambles and data signals. FIG. **8** shows this embodiment, and FIG. **9** shows the case proposed by Jan Boer et al. In FIG. **8**, reference symbol SP represents the received levels of the short preamble sequences **1**A to **1**D; LP, the received levels of the long preamble sequences **2**A to **2**D; Sig, the received levels of the first signal fields **3**A to **3**D and second signal fields **4**A to **4**D; and Data, the received levels of the data signals **5**. FIG. **9** shows examples of the received levels of short preamble sequences SP, long preamble sequences LP, signal fields Sig, and data signals Data assumed in practice when the preambles by Jan Boer et al. are transmitted in the MIMO-OFDM system.

The received levels of Rx**1** and Rx**2** corresponding to the receiving antennas **301**A and **301**B will be described in detail below. To clearly distinguish between the received levels of LP, Sig, and Data received by Rx**1** and Rx**2**, alternate long and short dashed lines and alternate long and two short dashed lines are added to FIGS. **8** and **9**. As shown in FIG. **8**, at the receiving antennas **301**A to **301**D, the received levels of the short preamble sequences **1**A to **1**D match the received levels of the long preamble sequences **2**A to **2**D, first signal fields **3**A to **3**D, second signal fields **4**A to **4**D, and data signals **5**. For example, the received level of SP and the received levels of LP, Sig, and Data at Rx**1** and Rx**2** shown in FIG. **8** are uniform as indicated by the alternate long and short dashed lines and alternate long and two short dashed lines. On the other hand, as shown in FIG. **9** indicating the case by Jan Boer et al., at some receiving antennas the received level of the short preamble sequences SP is different from the received levels of the long preamble sequences LP, signal fields Sig, and data signals Data. For example, at the antenna Rx**1**, the received level of SP is lower than the alternate long and short dashed lines and alternate long and two short dashed lines indicating the received levels of LP, Sig, and Data. At the antenna Rx**2**, the received level of SP is higher than the received levels of LP, Sig,. and Data. The reasons are as follows.

A general MIMO-OFDM system has an MIMO transmitter, a plurality of transmit antennas, a plurality of receiving antennas, and an MIMO receiver. In this MIMO-OFDM system, when the transmit antennas and receiving antennas are spatially separated from each other, channel from given transmit antennas to given receiving antennas are independent of each other. Therefore, the correlations between these channel are low. For this reason, even when transmission signals of equal powers are transmitted from these transmit antennas, the levels of these signals received by the receiving antennas are naturally different.

According to the proposition by Jan Boer et al. in which short preamble sequences are transmitted only from the transmit antenna Tx**1**, of the 16 channel impulse response between the four transmit antennas Tx**1** to Tx**4** and the four receiving antennas Rx**1** to Rx**4** shown in FIG. **7**, the short preamble sequences propagate on only four channel from Tx**1** to Rx**1**, Rx**2**, Rx**3**, and Rx**4**, and do not propagate on the 12 remaining channel from Tx**2**, Tx**3**, and Tx**4** to Rx**2**, Rx**3**, and Rx**4**. That is, since the channel are different, a phenomenon occurs at high probability in which received levels when the receiver receives the long preamble sequences LP, signal fields Sig, and data signals Data transmitted from the transmit antennas Tx**2** to Tx**4** are much higher or lower than the received level assumed by using the short preamble sequences SP transmitted from the transmit antenna Tx**1**.

On the other hand, when the short preamble sequences **1**A to **1**D, long preamble sequences **2**A to **2**D, first signal fields **3**A to **3**D, and second signal fields **4**A to **4**D are transmitted

from the antennas **205**A to **205**D in accordance with the embodiment of the present invention, the short preamble sequences **1**A to **1**D propagate on the same 16 channel, shown in FIG. **7**, as the long preamble sequences **2**A to **2**D, first signal fields **3**A to **3**D, second signal fields **4**A to **4**D, and data signals **5**. Consequently, at the receiving antennas Rx**1** to Rx**4**, the received levels of the short preamble sequences **1**A to **1**D match the received levels of the long preamble sequences **2**A to **2**D, first signal fields **3**A to **3**D, second signal fields **4**A to **4**D, and data signals **5**.

For example, compare the received level of the short preamble sequences SP and the received levels of the long preamble sequences LP, signal fields Sig, and data signals Data at the receiving antenna Rx**2** shown in FIGS. **8** and **9**. In this case, in AGC using the short preamble sequences **1**A to **1**D based on this embodiment, the received level of the short preamble sequences is equal to the received levels of the long preamble sequences, signal fields, and data signals as shown in FIG. **8**. This realizes fine AGC. That is, since the accuracy of AGC performed using the short preamble sequences increases, it is possible to avoid saturation or the increase in quantization error when the received signals are converted into digital signals by the analog to digital converter **403**. Consequently, wireless communication can be performed at a high transmission rate by suppressing communication errors of data signals.

When AGC control can be performed at high accuracy by using the short preamble sequences, the following effects are also obtained. That is, since received signals input to the analog to digital converter **403** in each of the receivers **302**A to **302**D are adjusted to adequate levels, channel estimation using the long preamble sequences can be rapidly performed. In addition, since channel estimation can be performed by using accurate digital signals, the estimation accuracy of the channel impulse response can be increased.

In this embodiment as described above, the transmitters **204**A to **204**D can be designed by the same level diagram in the transmission states of all the short preamble sequences, long preamble sequences, first and second signal fields, and data signals. This simplifies the wireless transmitting device **200**. Also, the output level of the transmitters **204**A to **204**D is1/(the number of antennas) of the total output level of the transmitter apparatus **200**. This makes downsizing of the power amplifier in the final stage and lower power consumption feasible.

Since the channel impulse response of the short preamble sequences are the same as the channel impulse response of the long preamble sequences, first and second signal fields, and data signals, AGC using the short preamble sequences can maintain high accuracy capable of tracking level variations with respect to transmission from a plurality of transmit antennas. Accordingly, the reception quality can be increased by suppressing the influence of saturation or quantization errors in the analog to digital converter.

Furthermore, since the reception accuracy increases, the number of bits of the analog to digital converter for converting received signals into digital signals can be reduced. This makes low power consumption of the receiver apparatus possible.

Another embodiment of the present invention will be described below. In the other embodiment of the present invention, as shown in FIG. **10**, a wireless transmitting device **200** additionally has a subcarrier division controller **206** connected to a digital modulator **203**. A memory **202**, transmitters **204**, and transmit antennas **205** are the same as in FIG. **2**, so an explanation thereof will be omitted.

The frequency fading statuses of the channel impulse response **60** shown in FIG. **7** of the MIMO-OFDM system can be detected by the known method. The subcarrier division controller **206** shown in FIG. **10** receives channel fading detection information indicating that fading is short-delay fading having a relatively short delay time or long-delay fading having a relatively long delay time. To detect the channel fading, the frequency response, included in the transmitting device **200**, of a received signal of a receiving device **300** can be used as a reference. It is also possible to cause the transmitting device **200** to notify the receiving device **300** of frequency response information of RF signals actually transmitted from transmit antennas **205**A to **205**D to receiving antennas **301**A to **301**D, and use this frequency response information as a reference. The propagation fading detection method may also be some other method, and is not particularly limited.

The subcarrier division controller **206** controls the digital modulator **203** in accordance with the channel fading detection information, thereby controlling the subcarrier dividing method, i.e., the allocation of subcarriers of short preamble sequences **1**A to **1**D, long preamble sequences **2**A to **2**D, first signal fields **3**A to **3**D, and second signal fields **4**A to **4**D to transmitters **204**A to **204**D.

FIGS. **11**A and **11**B illustrate the frequency fading. FIG. **11**A shows typical frequency fading in a short-delay fading environment, and FIG. **11**B shows typical frequency fading in a long-delay fading environment. The frequency fading is roughly divided into these two patterns. The period of a valley in which the frequency fading loss is large is typically about a few MHz indoors. The bandwidth of an OFDM signal to be used in IEEE 802.11a or in IEEE 802.11n whose standard will be established in the future is about 20 MHz. Therefore, a plurality of fading valleys shown in FIGS. **11**A and **11**B are present within this OFDM signal band.

The characteristics of the two frequency fading patterns described above will be briefly summarized below. The short-delay fading shown in FIG. **11**A has the characteristics that a specific signal band produces fading valleys and suffers a propagation path loss, but propagation path losses are relatively small in other bands. On the other hand, the long-delay fading shown in FIG. **11**B is characterized in that fading valleys appear in the entire signal band at narrow frequency intervals, i.e., periodic bands suffer large losses. These fading characteristics are determined in a channel between a transmit antenna and a receiving antenna. Therefore, the fading statuses of the 16 channel **60** shown in FIG. **7** are not the same, but have similar tendencies.

In this embodiment, the above-mentioned characteristics of the short-delay fading and long-delay fading are taken into consideration, and the subcarrier division controller **206** switches the subcarrier dividing methods of the digital modulator **203** on the basis of the channel fading status detection information. More specifically, if the channel **60** has the short-delay fading, subcarriers are sequentially selected and allocated one by one, in order of subcarrier arrangement shown in FIGS. **4**A to **5**D, to first to fourth PLCP signals **11** to **14** transmitted from the transmit antennas **205**A to **205**D, in accordance with the subcarrier dividing method explained in the above embodiment. That is, in the first to fourth PLCP signals **11** to **14**, subcarriers are allocated to the short preamble sequences **1**A to **1**D as shown in FIG. **4**, and are allocated to the long preamble sequences **2**A to **2**D as shown in FIG. **5**.

As shown in FIG. **11**A, in the short-delay fading, the influence of a frequency fading valley is small in a remote band. Accordingly, as the subcarrier dividing method as described

above, subcarriers allocated to the first to fourth PLCP signals **11** to **14** are dispersed in terms of frequency to avoid concentration of subcarriers to a band which suffers a large loss. This makes it possible to avoid the influence of a large propagation path loss caused by a frequency fading valley in a specific band.

On the other hand, if the channel **60** has the long-delay fading, as shown in FIGS. **12**A to **13**D, subcarriers selected from a plurality of subcarriers for each of a plurality of partial bands obtained by dividing the OFDM signal band are allocated to the first to fourth PLCP signals **11** to **14** transmitted from the transmit antennas **205**A to **205**D.

For example, to allocate subcarriers to the short preamble sequences **1**A to **1**D of the first to fourth PLCP signals **11** to **14**, the whole band of the OFDM signal is divided by the number of the transmit antennas, and these divided bands are allocated to the individual transmit antennas and transmitted. As shown in FIGS. **12**A to **12**D, the OFDM signal band is divided into four partial bands (first to fourth partial bands), and subcarriers at a period of four waves as subcarrier numbers are selectively allocated to each partial band.

That is, three subcarriers in the first partial band having the lowest frequency are allocated to the short preamble sequence **1**A, and three subcarriers in the second partial band having the second lowest frequency are allocated to the short preamble sequence **1**B. Similarly, three subcarriers in the third partial band having a frequency higher than that of the second partial band are allocated to the short preamble sequence **1**C, and three subcarriers in the fourth partial band having the highest frequency are allocated to the short preamble sequence **1**D.

The allocation of subcarriers to the long preamble sequences **2**A to **2**D of the first to fourth PLCP signals **11** to **14** is basically the same as the allocation of subcarriers to the short preamble sequences **1**A to **1**D described above. However, a larger number of subcarriers in the individual partial bands, e.g., all subcarriers having consecutive subcarrier numbers in the partial bands in the example shown in FIGS. **13**A to **13**D are allocated to the long preamble sequences **2**A to **2**D.

In the long-delay fading as shown in FIG. **11**B, frequency fading valleys periodically appear even in remote bands. However, in a narrow band of a few hundred kHz to a few MHz, e.g., in the adjacent subcarrier or the next adjacent subcarrier, large losses can be avoided on average. As shown in FIGS. **12**A to **13**D, therefore, subcarriers are divided for each of adjacent partial bands, and subcarrier groups close to each other in each partial band are allocated to the first to fourth PLCP signals **11** to **14**. This makes it possible to avoid a large propagation path loss caused when a frequency fading valley and the subcarrier arrangement match.

That is, when a signal is transmitted from a given transmit antenna and received by a given receiving antenna, it is possible to avoid a loss caused by superposition of a subcarrier on a band which periodically appears and has a large loss, and eliminate the influence of a fading loss on a subcarrier in one of adjacent bands. Accordingly, it is possible to smoothly perform frequency synchronization, channel estimation, and MIMO channel configuration information transmission by using the long preamble sequences **2**A to **2**D and first signal fields **3**A to **3**D, without degrading the accuracy of AGC control by the short preamble sequences **1**A to **1**D. It is also possible to suppress the influence of saturation and quantization errors in the analog to digital converter and improve the reception quality while maintaining the accuracy of the AGC function which tracks variations in received level in the receiver apparatus.

As described earlier, in a wireless propagation environment using the MIMO-OFDM system, fading patterns having various characteristics such as short-delay fading and long-delay fading occur. By switching the subcarrier dividing methods in accordance with the fading characteristics as in this embodiment, the influence of fading can by minimized in the receiver apparatus in any wireless propagation environment. This makes it possible to maintain the accuracy of the AGC function with respect to received level variations in a wireless propagation environment, suppress the influence of saturation and quantization errors in the analog to digital converter, and thereby improve the reception quality.

The MIMO-OFDM system desirably minimizes the influence of frequency fading by which a specific band suffers a large loss, when transmitting the short preamble sequences **1**A to **1**D, long preamble sequences **2**A to **2**D, first signal fields **3**A to **3**D, and second signal fields **4**A to **4**D by subcarrier division. This is so because 52 subcarriers as shown in, e.g., FIGS. **14**A to **14**D are arranged in the data signals **5**, and this averages the influence of frequency fading.

By contrast, in a subcarrier arrangement in which bands having undergone subcarrier division as shown in FIGS. **4**A to **4**D or FIGS. **12**A to **13**D are limited to portions of the signal band, the whole transmission signal may significantly deteriorate depending on the characteristics of frequency fading. This is so because AGC adjustment using the short preambles **1** may deviate from the gain adjustment target value which is optimized when the data signals **5** are received.

In this embodiment, however, it is possible to avoid a large loss of divided subcarriers in a channel between a given transmit antenna and a given receiving antenna, regardless of the fading environment of the propagation path. This makes it possible to smoothly perform frequency synchronization, channel estimation, and MIMO channel configuration information transmission by using the long preamble sequences **2**A to **2**D and first signal fields **3**A to **3**D without degrading the accuracy of AGC control by the short preamble sequences **1**A to **1**D.

In the embodiments of the present invention as described above, the output levels of the transmitters can be made uniform independently of transmission information of the short preamble sequences, long preamble sequences, signal fields, and data signals. Since this eliminates the problem that the output power of one antenna increases only when the short preamble sequences are transmitted, the redundancy of the transmitters can be suppressed. Also, since the output powers of the transmitters can be made uniform at a low level, the power consumption can be reduced.

In addition, the short preamble sequences are transmitted from a plurality of antennas and used in AGC. Therefore, the input levels of the analog to digital converter and wireless receiving device can be appropriately adjusted to data simultaneously transmitted from a plurality of antennas in MIMO, and the receiving performance of the wireless receiving device can be improved. Also, since the input level of the analog to digital converter can be set at an adequate value, the number of bits of the analog to digital converter can be reduced.

Furthermore, since the short preamble sequences transmitted from a plurality of antennas are used in AGC, accurate AGC can be performed not only when data is received but also when the long preamble sequences are received. Accordingly, deterioration of the reception accuracy can be avoided. This also prevents the transmission efficiency from being decreased by insertion of an extra preamble sequence.

On the other hand, in a propagation path in which signals are transmitted from a given transmit antenna and received by

a given receiving antenna, subcarriers of the short preamble sequences can be propagated while the influence of fading is minimized. Therefore, AGC which tracks received level variations on the receiving side can be made to correspond to the propagation path loss from each transmit antenna to each receiving antenna, so the reception accuracy can be increased. Furthermore, it is possible to reduce the number of bits of the analog to digital converter inserted to perform digital signal processing on received signals.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.

What is claimed is:

**1**. A wireless transmitting method of performing transmission by orthogonal frequency division multiplexing (OFDM) using a plurality of subcarriers orthogonal to each other, the method comprising:

transmitting, by using a plurality of transmit antennas, a plurality of preambles formed of a plurality of different subcarrier groups selected from the plurality of subcarriers; and

transmitting data by using the plurality of transmit antennas after the plurality of preambles are transmitted, wherein

transmitting the plurality of preambles includes, if a fading status of a propagation path to a wireless receiving device is short-delay fading, sequentially allocating, to each of the plurality of subcarrier groups of the plurality of preambles, subcarriers selected one by one from the plurality of subcarriers in order of arrangement, and, if a fading status of a propagation path is long-delay fading, allocating, to each of the plurality of subcarrier groups of the plurality of preambles, subcarriers selected from the plurality of subcarriers for each of a plurality of partial bands obtained by dividing a signal band in which the OFDM system is used.

**2**. The method according to claim **1**, wherein a preamble of the plurality of preambles contains a short preamble, a long preamble, and at least one signal field.

**3**. The method according to claim **2**, wherein the at least one signal field contains a first signal field based on IEEE 802.11 a.

**4**. The method according to claim **2**, wherein the at least one signal field contains a first signal field based on IEEE 802.11 a, and a second signal field placed after the first signal field and based on a standard other than IEEE 802.11 a.

* * * * *

# APPENDIX D

# 802.11 "Decrypted"

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## ABSTRACT
This short paper introduces wireless IEEE 802 standards and activities with a focus on explaining the purpose of the many 802.11 amendments.

## Categories and Subject Descriptors
A.1 [**INTRODUCTORY AND SURVEY]**

C.2.5 [**Local and Wide-Area Networks**]

## General Terms
Standardization

## Keywords
TBD

## 1. INTRODUCTION
As wireless technology increasingly pervades our lives, the decisions made in wireless standards bodies such as the IEEE 802.11 have the potential to impact our lives. From the user viewpoint, emerging standards will support new applications, higher throughput and increasing mobility. From the implementer viewpoint, the increasing complexity must be hidden from the user. New standards create new challenges and emergent behaviors that call for academic scrutiny.

The question addressed here is: what are 802 and 802.11, and what do the various letters after ".11" signify?

## 2. IEEE 802
IEEE 802 is a project of the Institute of Electrical and Electronic Engineers (IEEE) LAN/MAN Standards Committee (LMSC). It was created in February 1980 – hence the name 802.

The LMSC is a committee of the IEEE Standards Association (IEEE-SA), which is the body that publishes completed standards and their amendments.

Within project 802, are various *working groups* – each of which defines one or more standards or recommended practices.

The currently active working groups are listed in Table 1.

**Table 1 - IEEE 802 Working Groups**

| Working Group | Name |
|---|---|
| 802.1 | Higher Layer LAN protocols |
| 802.3 | Ethernet |
| 802.11 | Wireless LAN |
| 802.15 | Wireless PAN |
| 802.16 | Broadband Wireless Access |
| 802.17 | Resilient Packet Ring |
| 802.18 | Radio Regulatory technical advisory group |
| 802.19 | Coexistence technical advisory group |
| 802.20 | Mobile Broadband Wireless Access |
| 802.21 | Media Independent Handoff |
| 802.22 | Wireless Regional Area Networks |

## 3. 802.11
The 802.11 working group working held its first meeting in September 1990 and issued the first draft of the 802.11 standard in early 1995, completed in late 1997. This document included a medium access controller (MAC) and physical layer (PHY) definitions for three media:

- Infrared
- Frequency Hopping Spread Spectrum (FHSS) in the 2.4GHz ISM band (1, 2 Mbps)
- Direct Sequence Spread Spectrum (DSSS) in the 2.4 GHz ISM band (1, 2 Mbps)

Originally the FHSS PHY was the most popular because of its lower cost and robustness. The author is not aware of any commercial products using the Infrared PHY. The DSSS PHY did not become popular until 802.11b increased the PHY rates to 5.5 and 11 Mbps. 802.11b is the version that has made wireless networking a popular commercial product.

Since the original version, 802.11 spawned *task groups* to produce amendments to the 802.11 standard. The first task group (TG) is called "TGa", and its amendment is called 802.11a, and so on. Each TG is authorized by the IEEE-SA and has a well-defined scope defined in its Project Authorization Request (PAR) document. The 802.11 task groups are described in Table 2. Those task groups that are currently active are indicated as such.

**Table 2 - IEEE 802.11 Task Groups**

| Task Group | Description |
|---|---|
| TGa | This group developed a higher speed PHY based on orthogonal frequency division multiplexing (OFDM) in the 5GHz bands.<br>The group cooperated with the European ETSI BRAN project and the two produced very similar |

| | |
|---|---|
| | PHY specifications.<br>802.11a has the advantage of several hundred of MHz of spectrum in the 5GHz band. However, it did not have the popular impact that 802.11b had due to the increased cost of operating at these frequencies. 802.11g made 802.11a speeds available in the 2.4GHz band. As the costs of 5GHz components has fallen, 802.11a looks increasingly attractive, and 802.11 a/b/g combination products are commonly available. |
| TGb | 802.11b extended the DSSS PHY to support 5.5 and 11 Mbps. It has been the most successful version of 802.11 to date, and is now being replaced by 802.11g. |
| TGc | This defines 802.11 MAC procedures to support bridge operation. It is a supplement to 802.1D developed in cooperation with the 802.1 working group. |
| TGd | This extends support to additional regulatory domains and provides on-the-air signaling and control of parameters affected by the regulatory domain (such as channelization and hopping patterns). |
| TGe | TGe is still active, although it has nearly completed the standards process. It defines support for QoS for both distributed (EDCA) and centralized (HCCA) mechanisms. It supports QoS flows based on a user priority, suitable for connectionless data.<br>Although the 802.1 MAC interface does not support connection-oriented data transfer, the 802.11e traffic specification (TSPEC) comes close to defining a connection – describing a flow in terms of size, rate, period and many other parameters. This makes 802.11e also suitable for periodic data such as VoIP. Additional improvements include power-saving (APSD) and additional efficiency gains through a selective acknowledgement (Block Ack). |
| TGf | This group developed recommended practices for an Inter-Access Point Protocol (IAPP) intended to provide interoperable management of the distribution system between APs from different manufacturers.<br>It is uncertain what impact this recommended practice has had. |
| TGg | The 802.11g amendment essentially allows operation of the 802.11a OFDM modulation in the 2.4 GHz band.<br>It provides 802.11a throughput at close to 802.11b prices.<br>The challenge for 802.11g devices is to coexist with the installed base of 802.11b devices. This is achieved through various protection mechanisms, although there is some penalty in performance for operating in such an environment. |
| TGh | 802.11h defined enhancements to 802.11a to support operation in the license exempt bands in Europe. It supports measurement and reporting of channel energy in order to provide dynamic frequency selection (DFS).<br>It also provides control of transmit power (TPC). |
| TGi | This group was created to address issues and concerns with the original 802.11 WEP security mechanism.<br>802.11i defines two new mechanisms. TKIP is a medium strength mechanism designed for compatibility with hardware implementing the original 802.11 WEP security mechanism. WEP has proven to be susceptible to various types of attack, and TKIP provides a stopgap solution to these. AES provides the much stronger 128-bit block encryption, which is supported by newer hardware. |
| TGj | 802.11j supports operation in Japan in the 4.9 and 5GHz bands. It extends the operation of the 802.11a PHY to operate in a 10MHz channel (half the channel width of 802.11a), and also allows longer range communication by increasing the turnaround interval to allow for longer propagation delays. |
| TGk Active | 802.11k defines measurement of the radio channel that allows a device (a client device or an access point, or management software above) to make informed decisions relating to selecting an access point and selecting an operating channel.<br>TGk is currently active. |
| TGma | This group provides maintenance changes (editorial and technical corrections) to 802.11-1999, 2003 edition (incorporating 802.11a-1999, 802.11b-1999, 802.11b-1999 corrigendum 1-2001, and 802.11d-2001). |
| TGn Active | 802.11n will define modifications to both PHY and MAC layers to provide substantially higher throughput than 802.11 a/g. The project requires 100Mbps of useful throughput (at the top of the MAC interface), which requires about 200Mbps at the PHY.<br>TGn is currently in its down-selection process to select between proposed solutions.<br>Current proposals use multiple antenna technology and increased channel width to achieve significantly higher than the target. A maximum throughput of ~600Mbps at the PHY has been described, although first generation products are unlikely to support the optional features that achieve this figure.<br>The PHY fixed overheads are not reduced, and aggregation and other enhancements are necessary in the MAC to restore an acceptable level of efficiency (~70%). |
| TGp Active | The TGp amendment will support communication between vehicles and the roadside and between vehicles while operating at speeds up to a minimum of 200 km/h for communication ranges up to 1000 meters.<br>It will use the 5.850-5.925 GHz band within North |

| | |
|---|---|
| | America defined for this purpose. |
| TGr Active | TGr is chartered with developing a secure, fast BSS transition solution, when a Station (STA) roams from one Access Point (AP) to another AP, within an Extended Service Set (ESS). High BSS transition latencies using existing 802.11 mechanisms (including 802.11i Security addendum), along with a lack of inter-operability between STA and AP vendors in harmoniously executing these procedures in performing this transition, are technical hurdles for widespread deployment of Voice over Internet Protocol (VoIP) over 802.11 LANs.<br>Delay and jitter sensitive applications like multimedia, video, and voice, which have to co-exist with traditional, intermittent data traffic, demand a flexible and scalable solution, which maintains the security guarantees provided by IEEE 802.11i. It is a market-driven requirement that the BSS transitions be executed with minimal latencies, while maintaining the same Quality of Service (QoS), and confidentiality and integrity protection, that the STA was being afforded at the existing AP, when the STA moves to the next AP. By some estimates, the procedures recommended by TGr should take less than 50 milliseconds, in order to be effective for the voice/video class of applications.<br>TGr is progressing the merger of two proposals that were voted in at the January 2005 meeting, through a down-select process, from an initial pool of eight. |
| TGs Active | TGs is considering how to create a Mesh of APs to provide a Wireless Distribution System (WDS) using the existing IEEE 802.11 MAC/PHY layers.<br>The mesh needs to support broadcast and directed transmissions over potentially multiple "hops" between APs. It has to be self-configuring.<br>TGs are executing their selection process. They have a call for proposals out that will results in proposals being heard in July 2005. |
| TGu Active | TGu will define an amendment to IEEE 802.11 to support interworking with external networks.<br>The group is currently working on its functional requirements. |
| TGv Active | This group will provide Wireless Network Management enhancements to the 802.11 MAC, and PHY, to extend prior work in radio measurement to effect a complete and coherent upper layer interface for managing 802.11 devices in wireless networks. |
| TGw | 802.11 and later 802.11i established mechanisms to protect data frames, but does nothing to protect control frames internal to 802.11. For example, it is possible to forge disassociation requests. 802.11w is being chartered to extend the 802.11i protections to data frames. It is expected that 802.11w will begin its work in May 2005. |

## 4. References

The most accessible source of information are the IEEE web-sites.

The IEEE 802 LMSC home page is: http://grouper.ieee.org/groups/802/

The IEEE 802.11 WG home page is: http://www.ieee802.org/11/. This contains more detailed description of the scope and status of the individual task groups.

The IEEE 802.11 WG working documents are available (after free registration) from: http://802wirelessworld.com.

Approved amendments are available for download here: http://standards.ieee.org/getieee802/.

The author speaks for himself. Views expressed by the author are not necessarily endorsed by his employer.

# APPENDIX E

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# APPENDIX F

# pIEEE P802.11
# Wireless LANs

## WWiSE Proposal: High throughput extension to the 802.11 Standard

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## Abstract

Changes and additions to IEEE Std. 802.11-1999 (Reaff 2003), as amended by published amendments IEEE802.11a, IEEE802.11g, IEEE802.11h and IEEE802.11i and by IEEE draft standard 802.11e/D9.0 are provided to support a new high throughput physical layer (PHY) for operation in the 2.4 and 5 GHz bands.



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# Draft Amendment to IEEE Standard for Information technology-
# Telecommunications and information exchange between systems -
# Local and metropolitan area networks -
# Specific Requirements -

# Part 20: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications:

# High throughput extension for the 2.4 GHz and 5 GHz Bands

[This amendment is based on IEEE Std 802.11™, 1999 Edition (Reaff 2003), as amended by IEEE Std 802.11a™-1999 and IEEE Std 802.11g™-2003, and Draft Amendment IEEE P802.11e/D9.0]

## 3. Definitions

***Insert the following new definitions in alphabetical order, renumbering as necessary:***

**20 MHz transmission:** A frame transmission in which the modulation spans only one of the 20 MHz channels of a 40 MHz Channel Pair.

**40 MHz channel pair:** A pair of 20 MHz channels whose centre frequencies are separated by 20 MHz and which can be treated as a single channel for 40 MHz transmissions by a BSS, and where one of the 20 MHz channels will also be used for (non-overlapping) 20 MHz transmissions by the BSS.

**40 MHz transmission:** A frame transmission in which the modulation spans both 20 MHz channels of a 40 MHz channel pair.

**aggregated MSDU (A-MSDU):** A MSDU that encapsulates one or more MSDUs to be transmitted to the same destination.

**aggregated PPDU (A-PPDU):** A PPDU that contains one or more pairs of PLCP headers and PSDUs.

**HTP burst transmission:** A sequence of frames transmitted by a single high-throughput station in a single medium access. The frames may be transmitted as part of an A-PPDU, or with reduced interfame spacing to enhance medium efficiency.

**primary channel:** The channel in a 40 MHz channel pair that will be used for 20 MHz transmissions as well as being part of the 40 MHz channel for 40 MHz transmissions.

**secondary channel:** The channel in a 40 MHz channel pair that is used only as part of the 40 MHz channel for 40 MHz transmissions, and which is not used for 20 MHz transmissions.

**HTP rate group:** A group of rates supported by an HTP STA that use the same transmit bandwidth, the same number of transmit antennas, and the number of spatial streams.

**HTP STA:** A STA which conforms to the minimum mandatory requirements set forth in clause 20.

**40MHz HTP rate:** Any rate supported by an HTP STA that uses 40MHz of transmit bandwidth.

**20MHz HTP STA:** An HTP STA which does not support any 40MHz HTP rate.

**40MHz HTP STA:** An HTP STA which supports the ability to receive at least one 40MHz HTP rate.

**MIMO-OFDM:** Multiple input multiple output orthogonal frequency division multiplexing

# 4. Abbreviations and acronyms

***Insert the following acronyms alphabetically in the list in Clause 4:***

| | |
|---|---|
| A-MSDU | aggregated MSDU |
| A-PPDU | aggregated PPDU |
| ECC | error correction code |
| HT | high throughput |
| HTP | high-throughput PHY conforming to Clause 20 |
| LDPCC | low density parity check code |
| MIMO | multiple input multiple output |
| nHTP | non HTP PHY conforming to Clause 15 or Clause 17 or Clause 18 or Clause 19, but not to Clause 20 |
| RIFS | reduced interframe space |
| SDM | spatial data multiplexing |
| STBC | space time block code |

# 6. MAC Service Definition

## 6.1 Overview of MAC services

### 6.1.4 Data service architecture (informative)

***Change the paragraph in 6.1.4 (.11e) as shown:***

The MAC data plane architecture (i.e., processes that involve transport of all or part of an MSDU) is shown in Figure 11g. During transmission, an MSDU goes through some or all of the following processes: frame delivery deferral during power save mode, aggregation, sequence number assignment, fragmentation, encryption, integrity protection, and frame formatting. IEEE 802.1X may block the MSDU at the Controlled Port. At some point the Data frames that contain all or part of the MSDU are queued per access category/TS. This queuing may be at any of the three points indicated in Figure 11g.

During reception, a received data frame goes through processes of MPDU header + cyclic redundancy codecheck (CRC) validation, duplicate removal, possible reordering if the Block Ack mechanism is used, decryption, defragmentation, integrity checking, de-aggregation, and replay detection. After replay detection (or defragmentation if security is used), the MSDU is delivered to the MAC_SAP or to the DS. The IEEE 802.1X Controlled/ Uncontrolled Ports discards the MSDU if the Controlled Port is not enabled or if the MSDU does not represent an IEEE 802.1X frame. TKIP and CCMP MPDU frame order enforcement occurs after decryption, but prior to MSDU defragmentation; therefore, defragmentation will fail if MPDUs arrive out of order.

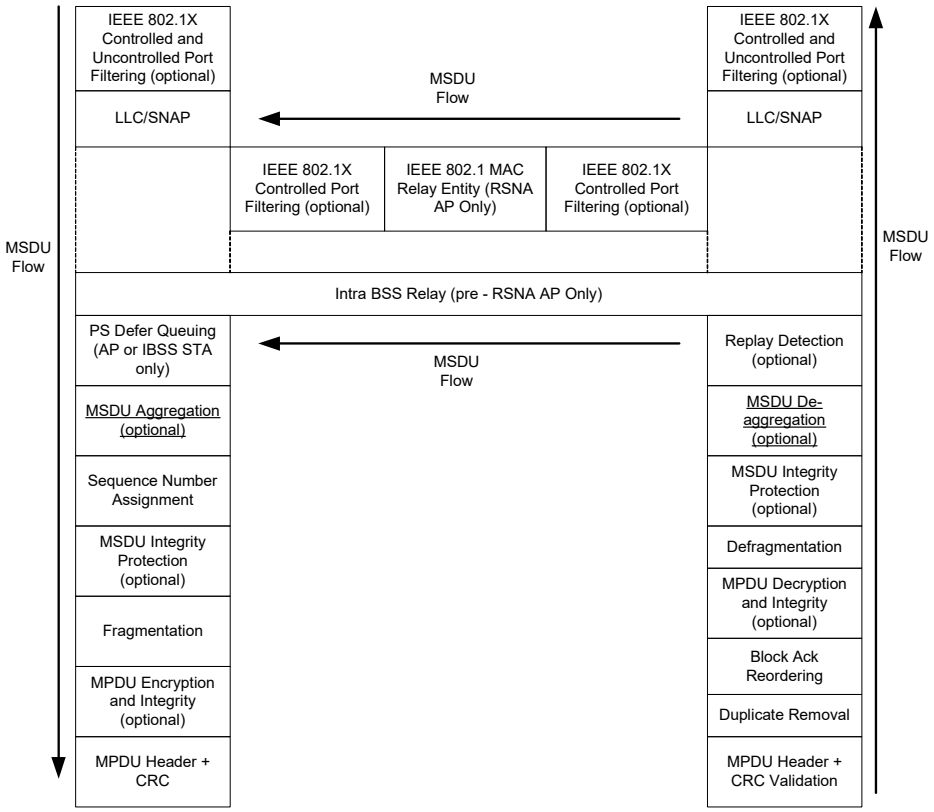



**Figure 11g – MAC data plane architecture**

## 6.2 Detailed service specification

### 6.2.1 MAC data services

#### 6.2.1.1 MA-UNITDATA.request

##### 6.2.1.1.2 Semantics of the service primitive

***Change the third from the last paragraph as follows:***

The data parameter specifies the MSDU to be transmitted by the MAC sublayer entity. For IEEE 802.11, the length of the MSDU ~~must~~shall be less than or equal to ~~2304~~ 8100 octets when a PHY defined in Clause 20 is employed or 4000 when a PHY defined in Clause 17 is employed.

# 7. Frame Formats

## 7.1 MAC frame formats

### 7.1.2 General frame format

***Change Figure 12(.11e) as follows:***

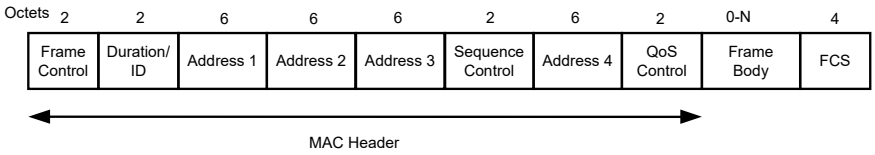



**Figure 12 – MAC frame format**

The maximum frame body length, N, is 8100 when a Clause 20 PHY is employed, and 4000 when a Clause 17 PHY is employed.

### 7.1.3 Frame fields

### 7.1.3.5 QoS Control field

***Change Table 3.1 in 7.1.3.5 (.11e) to appear as follows:***

**Table 3.1 – QoS Control field**

| Applicable Frame (sub) Types | Bits 0-3 | Bit 4 | Bit 5-6 | Bit 7 | Bits 8-15 |
|---|---|---|---|---|---|
| QoS (+)CF-Poll frames sent by HC | TID | EOSP | Ack Policy | Reserved | TXOP limit |
| QoS Data and QoS Data+CF-Ack frames sent by HC | TID | EOSP | Ack Policy | Aggregated MSDU Present | QAP PS Buffer State |
| QoS Null, QoS CFAck frames sent by HC | TID | EOSP | Ack Policy | Reserved | QAP PS Buffer State |
| QoS data type frames sent by non-AP QSTAs | TID | 0 | Ack Policy | Aggregated MSDU Present | TXOP duration requested |
| | TID | 1 | Ack Policy | Aggregated MSDU Present | Queue size |

# 7.2 Format of individual frame types

## 7.2.1 Control Frames

### 7.2.1.7 Block Acknowledgement Request (BlockAckReq) frame format

***Change the diagram of the BAR control field of 7.2.1.7 to appear as follows:***

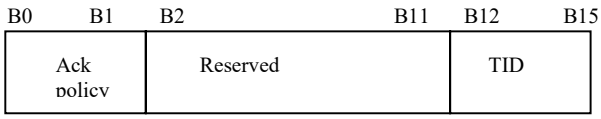



**Figure 21.2– BAR Control Field**

***Insert the following text and table immediately after Figure 21.2 within clause 7.2.1.7:***

The ACK Policy subfield of the BAR Control field contains the ACK policy for the BlockAckReq frame. The ACK policy subfield bits shall have the meaning indicated in table 3.3:

| **Bits in BAR Control field** | **Meaning** |
|---|---|
| **Bit 0 Bit 1** | |
| 0 0 | Normal acknowledgement.<br>The addressed recipient returns an ACK as defined in 9.2.8 or a Block Acknowledgement frame after a SIFS period, according to the previously negotiated block ack policy as described in 11.5. The Ack Policy field is set to this value in all directed Block Ack Request frames in which the sender requires immediate acknowledgement, including those requiring an immediate Block Acknowledgement. |
| 1 0 | No Acknowledgement<br>The addressed recipient performs no immediate response action upon receipt of the frame. More details are provided in 9.11. The Ack Policy is set to this value in all BlockAckReq frames in which the sender does not require immediate, explicit acknowledgement. |
| 0 1 | Reserved |
| 1 1 | Reserved |

**Table 3.3**

### 7.2.1.8 Block Acknowledgement (BlockAck) frame format

***Change the diagram of the BA control field of 7.2.1.8 to appear as follows:***

The BA control field defined in Figure 21.5 consists of the TID and Ack Policy subfields as shown in figure 21.5.

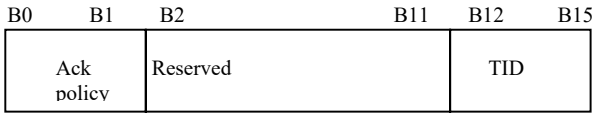



**Figure 21.5 – BA Control Field**

***Insert the following text and table immediately after Figure 21.5 within clause 7.2.1.8:***

The ACK Policy subfield of the BA Control field contains the ACK policy for the Block Acknowledgement frame. The ACK policy subfield bits shall have the meaning indicated in table 3.4:

| Bits in BAR Control field | Meaning |
|---|---|
| Bit 0 Bit 1 | |
| 0 0 | Normal acknowledgement.<br>The addressed recipient returns an ACK as defined in 9.2.8 after a SIFS period. The Ack Policy field is set to this value in all directed Block Acknowledgement frames in which the sender requires immediate acknowledgement. |
| 1 0 | No Acknowledgement<br>The addressed recipient performs no immediate response action upon receipt of the frame. More details are provided in 9.11. The Ack Policy is set to this value in all Block Acknowledgement frames in which the sender does not require immediate, explicit acknowledgement. |
| 0 1 | Reserved |
| 1 1 | Reserved |

**Table 3.4**

### 7.2.2 Data Frames

***Change the text, figures and tables in 7.2.2 (.11e) as shown:***

The frame format for a Data frame is dependent on the QoS subfield of the subtype field and is as defined in Figure 22.

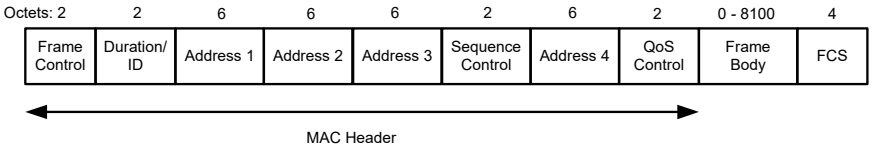



**Figure 22 – Data frame**

***Change the definitions as follows:***

The DA is the destination of the A-MSDU or MSDU (or fragment thereof) in the frame body field.

The SA is the address of the MAC entity which initiated the A-MSDU or MSDU (or fragment thereof) in the frame body field.

## 7.2.3 Management frames

### 7.2.3.1 Beacon frame format

***Insert the Channel Set entry and change the notes in Table 5(.11g) to read as follows:***

| Order | Information | Notes |
|---|---|---|
| 7 | DS Parameter Set | The DS Parameter Set information element is present within Beacon frames generated by STAs using Clause 15, Clause 18 and Clause 19 PHYs and by STAs using Clause 20 PHYs while operating in the 2.4GHz band. |
| 15 | Channel Set | The Channel Set information element is present within Beacon frames generated by APs using a Clause 20 PHY operating on a 40 MHz channel pair |
| 19 | ERP Information | The ERP Information element is present within Beacon frames generated by STAs using ERP PHYs and HTP PHYs and is optionally present in other cases. |

***Add a new clause 7.2.3.1.1 immediately after the existing clause 7.2.3.1 "Beacon Frame Format"***

#### 7.2.3.1.1 Secondary Channel Beacon Format

An AP with a Clause 20 PHY operating on a 40 MHz channel pair may send a Beacon frame on the secondary channel as described in clause 9.13.2.1. In contrast to the normal sending of Beacon frames, the aim of sending a Beacon frame on the secondary channel is to discourage use of that channel (other than as the secondary channel of the 40 MHz channel pair) and as a result, the required frame body is substantially different.

The contents of the fields of the Beacon frame sent on the secondary channel shall be the same as those of the Beacon frame sent on the primary channel, with the exceptions noted below.

The Supported Rate Set Information Element shall consist of a single Clause 20 rate, marked as a basic rate.

**Table 7.2.3.1.1T1 – Beacon Frame Body when used as a Secondary Channel Beacon**

| Order | Information | Notes |
|---|---|---|
| 1 | Timestamp | |
| 2 | Beacon Interval | |
| 3 | Capability | |
| 4 | Service Set Identifier (SSID) | |
| 5 | Supported Rate Set | |
| 6 | CF Parameter Set | May optionally be included to further discourage use of this channel. |
| 5 | Channel Set | |

## 7.2.3.9 Probe Response frame format

***Insert the Channel Set entry and change the notes in Table 12(.11g) to read as follows:***

| Order | Information | Notes |
|---|---|---|
| 7 | DS Parameter Set | The DS Parameter Set information element is present within Probe Response frames generated by STAs using Clause 15, Clause 18 and Clause 19 PHYs and by STAs using Clause 20 PHYs while operating in the 2.4GHz band. |
| 11 | Channel Set | The Channel Set information element is present within Probe Response frames generated by APs using a Clause 20 PHY operating on a 40 MHz Channel Pair |
| 18 | ERP Information | The ERP Information element is present within Probe Response frames generated by STAs using ERP PHYs and HTP PHYs and is optionally present in other cases. |

# 7.3 Management frame body components

## 7.3.1 Fixed fields

### 7.3.1.4 Capability Information field

***Change the second paragraph in 7.3.1.4(.11e) as shown:***

The length of the Capability Information field is 2 octets. The format of the Capability Information field is defined as illustrated in Figure 27. No subfield is supplied for ERP as a STA supports ERP operation if it includes all the clause 19 mandatory rates in its supported rate set. No subfield is supplied for HTP (STAs employing a Clause 20 PHY), as a STA supports HTP operation if it includes all of the Clause 20 mandatory rates in its supported rate set.

### 7.3.1.11 Action Field

***Add the following rows to Table 19A to:***

| Name | Value | See Subclause |
|---|---|---|
| High Throughput | 4 | 7.4.5 |

## 7.3.2 Information Elements

***Add a new row to Table 20 "Element IDs" as follows, and adjust reserved ids appropriately***

| | |
|---|---|
| Channel Set | XXX-To be assigned by ANA before letter ballot |

***Add the following text to the end of clause 7.3.2 after the table of Element IDs***

Individual information elements may be extended in length by future versions of this standard by adding new fields to the end of an existing information element. STAs shall ignore any additional information beyond the expected end of an Information Element, and shall treat any such information element as legal.

### 7.3.2.13 ERP Information element

***Change the text of clause 7.3.2.13(.11g) as follows:***

~~The ERP Information element contains information on the presence of Clause 15 or Clause 18 stations in the BSS that are not capable of Clause 19 (ERP-OFDM) data rates. It also contains the requirement of the ERP Information element sender (AP in a BSS or STA in an IBSS) as to the use of protection mechanisms to optimize BSS performance and as to the use of long or short Barker preambles. See Figure 42E for a definition of the frame element.~~

The ERP Information element contains information on:

a) the presence of Clause 15 or Clause 18 stations in the BSS that are not capable of Clause 19 (ERP-OFDM) data rates
b) the directive from the ERP Information element sender (the AP, or in an IBSS a STA) as to the use of protection mechanisms to optimize BSS performance in the presence of STA which have implemented a PHY from Clause 15 or Clause 18 and not including Clause 19 capability
c) the directive from the ERP Information element sender (AP in a BSS or STA in an IBSS) as to the use of long or short Barker preambles
d) the presence of Clause 19 stations in the BSS, when the ERP Information element sender is an HTP STA
e) the directive from the ERP Information element sender (AP in a BSS or STA in an IBSS) as to the use of OFDM-protection mechanisms to optimize BSS performance
f) the presence of Clause 17 stations in the BSS, when the ERP Information element sender is a HTP STA
g) the presence of Clause 17 stations in the secondary 20 MHz channel which potentially limits the ability of the HTP STA to utilize a 40 MHz wide channel, when the ERP Information element sender is a HTP STA
h) the presence of HTP STA in the BSS which are not capable of receiving 40 MHz channel transmissions (20MHz HTP STA), when the ERP Information element sender is an HTP STA
i) the directive from the ERP Information element sender (AP in a BSS or STA in an IBSS) as to the use of 20MHz-protection mechanisms to optimize BSS performance

See Figure 42E for a definition of the ERP Information element.

In an infrastructure BSS, if one or more NonERP STAs are associated in the BSS, the Use_Protection bit shall be set to 1 in transmitted ERP Information Elements.

In an infrastructure BSS, if one or more Clause 19 or Clause 17 STAs are associated in the BSS, then the Use_OFDM_Protection bit shall be set to 1 in ERP Information Elements transmitted by HTP STAs and may be set to 1 in ERP Information Elements transmitted by nHTP STAs.

In an infrastructure BSS, if one or more 20MHz HTP STAs are associated in the BSS, then the Use_20MHz_Protection bit shall be set to 1 in ERP Information Elements transmitted by HTP STAs and may be set to 1 in ERP Information Elements transmitted by nHTP STAs.

In an IBSS, the setting of the Use_Protection and Use_OFDM_Protection and Use_20MHz_Protection bits is left to the STA. In an IBSS, there is no uniform concept of association; therefore, a typical algorithm for setting the Use_Protection and Use_OFDM_Protection and Use_20MHz_Protection bits will take into account the traffic pattern and history on the network. If a member of an IBSS which is not an HTP STA detects one or more NonERP STAs that are members of the same IBSS, then the Use_Protection bit should be set to 1 in the ERP Information Element of transmitted Beacon and Probe Response frames. If a member of an IBSS which is a HTP STA detects one or more Clause 19 STAs or one or more Clause 17 STAs that are members of the same IBSS, then the Use_OFDM_Protection bit should be set to 1 in the ERP Information Element of transmitted Beacon and Probe Response frames. If a member of an IBSS which is an HTP STA detects one or more 20MHz HTP STAs that are members of the same IBSS, then the Use_20MHz_Protection bit should be set to 1 in the ERP Information Element of transmitted Beacon and Probe Response frames.

In an infrastructure BSS, the NonERP_Present bit shall be set to 1 when a NonERP STA is associated with the BSS. Examples of when the NonERP present bit may additionally be set to 1 include, but are not limited to, when:

a) A NonERP infrastructure or independent BSS is overlapping (a NonERP BSS may be detected by the reception of a Beacon where the supported rates contain only Clause 15 or Clause 18 rates).

b) In an IBSS, if a Beacon frame is received from one of the IBSS participants where the supported rate set contains only Clause 15 or Clause 18 rates.

c) A management frame (excluding a Probe Request) is received where the supported rate set includes only Clause 15 or Clause 18 rates.

In an infrastructure BSS, the OFDM_PRESENT bit shall be set to 1 in ERP Information Elements transmitted by HTP STA when a Clause 17 or Clause 19 STA is associated with the BSS. Examples of when the OFDM_PRESENT bit may additionally be set to 1 in an ERP Information Element transmitted by a HTP STA include, but are not limited to, when

a) A Clause 17 or Clause 19 infrastructure or independent BSS is overlapping. (A Clause 17 BSS may be detected by the reception of a Beacon where the supported rates element and extended supported rates element contain only Clause 17 rates. A Clause 19 BSS may be detected by the reception of a Beacon where the supported rates and extended supported rates elements contain at least one rate from the set of Clause 19 rates and no HTP rates.)

b) In an IBSS, if a Beacon frame is received from one of the IBSS participants where the supported rate set contains:

1) only Clause 17 rates
OR
2) at least one rate from the set of Clause 19 rates and no HTP rates.

c) A management frame (excluding a Probe Request) is received where the supported rate set includes:

1) only Clause 17 rates
OR
2) at least one rate from the set of Clause 19 rates and no HTP rates.

The OFDM_PRESENT bit may optionally be set to 1 in ERP Information Elements transmitted by nHTP STA.

In an infrastructure BSS, the 20MHz_HTP_PRESENT bit shall be set to 1 in ERP Information Elements transmitted by HTP STA when one or more 20MHz HTP STAs are associated in the BSS. Examples of when the 20MHz_HTP_PRESENT bit may additionally be set to 1 in an ERP Information Element transmitted by a HTP STA include, but are not limited to, when

a) An infrastructure or independent BSS which is overlapping and which has signalled the presence of 20MHz HTP STA as indicated by the 20MHz_HTP_PRESENT bit.

b) In an IBSS, if a Beacon frame is received from one of the IBSS participants where the supported rate set contains at least one rate from the set of Clause 20 rates, but no 40MHz HTP rates.

c) A management frame (excluding a Probe Request) is received where the supported rate set contains at least one rate from the set of Clause 20 rates, but no 40MHz HTP rates.

The 20MHz_HTP_PRESENT bit may optionally be set to 1 in ERP Information Elements transmitted by nHTP STA.

~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs shall invoke the use of a protection mechanism as described in clause 9.13 after transmission or reception of the Use_Protection bit with a value of 1 in an MMPDU to or from the BSS that the ~~ERP AP or ERP STA~~ ERP AP, ERP STA, HTP AP or HTP STA has joined or started. ~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs may additionally invoke clause 9.13 protection mechanism use at other times.

~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs may disable clause 9.13 protection mechanism use after transmission or reception of the Use_Protection bit with a value of 0 in an MMPDU to or from the BSS that the ~~ERP APs or ERP STAs~~ ERP AP, ERP STA, HTP AP or HTP STA has joined or started.

HTP APs and HTP STAs shall invoke the use of an OFDM protection mechanism after transmission or reception of the Use_OFDM_Protection bit with a value of 1 in an MMPDU to or from the BSS that the HTP AP or HTP STA has joined or started unless a protection mechanism as defined in clause 9.13 is being concurrently employed, in which case, the use of an OFDM protection mechanism is optional. HTP APs and HTP STAs may optionally invoke OFDM protection mechanism use at other times.

HTP APs and HTP STAs may disable OFDM protection mechanism use after transmission or reception of the Use_OFDM_Protection bit with a value of 0 in an MMPDU to or from the BSS that the HTP AP or HTP STA has joined or started.

40MHz HTP APs and 40MHz HTP STAs shall invoke the use of a 20MHz protection mechanism after transmission or reception of the Use_20MHz_Protection bit with a value of 1 in an MMPDU to or from the BSS that the 40MHz HTP AP or 40MHz HTP STA has joined or started unless a protection mechanism as defined in clause 9.13, or an OFDM protection mechanism is being concurrently employed, in which case, the use of a 20MHz protection mechanism is optional. 40MHz HTP APs and 40 MHz HTP STAs may optionally invoke 20MHz protection mechanism use at other times.

40MHz HTP APs and 40MHz HTP STAs may disable 20MHz protection mechanism use after transmission or reception of the Use_20MHz_Protection bit with a value of 0 in an MMPDU to or from the BSS that the 40MHz HTP AP or 40MHz HTP STA has joined or started.

When there are no NonERP STAs associated with the BSS and the ERP Information Element sender's dot11ShortPreambleOptionImplemented MIB variable is set to true, then the Barker_Preamble_Mode bit may be set to 0. The Barker_Preamble_Mode bit shall be set to 1 by the ERP Information Element sender if one or more associated NonERP STAs are not short preamble capable as indicated in their Capability Information field, or if the ERP Information Element senders dot11ShortPreambleOptionImplemented MIB variable is set to false.

If a member of an IBSS detects one or more non-short preamble-capable STAs that are members of the same IBSS, then the Barker_Preamble_Mode bit should be set to 1 in the transmitted ERP Information Element.

~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs shall use long preambles when transmitting Clause 15, Clause 18, and Clause 19 frames after transmission or reception of an ERP Information Element with a Barker_Preamble_Mode value of 1 in an MMPDU to or from the BSS that the ~~ERP APs or ERP STAs~~ ERP AP, ERP STA, HTP AP or HTP STA has joined or started, regardless of the value of the short preamble capability bit from the same received or transmitted MMPDU that contained the ERP Information Element. ~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs may additionally use long preambles when transmitting Clause 15, Clause 18, and Clause 19 frames at other times. ~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs may use short preambles when transmitting Clause 15, Clause 18, and Clause 19 frames after transmission or reception of an ERP Information Element with a Barker_Preamble_Mode value of 0 in an MMPDU to or from the BSS that the ~~ERP APs or ERP STAs~~ ERP AP, ERP STA, HTP AP or HTP STA has joined or started, regardless of the value of the short preamble capability bit from the same received or transmitted MMPDU. ~~NonERP STAs and NonERP APs~~STAs which are neither ERP nor HTP and APs which are neither ERP nor HTP may also follow the rules given in this paragraph.

The Secondary_Channel_Used bit may be set to 0 in ERP Information Elements transmitted by HTP STAs or HTP APs if no frames with a Clause 17 BSSID have been received within the last two seconds on the secondary 20 MHz channel of the BSS that the HTP AP or HTP STA has joined or started, otherwise, the Secondary_Channel_Used bit shall be set to 1. nHTP STAs and nHTP APs shall always set the Secondary_Channel_Used bit to 0 if they transmit ERP Information elements.

Recommended behavior for setting the Use_Protection bit is contained in 9.10.

The ERP Information element shall have the form shown in Figure 42E.

| B0-B7 | B0-B7 | B0 | B1 | B2 | B3 | B4 | B5 | B6 | B7 |
|---|---|---|---|---|---|---|---|---|---|
| ElementID | Length(1) | NonERP Present | Use_protection | Barker preamble mode | OFDM_present | Use_OFDM_Protection | Secondary_Channel_Used | 20MHz_HTP_PRESENT | USE_20MHz_PROTECTION |

**Figure 42E**

~~Bits r3 through r7 are reserved, set to 0, and are ignored on reception. Note that the length of this element is flexible and may be expanded in the future.~~

Note that the length of this element is flexible and may be expanded in the future.

### 7.3.2.22.1 Basic Report

***Change one of the reserved bits in figure 46o "Map Field Format" to be "Secondary Channel"***

***Add the following after the definition of the "Unmeasured bit"***

— Secondary Channel bit, which shall be set to 1 when at least one valid Secondary Channel Beacon (as described in clause 9.13.2.1) was received during the measurement period from another BSS. Otherwise the Secondary Channel bit shall be set to zero.

***Add the following new clauses as the last sub-clauses of 7.3.2 "Information Elements"***

### 7.3.2.25 Channel Set

The Channel Set information element is used to convey information about the channels from which a 40 MHz Channel Pair are formed. The Primary Channel field shall contain the channel number of the primary channel. The Secondary Channel shall contain the channel number of the secondary channel.

This information element may be extended in later versions of this standard.

See Figure 000n:

| | Element ID | Length | Primary Channel | Secondary Channel |
|---|---|---|---|---|
| Octets: | 1 | 1 | 1 | 1 |

**Figure 000n- Channel Set element format**

### 7.4.5 High Throughput action details

Four Action frame formats are defined for High Throughput. An action field, in the octet field immediately after the Category field, differentiates the four formats. The Action field values associated with each format are defined in Table 20.22.

**Table 20.22 – High Throughput Action field values**

| Action field value | Description |
|---|---|
| 0 | Mode Request |
| 1 | Mode Report |
| 2 | MIMO Channel Request |
| 3 | MIMO Channel Report |
| 4-255 | Reserved |

### 7.4.5.1 Mode Request frame format

The Mode Request frame uses the Action frame body format and is transmitted by a STA requesting the receiving STA to indicate the best transmission mode to employ for high throughput communication. The format of the Mode Request frame is shown in Figure 000n1.

The Category field shall be set to 4 (representing High Throughput).

The Actions field shall be set to 0 (representing a Mode Request Frame).

The Dialog Token field shall be set to a nonzero value chosen by the STA sending the Mode Request to identify the request/report transaction.

The Mode Request field shall be set to 1. All other values for this field are reserved.

| | Category | Action | Dialog Token | Mode Request |
|---|---|---|---|---|
| Octets: | 1 | 1 | 1 | 1 |

**Figure 000n1- Mode Request frame format**

Upon reception of a Mode Request frame, an STA must respond with a Mode Response, as described in 7.4.5.2. A null response may be used.

### 7.4.5.2 Mode Response frame format

The Mode Response frame uses the Action frame body format and is transmitted by a STA in response to a Mode Request frame. It may also be used as an unsolicited request to use a certain PHY mode. The format of the Mode Response frame is shown in Figure 000n2.

The Category field shall be set to 4 (representing High Throughput).

The Actions field shall be set to 1 (representing a Mode Response Frame).

The Dialog Token field shall be set to the value in any corresponding Mode Request Frame. If the Mode Response is not being transmitted in response to a Measurement Request frame, the Dialog token shall be set to zero.

The Mode Response field shall contain the mode that the STA would prefer the requesting station to employ. The specific mechanism for determining this mode is implementation dependent. A null response of all ones (i.e. 0xFFFF) is used if the station is unable to determine a mode. Otherwise, the mode is indicating using bits b6:b21 as shown in Figure 017 (SIG-N field). All other bits are reserved and set to zero.

| | Category | Action | Dialog Token | Mode Response |
|---|---|---|---|---|
| Octets: | 1 | 1 | 1 | 4 |

**Figure 000n2- Mode Response frame format**

### 7.4.5.3 MIMO Channel Request frame format

The MIMO Channel Request frame uses the Action frame body format and is transmitted by a STA requesting the receiving STA to provide its estimate of the MIMO channel matrix seen on receiving this frame. The format of the MIMO Channel Request frame is shown in Figure 000n3.

The Category field shall be set to 4 (representing High Throughput).

The Actions field shall be set to 2 (representing a MIMO Channel Request Frame).

The Dialog Token field shall be set to a nonzero value chosen by the STA sending the MIMO Channel Request to identify the request/report transaction.

The MIMO Channel Request field shall be set to 1. All other values for this field are reserved.

| | Category | Action | Dialog Token | MIMO Channel Request |
|---|---|---|---|---|
| Octets: | 1 | 1 | 1 | 1 |

**Figure 000n3- MIMO Channel Request frame format**

### 7.4.5.4 MIMO Channel Response frame format

The MIMO Channel Response frame uses the Action frame body format and is transmitted by a STA in response to a MIMO Channel Request frame. It may also be used as an unsolicited indication of the observed MIMO channel matrix. The format of the MIMO Channel Response frame is shown in Figure 000n4.

The Category field shall be set to 4 (representing High Throughput).

The Actions field shall be set to 3 (representing a MIMO Channel Response Frame).

The Dialog Token field shall be set to the value in any corresponding MIMO Channel Request Frame. If the MIMO Channel Response is not being transmitted in response to a MIMO Channel Request frame, the Dialog token shall be set to zero.

| | Category | Action | Dialog Token | Mode Response |
|---|---|---|---|---|
| Octets: | 1 | 1 | 1 | N |

**Figure 000n4- MIMO Channel Response frame format**

The Mode Response field is of varying length depending on the actual channel matrix being encoded. The octets of the Mode Response field are set according to the table below.

**Table XYZ – Mode Response Encoding**

| Octet | Contents |
|---|---|
| 1-2 | Length of Mode Response field in octets (16 bit unsigned integer) |
| 3 | Response type<br>0 for Null<br>1 for MIMO channel estimate<br>2-255 Reserved |
| 4 | Number of Rows in Channel Matrix (i.e. NRX antennas) |
| 5 | Number of Columns in Channel Matrix (i.e. NTX antennas) |
| 6 to (5+Nst*Nrows*Ncols*4) | Channel matrix elements row by row starting with element (1,1) from lowest to highest subcarrier. Each element is encoded as two 16 bit signed integers (I and Q). |

For the MIMO channel estimate, the station sends the actual channel estimate it computes during preamble processing of a MIMO Channel Request Frame.

# 9. MAC sublayer functional description

## 9.1 MAC architecture

***Insert the following subclause after clause 9.1.3(.11e) and renumber existing subclauses 9.1.4(.11e) through 9.1.5(.11e) to be subclauses 9.1.5 through 9.1.6***

### 9.1.4 MSDU aggregation

One or more MSDUs being sent to the same receiver can be aggregated into a single A-MSDU. Aggregation of more than one frame can improve system efficiency as seen at the MAC sub-layer due to the fact that the overheads associated with channel access (e.g. PLCP preamble, MAC header, IFS spacing, etc.) can be amortized over two or more MSDUs. Frames with address types of Broadcast ,Multicast, or Unicast frames can be aggregated with other frames of the same address type, but not with frames of different address type due to the requirement to share the receiver address. Aggregation is optional and the process is considered a "sub-process" between MSDU queuing and sequence number assignment in Figure 11g of Clause 6.1.4.

A STA shall only use MSDU aggregation where it knows that the receiver supports MSDU aggregation. A STA shall not aggregate MSDUs that have different values of priority as indicated by the MA-UNITDATA.request primitive. A STA may aggregate MSDUs with different values of destination address as long as they would have the same value in the Address 1 field had they been sent as individual MPDUs.

To form an A-MSDU, two or more MSDUs are aggregated together, separated by a sub-frame header. This is shown in Figure 001n. The resulting A-MSDU is therefore the combination of all MSDUs in the A-MSDU along with a sub-frame header for each constituent MSDU.

The destination address of the A-MSDU is the address of the STA that is the next immediate intended receiver of the aggregated frame. The source address of the A-MSDU is the MAC address of the STA that created the A-MSDU.

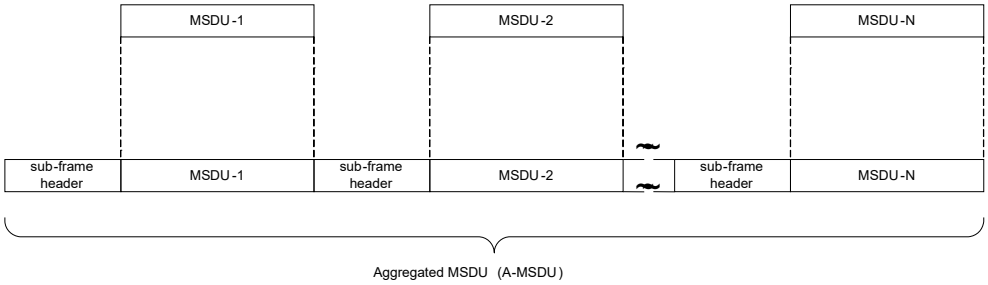



**Figure 001n – Formation of an A-MSDU**

The format for the sub-frame header is given in Figure 002n. The sub-frame header is 14 octets in length and consists of a 16-bit MSDU length field, a 6-octet source address of the constituent MSDU, and a 6-octet destination address of the constituent MSDU. The MSDU length field indicates the length, in octets, of the constituent MSDU.

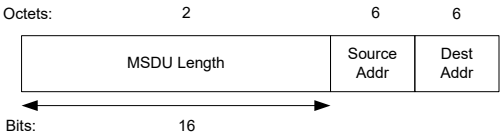



**Figure 002n – Sub-Frame Header**

A data frame bearing an A-MSDU within its frame body is identified by a '1' in the Aggregated MSDU bit of the QoS Control Field (Clause 7.1.3.5). For data frames containing a non-aggregated MSDU, this bit will be zero.

After aggregation, the procedures for handling an A-MSDU are no different from an MSDU including sequence number assignment, optional MSDU integrity protection, and fragmentation, with the single exception of the Aggregated MSDU bit described above. Once formed, A-MSDUs shall not be un-aggregated by the transmitter, as there are no facilities for individual sequencing or retransmission of the constituent MSDUs.

A method for determining when to engage optional MSDU aggregation is out of scope for this standard.

***Insert the following subclause after clause 9.1.3(.11e) and renumber existing subclauses 9.1.6(.11e) to be subclauses 9.1.7***

### 9.1.6 HTP Burst Transmission overview

The high-throughput PHY defines burst transmission formats that permit more efficient usage of the medium. A HTP burst transmission is performed in a single medium access, and permits frames to be sent to different destination addresses. These formats shall only be used to transmit frames to other HTP STAs, and may be used as part of any kind of TXOP. The medium spacing before and after a HTP burst transmission shall be governed by the rules covering the spacing before and after a non-burst transmission in the TXOP.

A HTP burst transmission consists of a sequence of frames transmitted by a single HTP STA without intervening frames by any other STA. The frames of the HTP burst transmission shall be transmitted using a single HTP rate group as defined in 20.3.2.2. During a HTP burst transmission, the MAC may utilise RIFS and/or instruct the PHY to aggregate multiple frames into a single A-PPDU. These formats are illustrated in Figure 003n.

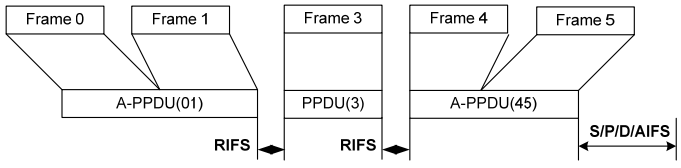



**Figure 003n – HTP Burst transmission**

Frames may be aggregated into a single A-PPDU if they are being transmitted at the same TXPWR_LEVEL. A frame that uses a different TXPWR_LEVEL as the previous frame in the HTP burst transmission may use RIFS.

# 9.2 DCF

## 9.2.3 Interframe Space (IFS)

***Change the text in clause 9.2.3(.11e) as follows***

The time interval between frames is called the IFS. A STA shall determine that the medium is idle through the use of the carrier sense function for the interval specified. An interframe space, RIFS, is defined for use between frames in a HTP burst transmission, and another five IFSs are defined to provide priority levels for access to the wireless media. To obtain access to the medium, a STA shall determine that the medium is idle through the use of the carrier sense function for the interval specified. ~~Five different IFSs are defined to provide priority levels for access to the wireless media; they~~ The interframe spaces are listed in order, from the shortest to the longest except for AIFS. Figure 49 shows some of these relationships.

a) RIFS Reduced Interframe Space
b) Short Interframe Space
c) PIFS Point Coordination Function (PCF) Interframe Space
d) DIFS Distributed Coordination Function (DCF) Interframe Space
e) AIFS Arbitration Interframe Space (used by the QoS facility)
f) EIFS Extended Interframe Space

***Insert the following subclause after clause 9.2.3(.11e) and renumber existing subclauses 9.2.3.1(.11e) through 9.2.3.5(.11e) to be subclauses 9.2.3.2 through 9.2.3.6.***

### 9.2.3.1 RIFS

The RIFS may be used for the second or subsequent frame of a HTP burst transmission if the frame will be transmitted at a different power than the immediately previous frame.

## 9.2.12 Determination of PLME aCWmin characteristics

***Modify the first paragraph of clause 9.2.12 as follows:***

In the case of the Clause 19 Extended Rate PHY and Clause 20 High Throughput PHY, the aCWmin value is dependent on the requestor's characteristic rate set. The characteristic rate set is equal to the IBSS's supported rate set when the STA is operating as a member of an IBSS. It is equal to the AP's supported rate set when the STA is associated with an AP. At all other times, it is equal to the STA's mandatory rate set. The MAC variable aCWmin is set to aCWmin(0) if the characteristic rate set includes only rates in the set 1, 2, 5.5, 11 otherwise, aCWmin is set to aCWmin(1). If the returned value for aCWmin is a scalar, then the MAC always sets the variable aCWmin to the returned scalar value of aCWmin.

# 9.6 Multirate support

***Make the following changes to paragraph 7 of clause 9.6(.11g) "Multirate Support":***

To allow the transmitting STA to calculate the contents of the Duration/ID field, a STA responding to a received frame shall transmit its Control Response (either CTS or ACK) frames at the highest rate in the BSSBasicRateSet

that is less than or equal to the rate of the immediately previous frame in the frame exchange sequence (as defined in 9.7) and that is of the same modulation ~~type~~ class (see Clause 9.6.1) as the received frame. If no rate in the basic rate set meets these conditions, then the control frame sent in response to a received frame shall be transmitted at the highest mandatory rate of the PHY that is less than or equal to the rate of the received frame, and that is of the same modulation ~~type~~ class as the received frame. In addition, the Control Response frame shall be sent using the same PHY options as the received frame, unless they conflict with the requirement to use the BSSBasicRateSet.

***Add new clause 9.6.1 immediately following the existing clause 9.6***

### 9.6.1 Modulation Classes

In order to determine the rules for response frames given in clause 9.6, the following modulation classes are defined. Each row defines a modulation class. Modulation types within the same row have the same modulation class, while modulation types in different rows have different modulation classes.

**Table 9.6.1T Modulation Classes**

| Modulation Class | Description |
|---|---|
| 1 | Clause 16 Infrared PHY |
| 2 | Clause 14 Frequency Hopping Spread Spectrum PHY |
| 3 | Clause 15 DSSS PHY, and Clause 18 High Rate DSSS PHY |
| 4 | Clause 19.6 ERP-PBCC PHY |
| 5 | Clause 19.7 DSSS-OFDM |
| 6 | Clause 19.5 ERP-OFDM PHY |
| 7 | Clause 17 Orthogonal Frequency Division Multiplexing PHY in the 5GHz band |
| 8 | Clause 20 High Throughput PHY (20 MHz transmissions) |
| 9 | Clause 20 High Throughput PHY (40 MHz transmissions) |

## 9.9 HCF

### 9.9.1 HCF contention-based channel access (EDCA)

### 9.9.1.4 Multiple frame transmission in an EDCA TXOP

***Change the first paragraph of subclause 9.9.1.4(.11e) as follows:***

Multiple frames may be transmitted in an acquired EDCA TXOP following the rules in 9.9.1.3. if there are more than one frame pending in the AC for which the channel has been acquired. However, those frames that are pending in other ACs shall not be transmitted in this EDCA TXOP. If a QSTA has in its transmit queue an

additional frame of the same AC as the one just transmitted, and the duration of transmission of that frame plus any expected acknowledgement for that frame is less than the remaining medium occupancy timer value, then the QSTA may commence transmission of that frame ~~at SIFS after the completion of the immediately preceding frame exchange sequence~~ after the completion of the appropriate interframe space from the end of the immediately preceding frame exchange sequence. The intention of using the multiple frame transmission shall be indicated by the QSTA through the setting of the duration/ID values in one of the following two ways (see 7.1.4):

### 9.9.2 HCF controlled channel access

### 9.9.2.1 HCF controlled channel access procedure

### 9.9.2.1.2 CAP generation

***Change the second paragraph of subclause 9.9.2.1.2(.11e) as follows***

~~During a CFP or a TXOP in CP, after each data, QoS data or management type frame with a group address in the Address1 field, the HC shall wait for at least one PIFS period, and shall only continue to transmit if the WM is idle.~~ After the last frame of all ~~other non-final~~ frame exchange sequences ~~(e.g., sequences that convey unicast QoS data or management type frames)~~ during a TXOP, the holder of the current TXOP shall wait for one SIFS period before transmitting the first frame of the next frame exchange sequence, unless the frame exchange is part of a HTP burst transmission when the rules identified in clause 9.1.6 apply. The HC may sense the channel and reclaim the channel after a duration of PIFS after the TXOP, if the channel remains idle. A CAP ends when the HC does not reclaim the channel after a duration of PIFS after the end of a TXOP.

### 9.9.2.2 TXOP structure and timing

***Change the first paragraph of subclause 9.9.2.2(.11e) as follows***

Any QoS data type frame of a subclass that includes CF-Poll contains a TXOP limit in its QoS control field. The ensuing polled TXOP is protected by the NAV set by the Duration field of the frame that contained the QoS (+) CF-Poll function, as shown in Figure 62.4. Within a polled TXOP a QSTA may initiate the transmission of one or more frame exchange sequences, with all such sequences being part of a HTP burst transmission, or being nominally separated by a SIFS interval. The QSTA shall not initiate transmission of a frame unless the transmission, and any acknowledgement or other immediate response expected from the peer MAC entity, are able to complete prior to the end of the remaining TXOP duration. All transmissions, including the response frames, within the polled TXOP are considered to be the part of the TXOP and the HC shall account for these when setting the TXOP limit. If the TXOP Limit subfield in the QoS Control field of the QoS data type frame that includes CF-Poll is set to 0, then the QSTA to which the frame is directed to shall respond with either one MPDU or one QoS Null frame.

## 9.10 Block acknowledgment

### 9.10.1 Introduction (Informative)

***Change the first paragraph of subclause 9.9.10.1(.11e) as follows***

The Block Acknowledgement (Block Ack) mechanism allows a block of QoS Data MPDUs to be transmitted between two QSTAs without intervening ACK frames ~~each separated by a SIFS period, between two QSTAs~~. The mechanism is for improving the channel efficiency by aggregating several acknowledgements into one frame. There are two types of Block Ack mechanisms: immediate and delayed. Immediate Block Ack is suitable for

high-bandwidth, low latency traffic while the delayed Block Ack is suitable for applications that tolerate moderate latency. In this clause, the QSTA with data to send using the Block Ack mechanism is referred to as the originator and the receiver of that data as the recipient.

### 9.10.3 Data and acknowledgement transfer

***Change the first paragraph of subclause 9.9.10.1(.11e) as follows***

After setting up for the Block exchange following the procedure in 9.10.2, the originator may transmit a Block of QoS data type frames ~~separated by SIFS period,~~ with the total number of frames not exceeding the Buffer Size subfield in the associated ADDBA response frame. Each of the frames shall have the Ack policy subfield in the QoS Control set to "Block Acknowledgement". The RA field of the frames shall be the recipient's *unicast* address. The originator requests acknowledgement of outstanding QoS Data type frames by sending a BlockAckReq frame. The recipient shall maintain a Block Ack record for the block.

## 9.12 Frame exchange sequences

***Edit Table 22.1(.11e) <HCF sequence> and replace all "=" with"-".***

***Remove definition 36 from end of Table 22.4(.11e) (no PIFS spacing defined anymore).***

***Replace the last sentence of the text in subclause 9.12 as follows(.11e) with:***

Individual frames within each of these sequences ~~are separated by a SIFS~~ may be send as part of a HTP burst transmission if the frames meet the rules identified in clause 9.16., otherwise a SIFS separation is used unless an "=" sign appears between frames in the table, in which case, PIFS is used.

***Edit Table 22 <CF frame sequences> and change field "frames in sequence" for row "Beacon(CF)" from "1" to "1 or 2" and modify legend 14 (for Beacon) as follows:***

14—"Beacon(CF)" represents a management frame of subtype Beacon with a nonzero value in the CFPDurRemaining field of its CF Parameter Set element. The optional second Beacon shall be sent after the first Beacon using a lower rate. For example, this enables STAs which are out of normal communication range to receive a Beacon.

## 9.13 Protection mechanism

***Delete two paragraphs from the text of clause 9.13 as follows:***

If a protection mechanism is being used, a fragment sequence may only employ ERP-OFDM modulation for the final fragment and control response.

The rules for calculating RTS/CTS NAV fields are unchanged when using RTS/CTS as a protection mechanism.

***Insert the following two new subclauses after clause 9.13:***

### 9.13.1 OFDM Protection

The intent of an OFDM protection mechanism is to ensure that an HTP STA does not transmit an MPDU of type Data or an MMPDU, using a Clause 20 rate which is not also a Clause 17 or Clause 19 rate unless it has

attempted to update the NAV or cause a PHY-CCA.indicate(status=BUSY) to be elicited by receiving Clause 17 or Clause 19 STAs.

The updated NAV period shall be longer than or equal to the total time required to send the data and any required response frames.

The PHY-CCA.indicate(status=BUSY) shall be longer than or equal to the total time required to send the data and any required response frames.

HTP STAs shall use OFDM protection mechanisms (such as RTS/CTS or CTS-to-self employing a Clause 19 or Clause 17 rate) for Clause 20-only rate MPDUs of type Data or MMPDUs when the Use_OFDM_Protection field of transmitted or received ERP Information elements is set to 1 and the BSSID of the frame which contained the ERP Information element is the same as the BSS which the HTP STA has joined or started. Clause 19 rates shall be employed when the BSS is operating in a Clause 19 channel. Clause 17 rates shall be employed when the BSS is operating in a Clause 17 channel.

OFDM Protection mechanism frames shall conform to at least one of the following conditions:
a) The frame shall be sent using one of the mandatory Clause 19 or Clause 17 rates and using one of the mandatory Clause 17 or Clause 19 waveforms, so that all known ERP or Clause 17 STAs in the BSA will know the duration of the exchange even if they cannot detect the Clause 20 frames using their CCA function
b) The frame shall be sent using a Clause 17 preamble and signal field (additional, non-clause 17 preamble and signal field may be present following the Clause 17 preamble and signal field)
c) The frame shall be sent using a Clause 19 preamble and signal field (additional, non-clause 19 preamble and signal field may be present following the Clause 19 preamble and signal field)

In the case of a BSS composed of only HTP STAs, but with knowledge of a neighboring co-channel BSS having nHTP traffic, the AP may require either or both of protection mechanisms and OFDM protection mechanisms to protect the BSSs traffic from interference. This will provide propagation of NAV of PHY-CCA.indicate(status=BUSY) to all associated STAs and all STAs in a neighboring co-channel BSS within range through BSS basic rate set modulated messages. Frames that propagate the NAV throughout the BSS include RTS/CTS/ACK frames, all data frames with the “more fragments” field set to 1, all data frames sent in response to PS-Poll that are not preceded in the frame sequence by a data frame with the “more fragments” field set to 1, Beacon frames with nonzero CF time, +CF-POLL frames, various QOS frames, and CF-End frames. Frames that propagate PHY-CCA.indicate(status=BUSY) throughout the BSS include any frames which commence with an appropriately chosen preamble and signal field.

If any of the rates in the BSSBasicRateSet of the OFDM protection mechanism frame transmitting STAs BSS are Clause 17 or Clause 19 rates, then the OFDM protection mechanism frames shall be sent at one of those Clause 17 or Clause 19 basic rates, unless either condition b) or condition c) from above has been met, in which case, no rate restrictions apply.

OFDM Protection Mechanisms shall not be used where the frame transmission will be protected by the Protection Mechanism defined in clause 9.13

### 9.13.2 20MHz Protection

The intent of a 20MHz protection mechanism is to ensure that a 40MHz HTP STA does not transmit an MPDU of type Data or an MMPDU as a 40MHz transmission unless it has attempted to update the NAV or cause a PHY-CCA.indicate(status=BUSY) to be elicited by receiving 20MHz HTP STAs which may be present.

The updated NAV period shall be longer than or equal to the total time required to send the data and any required response frames.

The PHY-CCA.indicate(status=BUSY) shall be longer than or equal to the total time required to send the data and any required response frames.

40MHz HTP STAs shall use 20MHz protection mechanisms (such as RTS/CTS or CTS-to-self employing a 20MHz HTP rate) for 40MHz transmissions of MPDUs of type Data or MMPDUs when the Use_20MHz_Protection field of transmitted or received ERP Information elements is set to 1 and the BSSID of the frame which contained the ERP Information element is the same as the BSS which the 40MHz HTP STA has joined or started.

20MHz Protection mechanism frames shall conform to at least one of the following conditions:
a) The frame shall be sent using one of the mandatory 20MHz HTP rates, so that all known 20MHz HTP STAs in the BSA will know the duration of the exchange even if they cannot detect 40MHz transmissions using their CCA function.
b) The frame shall be sent using a 20MHz preamble and signal field (additional, non-20MHz preamble and signal field may be present following the 20MHz preamble and signal field)

In the case of a BSS composed of only 40MHz HTP STAs, but with knowledge of a neighboring co-channel BSS having nHTP traffic, the AP may require any of clause 9.13 protection mechanisms, OFDM protection mechanisms and 20MHz protection mechanisms to protect the BSSs traffic from interference. This will provide propagation of NAV of PHY-CCA.indicate(status=BUSY) to all associated STAs and all STAs in a neighboring co-channel BSS within range through BSS basic rate set modulated messages. Frames that propagate the NAV throughout the BSS include RTS/CTS/ACK frames, all data frames with the “more fragments” field set to 1, all data frames sent in response to PS-Poll that are not preceded in the frame sequence by a data frame with the “more fragments” field set to 1, Beacon frames with nonzero CF time, +CF-POLL frames, various QOS frames, and CF-End frames. Frames that propagate PHY-CCA.indicate(status=BUSY) throughout the BSS include any frames which commence with an appropriately chosen preamble and signal field.

If any of the rates in the BSSBasicRateSet of the 20MHz protection mechanism frame transmitting STAs BSS are 20MHz rates, then the 20MHz protection mechanism frames shall be sent at one of those 20MHz basic rates, unless condition b) from above has been met, in which case, no rate restrictions apply.

OFDM Protection Mechanisms shall not be used where the frame transmission will be protected by the Protection Mechanism defined in clause 9.13

***Insert new clause 9.14 and sub-clauses as follows:***

## 9.14 40 MHz Channel Pairs

Clause 20 defines a mode in which High Throughput PHYs can transmit a frame utilising a 40 MHz channel pair in order to achieve lower frame durations than if a single 20 MHz channel was used. This clause describes the MAC support for this feature in an infrastructure BSS. 40 MHz transmissions shall only be used when the STA has joined or started an Infrastructure BSS.

A 40 MHz channel pair consists of two 20 MHz channels, and a BSS operating on a 40 MHz Channel Pair will make use of one of these channels (called the primary channel) for 20 MHz transmissions. The other channel (called the secondary channel) will not be used by the BSS for 20 MHz transmissions.

### 9.14.1 40 MHz Fundamentals of Operation

A 40 MHz channel pair consists of two 20 MHz channels, on each of which there could be 20 MHz transmissions (from an overlapping BSS on either channel, or from 20 MHz transmissions on the primary channel), and on each of which the Carrier Sense mechanism described in clause 9.2.1 could be run. However, it is not possible to combine two Carrier Sense mechanisms without degrading the effective priority of 40 MHz transmissions to such an extent that they would provide no benefit.

For this reason the MAC models a 40 MHz channel pair as a single 20 MHz channel (the primary channel) in which some transmissions happen to "overflow" into the Secondary Channel.

A STA that wishes to transmit on both channels of a 40MHz channel shall conduct CCA on the primary channel, with the following extension. For any frame transmission that requires the CCA function to indicate a clear channel before transmission, the secondary channel CCA state shall also be checked. If the secondary channel CCA indicates a busy channel, the STA shall not transmit on the secondary channel. It shall either fall back to 20MHz operation (for only the current transmission), or shall consider the frame transmission to have failed (including all incrementing of retry counters and contention windows etc where required).

An AP shall indicate that it is operating on a 40 MHz channel pair by including the Channel Set information element in its Beacon frames. An AP shall not change the information contained in the Channel Set information element without invoking the channel move procedure described in clause 11.6.7. A STA that has joined a BSS and that wishes to use 40 MHz transmissions shall check the setting of the Secondary_Channel_Used bit in the ERP Information Element in the last valid Beacon frame received from the BSS, and shall not use 40 MHz transmissions where the Secondary_Channel_Used bit is set to 1.

A STA shall not send a 20 MHz transmission to a member STA of a BSS on the secondary channel of that BSS. A STA that has joined or started a BSS operating on a 40 MHz channel pair shall discard all 20 MHz transmissions received on the secondary channel. A STA shall not join a BSS on its secondary channel.

An AP that detects significant evidence of collisions on the secondary channel may invoke the channel move procedure described in clause 11.6.7.

#### 9.14.2.1 Secondary Channel Beacon

In order to reduce the chance of the secondary channel being used by an overlapping BSS, an AP may send a Beacon frame using the secondary channel with contents chosen to discourage use of the secondary channel by other BSSes.

The frame body of such a beacon is shown in Clause 7.2.3.1.1. These beacons contain a rate set consisting of a single clause 20 basic rate, and so should not cause non-clause 20 STAs to attempt to associate with the AP on the secondary channel.

When transmitting a beacon on the secondary channel, the AP may observe the channel access mechanisms described elsewhere in clause 9 for the transmission of Beacon frames, or it may transmit the Beacon frame without consideration of the state of the secondary channel.

### 9.14.3 Beacon Transmission

An AP operating on a 40 MHz channel pair shall send Beacon frames (with the exception of Secondary Channel Beacon frames) on the primary channel using a 20 MHz transmission.

### 9.14.4 Limits on Channel Numbering

Both the primary and secondary Channels shall be legal 20 MHz channels in the 5GHz band. For a primary channel number "n", the secondary channel number shall be either "n+4" or "n-4".

# 10. Layer management

## 10.4 PLME SAP interface

### 10.4.3 PLME_CHARACTERISTICS.confirm

#### 10.4.3.2 Semantics of the service primitive

***Change the primitive description as follows:***

The primitive provides the following parameters:

PLME-CHARACTERISTICS.confirm(
aSlotTime,
aSIFSTime,
aRIFSTime,
aCCATime,
aRxTxTurnaroundTime,
aTxPLCPDelay,
aRxPLCPDelay,
aRxTxSwitchTime,
aTxRampOnTime,
aTxRampOffTime,
aTxRFDelay,
aRxRFDelay,
aAirPropagationTime,
aMACProcessingDelay,
aPreambleLength,
aPLCPHeaderLength,
aMPDUDurationFactor,
aMPDUMaxLength,
aCWmin,
aCWmax
)

***Add the following entry to the table:***

| | | |
|---|---|---|
| aRIFSTime | integer | The minimum time (in microseconds) that the PHY requires between PSDUs that are transmitted with differing TXPWR_LEVELs within a HTP burst transmission. |

## 10.4.4 PLME-DSSSTESTMODE.request

### 10.4.4.2 Semantics of the service primitive

***Change the sixth row in the table in 10.4.4.2 as shown:***

| | | | |
|---|---|---|---|
| DATA_RATE | Integer | 2, 4, 11, 12,<br>18, 22, 24,<br>36, 44, 48,<br>66, 72, 73-92, 96,<br>97-106, 108, 109-121 | Selects among rates and transmission modes<br>02 = 1 Mbit/s<br>04 = 2 Mbit/s<br>11 = 5.5 Mbit/s<br>12 = 6 Mbit/s<br>18 = 9 Mbit/s<br>22 = 11 Mbit/s<br>24 = 12 Mbit/s<br>36 = 18 Mbit/s<br>44 = 22 Mbit/s<br>48 = 24 Mbit/s<br>66 = 33 Mbit/s<br>72 = 36 Mbit/s<br>96 = 48 Mbit/s<br>108 = 54 Mbit/s<br>73-95, 97-107, 109-122 = See Tables 003-009 and Table 019 in subclause 20.3.2.2 and 20.3.5.10 respectively |

# 20. High throughput PHY specification for the 2.4 and 5 GHz bands

## 20.1 Overview

This clause specifies the PHY entity for a multiple input multiple output orthogonal frequency division multiplexing (MIMO-OFDM) system and the additions that have to be made to the base standard to accommodate the MIMO-OFDM PHY. The radio frequency LAN system is aimed for both the 2.4 GHz band and the 5 GHz bands, as specified in subclause 20.3.8.3

### 20.1.1 Introduction

The MIMO-OFDM system provides a wireless LAN with mandatory data payload communication capabilities of up to 135 Mbit/s and with optional modes capable of supporting data rates up to 540 Mbit/s. The MIMO-OFDM PHY draws from the basic OFDM PHY defined in Clause 17, and builds its extensions to two, three, and four transmit antenna modes (hereafter known as 2TX, 3TX, and 4TX, respectively), operating in 20 MHz bandwidth. Additionally, 1TX, 2TX, 3TX, and 4TX modes are also defined for operation in 40 MHz bandwidth.

### 20.1.2 Operational Modes

The radio portion of all Clause 20 compliant MIMO-OFDM PHY systems shall implement all mandatory and optional data rates defined in Clause 17, all mandatory data rates defined in Clause 19, and all optional data rates of the OFDM-based ERP defined in Clause 19, in their respective bands of operation. In addition, support for transmitting and receiving data using the MIMO-OFDM PHY defined in this Clause is mandatory for all rates specified for the 2TX, 20 MHz mode in subclause 20.3.2.2. Support for 3TX and 4TX modes in 20 MHz; 1TX, 2TX, 3TX, and 4TX modes in 40 MHz; and all modes defined in subclause 20.3.5.10 shall be optional.

Furthermore, the amendment extends the optional ‘half-clocked’ operation with 10 MHz channel spacings described in Section 17 and Annex J to high throughput modes. For each mode offered at 20 MHz channel spacing, a corresponding mode with half the data rate is offered with 10 MHz channel spacing. Support of the 27, 40.5, 54, 60.75, and 67.5 Mbps modes corresponding to the modes in Table 003 is mandatory when using 10 MHz channel spacing.

### 20.1.3 Scope

This subclause describes the PHY services provided to the IEEE 802.11 wireless LAN MAC by the MIMO-OFDM system. The MIMO-OFDM PHY layer consists of two protocol functions, defined as follows:

a) A PHY convergence function, which adapts the capabilities of the physical medium dependent (PMD) system to the PHY service. This function is supported by the physical layer convergence procedure (PLCP), which defines a method of mapping the IEEE 802.11 PHY sublayer service data units (PSDU) into a framing format suitable for sending and receiving user data and management information between two or more stations using the associated PMD system.

b) A PMD system whose function defines the characteristics and method of transmitting and receiving data through a wireless medium between two or more stations, each using the MIMO-OFDM PHY.

### 20.1.4 MIMO-OFDM PHY functions

The architecture of the MIMO-OFDM PHY is depicted in the ISO/IEC basic reference model shown in Figure 141 of 18.4.1. The MIMO-OFDM PHY contains three functional entities: the PMD function, the PHY convergence function (PLCP), and the layer management function.

The MIMO-OFDM PHY service is provided to the MAC through the PHY service primitives defined in Clause 12. Interoperability is addressed by use of the carrier sense mechanism specified in 9.2.1 and the protection mechanism in 9.10. This mechanism allows non-MIMO-OFDM stations to know of MIMO-OFDM traffic that they cannot demodulate so they may defer the medium to that traffic.

## 20.2 PHY-specific service parameter list

The architecture of the IEEE 802.11 MAC is intended to be PHY independent. Some PHY implementations require PHY-dependent MAC state machines running in the MAC sublayer in order to meet certain PMD requirements. The PHY-dependent MAC state machine resides in a sublayer defined as the MAC sublayer management entity (MLME). In certain PMD implementations, the MLME may need to interact with the PLME as part of the normal PHY SAP primitives. These interactions are defined by the PLME parameter list currently defined in the PHY service primitives as TXVECTOR and RXVECTOR. The list of these parameters, and the values they may represent, are defined in the specific PHY specifications for each PMD. This subclause addresses the TXVECTOR and RXVECTOR for the MIMO-OFDM PHY.

The parameters in Table 001 are defined as part of the TXVECTOR parameter list in the PHY-TXSTART.request service and PLME-TXTIME.request primitives.

**Table 001—TXVECTOR parameters**

| Parameter | Value |
|---|---|
| DATARATE | The rate used to transmit the PSDU in Mbit/s. Allowed value depends on the values of TRANSMISSION_MODE and NUM_STREAMS parameters<br><br>Values: 6.75, 10.125, 13.5, 20.25, 27, 40.5, 54, 60.75, 67.5, 81, 108, 121.5, 135, 162, 182.25, 202.5, 216, 243, 270, 324, 364.5, 405, 432, 486, 540 |
| LENGTH | The length of the PSDU in octets<br><br>Range: 1-8191 |
| TRANSMISSION_MODE | The mode used for transmission of the PPDU. Determines the preamble type used.<br><br>Enumerated type: 2TX20GF, 3TX20GF, 4TX20GF, 2TX20MM, 3TX20MM, 4TX20MM, 1TX40GF, 2TX40GF, 3TX40GF, 4TX40GF, 1TX40MM, 2TX40MM, 3TX40MM, 4TX40MM. |
| NUM_STREAMS | The number of independent spatial streams transmitted.<br><br>Values: 1, 2, 3, 4. |
| CODE_TYPE | Convolutional or LDPC<br><br>Values: 0 (convolutional), 1 (LDPC) |
| SERVICE | The scrambler initialization vector.<br><br>16 null bits |

| | |
|---|---|
| TXPWR_LEVEL | The transmit power level. The definition of these levels is up to the implementer.<br><br>Range: 1-8 |
| LPI | Indicates that this is the last PSDU to be aggregated into the current PPDU<br><br>Values: true, false |
| BURST_ DURATION | The length in microseconds of the BURST_DURATION field in the ~~mixed mode~~mixed-mode preamble. Only used when a ~~mixed mode~~mixed-mode TRANSMISSION_MODE is selected.<br><br>Range: 0-4095 |

The parameters in Table 002 are defined as part of the RXVECTOR parameter list in the PHY-RXSTART.indicate service primitive. When implementations require the use of these vectors, some or all of these parameters may be used in the vectors.

**Table 002—RXVECTOR parameters**

| Parameter | Value |
|---|---|
| DATARATE | The rate at which the PSDU was received in Mbit/s. Allowed value depends on the values of TRANSMISSION_MODE and NUM_STREAMS parameters<br><br>Values: 6.75, 10.125, 13.5, 20.25, 27, 40.5, 54, 60.75, 67.5, 81, 108, 121.5, 135, 162, 182.25, 202.5, 216, 243, 270, 324, 364.5, 405, 432, 486, 540 |
| LENGTH | The length of the PSDU in octets.<br><br>Range: 1-8191 |
| TRANSMISSIO N_MODE | The transmission type detected during reception of the PPDU<br><br>Enumerated type: 2TX20GF, 3TX20GF, 4TX20GF, 2TX20MM, 3TX20MM, 4TX20MM, 1TX40GF, 2TX40GF, 3TX40GF, 4TX40GF, 1TX40MM, 2TX40MM, 3TX40MM, 4TX40MM. |
| NUM_STREAM S | The number of independent spatial streams transmitted.<br><br>Values: 1,2,3,4. |
| CODE_TYPE | Convolutional or LDPC<br><br>Values: 0 (convolutional), 1 (LDPC) |
| SERVICE | Null |
| RSSI | The RSSI is a measure of the RF energy received by the MIMO-OFDM PHY, averaged across all RX antennas. The 8-bit value is in the range of 0 to RSSI maximum as described in 17.2.3.2. |
| LPI | Indicates that this is the last PSDU to be aggregated into the current PPDU<br><br>Values: true, false |
| BURST_ DURATION | The length in microseconds of the BURST_DURATION field in the ~~mixed mode~~mixed-mode preamble. Only valid when a ~~mixed mode~~mixed-mode TRANSMISSION_MODE is used.<br><br>Range: 0-4095 |

# 20.3 MIMO-OFDM PLCP sublayer

### 20.3.1 Introduction

This subclause provides a convergence procedure by which PSDUs are converted to and from PPDUs at the transmitter and receiver. During transmission, the PSDU shall be appended with a PLCP preamble and header to create the PPDU. At the receiver, the PLCP preamble and header are processed to aid in the demodulation and delivery of the PSDU.

Stations implementing the MIMO-OFDM PHY shall use one of two methods of access to the medium. The medium may be reserved solely via a MAC mechanism, as defined in subclause 9.13. Alternatively, a special PLCP frame format may be used to cause non-MIMO-OFDM stations to defer the medium to MIMO-OFDM traffic. Hereafter, these two methods of access shall be known as greenfield and mixed-mode, respectively.

### 20.3.2 PLCP frame format

Figure 001 shows the format of the PPDU used with greenfield access in the 1TX mode of operation in 40 MHz and the 2TX modes of operation in both 20 and 40 MHz. The PPDU consists of a MIMO-OFDM PLCP preamble, MIMO-OFDM PLCP header, PSDU, and may consist of appended tail bits and pad bits.

The MIMO-OFDM PLCP preamble is composed of a sequence of short and long training symbols. The format of the PLCP preamble is defined in subclause 20.3.3 for each mode of operation in the MIMO-OFDM PHY.

The MIMO-OFDM PLCP header is composed of the SIGNAL-N field and the SERVICE field. The SIGNAL-N field is defined in 20.3.4 and consists of 54 bits that specify all configuration and length-related parameters associated with PPDU transmission. The SERVICE field is composed of 16 bits and is defined in subclause 20.3.5.1.

The SERVICE field of the PLCP header and the PSDU (with tail and pad bits appended, if necessary) are denoted as DATA and may constitute multiple MIMO-OFDM symbols. These symbols are transmitted according to the configuration parameters specified in the SIGNAL-N field.

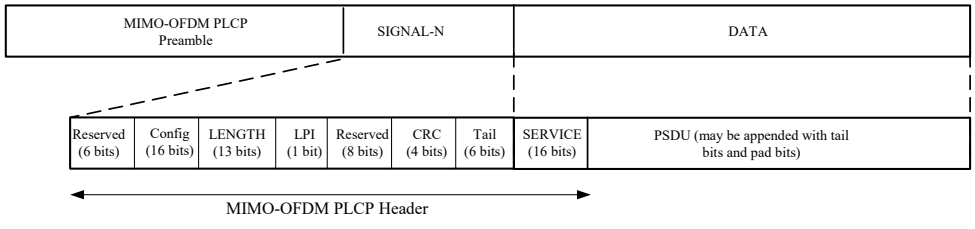



**Figure 001 – PPDU frame format: Greenfield access in the 1TX (40 MHz) and 2TX (20 and 40 MHz) modes**

Figure 002 shows the format of the PPDU used with greenfield access in the 3TX and 4TX modes of operation in both 20 and 40 MHz. In these modes the MIMO-OFDM PLCP preamble field is extended according to subclause 20.3.3 in order to provide training from the additional transmit antennas.

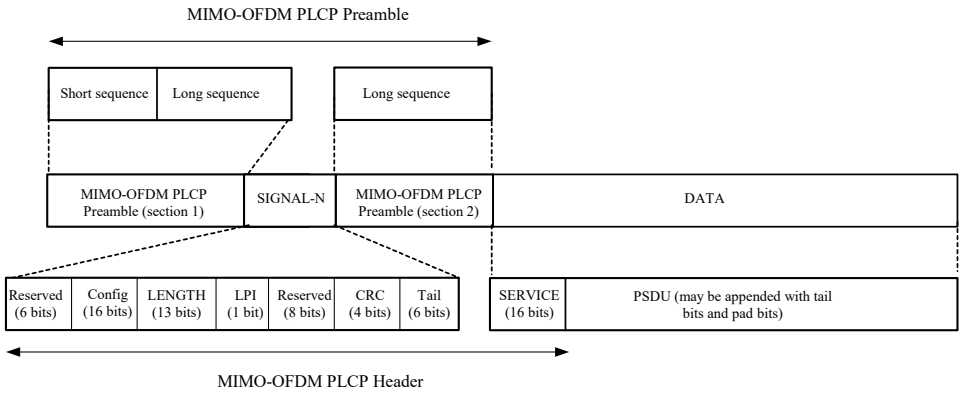



**Figure 002 – PPDU frame format: Greenfield access in the 3TX and 4TX modes (20 and 40 MHz)**

Figure 003 shows the format of the PPDU used with mixed-mode access in the 1TX mode of operation in 40 MHz and the 2TX modes of operation in both 20 and 40 MHz. The PLCP header in these modes consists of an additional SIGNAL-MM field that conveys information about the MIMO-OFDM PPDU transmission to non-MIMO-OFDM stations, causing them to defer the medium for the duration of the MIMO-OFDM transmission. The SIGNAL-MM field is defined in subclause 20.3.4.

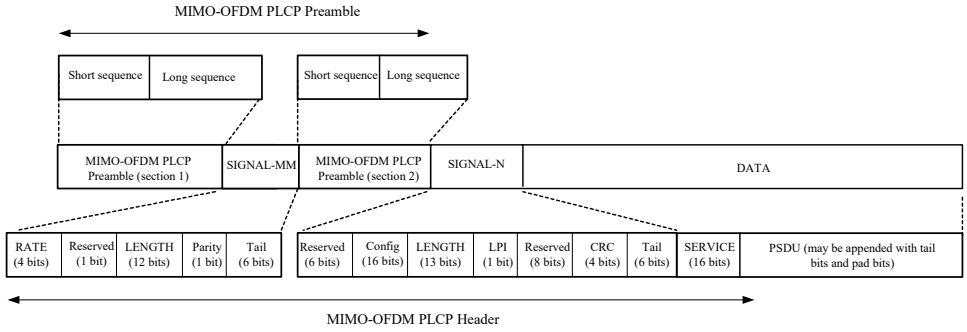



**Figure 003 – PPDU frame format: ~~Mixed mode~~Mixed-mode access in the 1TX (40 MHz) and 2TX (20 and 40 MHz) modes**

Figures 004 and 005 shows the format of the PPDU used with ~~mixed mode~~mixed-mode access in the 3TX and 4TX modes, operating in 20 MHz and 40 MHz, respectively.

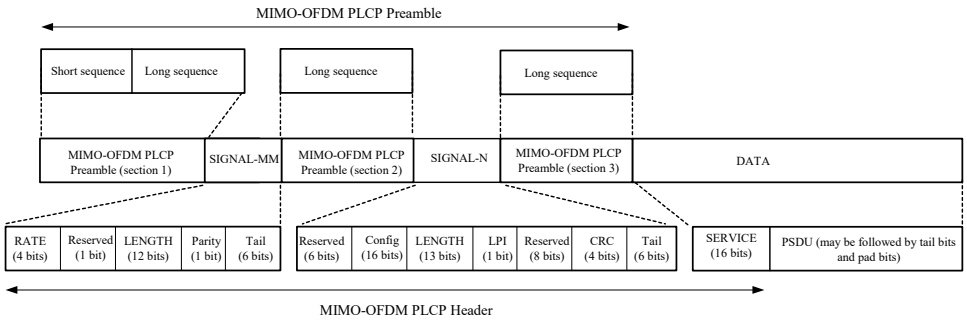



**Figure 004– PPDU frame format: ~~Mixed mode~~Mixed-mode access in the 3TX and 4TX modes (20 MHz)**

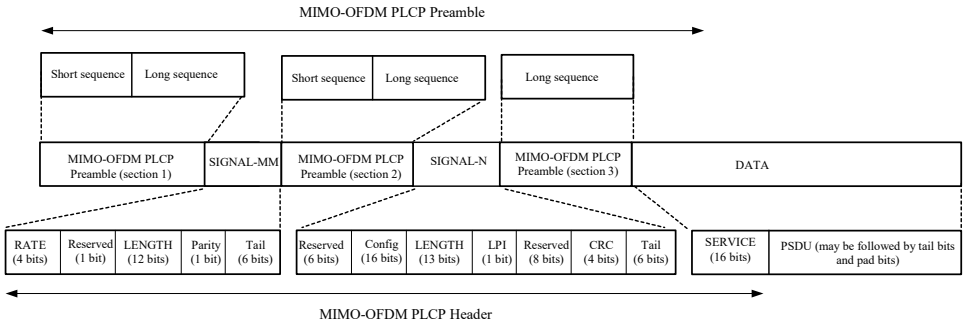



**Figure 005– PPDU frame format: ~~Mixed mode~~Mixed-mode access in the 3TX and 4TX modes (40 MHz)**

### 20.3.2.1 Overview of the PPDU encoding process

The encoding process is composed of many detailed steps, which are described fully in later subclauses, as noted below. The following overview intends to facilitate understanding the details described in these subclauses:

a) Produce the PLCP preamble fields for each transmit antenna based on the TRANSMISSION_MODE field of the TXVECTOR. Refer to 20.3.3 for details.

b) Produce the PLCP header field from the LENGTH, DATARATE, TRANSMISSION_MODE, NUM_STREAMS, CODE_TYPE, and SERVICE fields of the TXVECTOR by filling the appropriate bit fields, as described in subclause 20.3.4 and subclause 20.3.5.1.

c) Calculate from the DATARATE, TRANSMISSION_MODE, and NUM_STREAMS fields of the TXVECTOR, the number of data bits per MIMO-OFDM symbol ($N_{DBPS}$), the code rate (R), the number of bits in each OFDM subcarrier per antenna ($N_{BPSC}$), the number of coded bits per MIMO-OFDM symbol ($N_{CBPS}$), the number of spatial streams ($N_{SS}$), and the number of encoding streams ($N_{ES}$).

d) Extend the data bit string with “zero” bits (at least 6 bits for each encoding stream) so that the resulting length will be a multiple of the number of data bits per OFDM symbol ($N_{DBPS}$).

e) Initiate the scrambler with a pseudorandom non-zero state; generate a sequence of scrambled data bits as defined in subclause 20.3.5.4.

f) Demultiplex every other bit of the "data" to the $N_{ES}$ encoding streams, with bit 0 directed to the first encoder.

g) Replace the six scrambled "zero" bits following the "data" of each parallel encoding stream with six nonscrambled "zero" bits (These bits return the convolutional encoder to the "zero state" and are denoted as "tail bits.").

h) Encode each extended, scrambled parallel encoding stream data string with a convolutional encoder (R = 1/2). Omit (puncture) some of the encoder output string (chosen according to "puncturing pattern") to reach the desired "code rate", as defined in subclause 20.3.5.5.

i) Divide the parallel encoded bit strings into groups of $N_{CBPS} / N_{ES}$ bits and multiplex them alternately between the $N_{ES}$ encoders' outputs to obtain a single aggregated bit string.

j) Divide the aggregated bit string into groups of $N_{CBPS}$ bits. Within each group, perform an "interleaving" (reordering) of the bits according to the rule specified in subclause 20.3.5.6. The interleaving parameters are independent of $N_{ES}$.

k) Divide the resulting coded and interleaved data string into groups of $N_{BPSC}$ bits. For each of the bit groups, convert the bit group into a complex number according to the modulation encoding tables.

l) Divide the complex number string into groups of $N_{SD} \times N_{SS}$ complex numbers, where $N_{SD}$ is the number of data subcarriers per OFDM symbol, and $N_{SS}$ is the number of spatial streams to be transmitted. Map the complex numbers to antennas and subcarriers, as specified in subclause 20.3.5.8. The first $N_{SD}$ complex numbers are modulated on the subcarriers of the first transmit antenna.

m) Insert $N_{SP}$ subcarriers as pilots on each transmit antenna, according to subclause 20.3.5.9.

n) For each group of subcarriers, and on each TX antenna, convert the subcarriers to time domain using inverse Fourier transform. Prepend to the Fourier-transformed waveform a circular extension of itself thus forming a guard interval (GI), and truncate the resulting periodic waveform to a single OFDM symbol length by applying time domain windowing. Refer to 20.3.2.4 for details.

o) Append the OFDM symbols for each antenna one after another, starting with the SIGNAL symbols defined in subclause 20.3.4, and with fields of the PLCP preamble inserted in between if necessary. Refer to 20.3.3 for details.

p) Up-convert the resulting "complex baseband" waveform on each antenna to an RF frequency according to the center frequency of the desired channel and transmit. Refer to 20.3.2.4 and 20.3.8.1 for details.

#### 20.3.2.2 RATE-dependent parameters

When the number of transmitted spatial streams $N_{SS}$ is equal to the number of transmit antennas $N_{TX}$, the RATE-dependent modulation parameters shall be set according to the values defined in Tables 003, 004, and 005 respectively for the 2TX, 3TX, and 4TX modes in 20 MHz. The RATE-dependent parameters for the 1TX, 2TX, 3TX, and 4TX modes in 40 MHz shall be set according to the values defined in Tables 006, 007, 008, and 009, respectively.

The number of parallel encoding streams $N_{ES}$ shall be 2 for all modes in 40 MHz in which the number of spatial streams $N_{SS}$ is greater than two. $N_{ES}$ shall be 1 for all other modes.

**Table 003—Rate-dependent parameters for 20 MHz, $N_{SS}$ = 2 ($N_{ES}$ = 1)**

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data sub-carriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 54 | 16-QAM | 1/2 | 4 | 54 | 2 | 432 | 216 | 73 |
| 81 | 16-QAM | 3/4 | 4 | 54 | 2 | 432 | 324 | 74 |
| 108 | 64-QAM | 2/3 | 6 | 54 | 2 | 648 | 432 | 75 |
| 121.5 | 64-QAM | 3/4 | 6 | 54 | 2 | 648 | 486 | 76 |
| 135 | 64-QAM | 5/6 | 6 | 54 | 2 | 648 | 540 | 77 |

**Table 004—Rate-dependent parameters for 20 MHz, $N_{SS}$ = 3 ($N_{ES}$ = 1)**

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data sub-carriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 81 | 16-QAM | 1/2 | 4 | 54 | 2 | 648 | 324 | 78 |
| 121.5 | 16-QAM | 3/4 | 4 | 54 | 2 | 648 | 486 | 79 |
| 162 | 64-QAM | 2/3 | 6 | 54 | 2 | 972 | 648 | 80 |
| 182.25 | 64-QAM | 3/4 | 6 | 54 | 2 | 972 | 729 | 81 |
| 202.5 | 64-QAM | 5/6 | 6 | 54 | 2 | 972 | 810 | 82 |

**Table 005—Rate-dependent parameters for 20 MHz, $N_{SS}$ = 4 ($N_{ES}$ = 1)**

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data sub-carriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 108 | 16-QAM | 1/2 | 4 | 54 | 2 | 864 | 432 | 83 |
| 162 | 16-QAM | 3/4 | 4 | 54 | 2 | 864 | 648 | 84 |
| 216 | 64-QAM | 2/3 | 6 | 54 | 2 | 1296 | 864 | 85 |
| 243 | 64-QAM | 3/4 | 6 | 54 | 2 | 1296 | 972 | 86 |
| 270 | 64-QAM | 5/6 | 6 | 54 | 2 | 1296 | 1080 | 87 |

**Table 006—Rate-dependent parameters for 40 MHz, $N_{SS}$ = 1 ($N_{ES}$ = 1)**

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data sub-carriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 13.5 | BPSK | 1/2 | 1 | 108 | 4 | 108 | 54 | 88 |
| 20.25 | BPSK | 3/4 | 1 | 108 | 4 | 108 | 81 | 89 |
| 27 | QPSK | 1/2 | 2 | 108 | 4 | 216 | 108 | 90 |
| 40.5 | QPSK | 3/4 | 2 | 108 | 4 | 216 | 162 | 91 |
| 54 | 16-QAM | 1/2 | 4 | 108 | 4 | 432 | 216 | 92 |
| 81 | 16-QAM | 3/4 | 4 | 108 | 4 | 432 | 324 | 93 |
| 108 | 64-QAM | 2/3 | 6 | 108 | 4 | 648 | 432 | 94 |
| 121.5 | 64-QAM | 3/4 | 6 | 108 | 4 | 648 | 486 | 95 |
| 135 | 64-QAM | 5/6 | 6 | 108 | 4 | 648 | 540 | 97 |

Table 007—Rate-dependent parameters for 40 MHz, $N_{SS}$ = 2 ($N_{ES}$ = 1)

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data sub-carriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 108 | 16-QAM | 1/2 | 4 | 108 | 4 | 864 | 432 | 98 |
| 162 | 16-QAM | 3/4 | 4 | 108 | 4 | 864 | 648 | 99 |
| 216 | 64-QAM | 2/3 | 6 | 108 | 4 | 1296 | 864 | 100 |
| 243 | 64-QAM | 3/4 | 6 | 108 | 4 | 1296 | 972 | 101 |
| 270 | 64-QAM | 5/6 | 6 | 108 | 4 | 1296 | 1080 | 102 |

Table 008—Rate-dependent parameters for 40 MHz, $N_{SS}$ = 3 ($N_{ES}$ = 2)

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data sub-carriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 162 | 16-QAM | 1/2 | 4 | 108 | 4 | 1296 | 648 | 103 |
| 243 | 16-QAM | 3/4 | 4 | 108 | 4 | 1296 | 972 | 104 |
| 324 | 64-QAM | 2/3 | 6 | 108 | 4 | 1944 | 1296 | 105 |
| 364.5 | 64-QAM | 3/4 | 6 | 108 | 4 | 1944 | 1458 | 106 |
| 405 | 64-QAM | 5/6 | 6 | 108 | 4 | 1944 | 1620 | 107 |

Table 009—Rate-dependent parameters for 40 MHz, $N_{SS}$ = 4 ($N_{ES}$ = 2)

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data sub-carriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 216 | 16-QAM | 1/2 | 4 | 108 | 4 | 1728 | 864 | 109 |
| 324 | 16-QAM | 3/4 | 4 | 108 | 4 | 1728 | 1296 | 110 |
| 432 | 64-QAM | 2/3 | 6 | 108 | 4 | 2592 | 1728 | 111 |
| 486 | 64-QAM | 3/4 | 6 | 108 | 4 | 2592 | 1944 | 112 |
| 540 | 64-QAM | 5/6 | 6 | 108 | 4 | 2592 | 2160 | 113 |

#### 20.3.2.3 Timing related parameters

Table 010 is a list of timing parameters associated with the MIMO-OFDM PLCP.

**Table 010—Timing-related parameters**

| Parameter | Value (20 MHz modes) | Value (40 MHz modes) | Remarks |
|---|---|---|---|
| $N_{SD}$ : Number of data subcarriers | 54 | 108 | |
| $N_{SP}$ : Number of pilot subcarriers | 2 | 4 | |
| $N_{ST}$ : Number of subcarriers, total | 56 | 112 | $N_{ST} = N_{SD} + N_{SP}$ |
| $N_{OT}$: Index of outermost populated subcarrier | 28 | 58 | |
| $N_{TX}$: Number of transmit antennas | 2,3,4 | 1,2,3,4 | |
| $\Delta_F$: Subcarrier frequency spacing | 0.3125 MHz | 0.3125 MHz | $\Delta_F$ = 20/64 = 40/128 MHz |
| $T_{FFT}$ : IFFT/FFT period | 3.2 µs | 3.2 µs | $T_{FFT} = 1/\Delta_F$ |
| $T_{GI}$ : GI duration | 0.8 µs | 0.8 µs | ($T_{FFT}$ /4) |
| $T_{GI2}$ : Training symbol guard duration | 1.6 µs | 1.6 µs | |
| $T_{SYM}$ : Symbol interval | 4 µs | 4 µs | ($T_{GI} + T_{FFT}$ ) |

#### 20.3.2.4 Mathematical conventions in the signal descriptions

The transmitted signal will be described in a complex baseband signal notation. The RF (radio frequency) signal issued from the antenna is related to the complex baseband signal by the following relation:

$$r_{RF}(t) = \mathrm{Re}\{r(t)\exp(j2\pi f_c t)\} \quad (1)$$

where Re(.) represents the real part of the complex argument, and $f_c$ denotes the carrier frequency. The actual RF signal over the air is the sum of RF signals emanated from each transmit antenna.

The transmitted baseband signal from any antenna is composed of contributions from several OFDM symbols, including preamble, signal, and data. Each symbol is constructed as an inverse Fourier transform of a set of coefficients $C_k$, with $C_k$ defined later as data, pilots, or training symbols in subclause 20.3.3 through 20.3.5:

$$r_{SYMBOL}(t) = w_{SYMBOL}(t) \sum_{k=-N_{OT}}^{N_{OT}} C_k \exp(j2\pi k\Delta_F (t - T_{GUARD})). \quad (2)$$

The parameters $\Delta_F$ and $N_{OT}$ are defined in Table 010. The resulting waveform is periodic with a period of $T_{FFT} = 1/\Delta_F$. Shifting the time by $T_{GUARD}$ creates the "cyclic prefix" used in OFDM to avoid ISI from the previous symbol. Three kinds of $T_{GUARD}$ are defined: for the short training sequence (= 0µs), for the long training sequence (=$T_{GI2}$), and for data OFDM symbols (=$T_{GI}$). Informative considerations related to the windowing function $w_{SYMBOL}(t)$ and other implementation aspects, as specified in subclause 17.3.2.4, may also apply on a per-antenna basis in the MIMO-OFDM PHY.

The common way to implement the inverse Fourier transform, as shown in Equation (2), is by an inverse Fast Fourier Transform (IFFT) algorithm. If, for example, a 128-point IFFT is used to implement the 40 MHz transmission modes, the coefficients 3 to 58 are mapped to the same numbered IFFT inputs, while the coefficients

-58 to -3 are copied into IFFT inputs 70 to 125. The rest of the inputs, 59 to 69, 1, 2, 126, 127, as well as the 0 (dc) input, shall be set to zero. This mapping is illustrated in Figure 006. After performing an IFFT, the output is cyclically extended to the desired length.

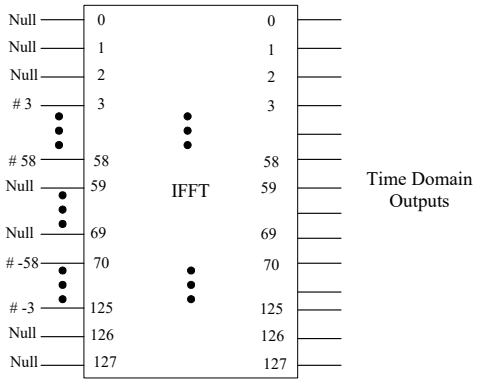



**Figure 006– Inputs and outputs of 128-point IDFT for 40 MHz data transmission**

### 20.3.3 PLCP preamble (SYNC)

The PLCP preamble field is used for synchronization. It consists of a sequence of short symbols and long symbols that are transmitted simultaneously from all transmit antennas, as described in this subclause.

Figure 007 shows the PLCP preamble format for greenfield 2TX mode in 20 MHz. The PLCP preamble is followed in this mode by the SIGNAL-N field and DATA. The total duration of the training symbols is 16 μsec. The short MIMO-OFDM training sequence transmitted from the first antenna consists of 12 subcarriers, which are modulated by elements of the sequence $SS_{20}$, given by

$SS_{20}[-28,28] = \sqrt{7/3} \times$ {0, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, –1–j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 0}. (3)

The second antenna transmits a cyclically shifted version of the sequence transmitted from the first antenna, such that the first sample of the short sequence transmitted from the first antenna is the sample that is transmitted 400 nsec after the start of the short sequence on the second antenna. This is denoted by "(400 ns cs)" in Figure 007. More generally, an indicator "S ($t_0$ ns cs)" in Figures 007 through 016 denotes that the transmitted sequence $r'(t)$ is obtained by cyclically shifting by $t_0$ nsec, the time-domain sequence $r(t)$ corresponding to frequency domain sequence S:

$$r'(t) = r(t - t_0 \text{ ns}). \quad (4)$$

The indicator "GI" or "GI2" in these figures denotes respectively the last $T_{GI}$ or $T_{GI2}$ duration of waveform of the immediately ensuing OFDM symbol, prepended to the OFDM symbol as a guard interval.

The short sequence is followed by a long OFDM training sequence which is generated by modulating the elements of the sequence

$LS_{20}$ [-28..28] = {1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 0, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, -1, -1}

((5)

according to the equation

$$r_{LONG}(t) = w_{TLONG}(t) \sum_{k=-N_{ST}/2}^{N_{ST}/2} LS_{20}[k] \exp\left(j2\pi k\Delta_F \left(t - T_{GI2}\right)\right), \quad (6)$$

where $T_{GI2}$ = 1.6 μsec. Two periods of the long symbol are transmitted for improved channel estimation accuracy. The long training sequence is also transmitted simultaneously from both antennas. The second antenna transmits a 1600 nsec cyclically shifted version of the long training symbols transmitted from the first antenna.

The PLCP preamble format for 2TX mixed-mode operation in 20 MHz is shown in Figure 008. The definition of the long and short sequences, as well as relative cyclic shifts between transmit antennas in this mode shall follow the description provided in Figure 008. The first and second TX antennas simultaneously transmit the first and second rows respectively of the MIMO-OFDM training structure shown in the figure.

Figure 009 and 010 define the PLCP preamble format for the 3TX and 4TX modes in 20 MHz, with greenfield access and mixed-mode access respectively. In the 3TX modes, only the first three rows shown in the corresponding MIMO-OFDM training structure are transmitted.

Figures 011, 013, and 015 show the PLCP preamble format for the 1TX, 2 TX, and 3TX/4TX greenfield modes in 40 MHz. The short sequence in these modes are obtained by modulating the elements of the sequence

$SS_{40GF}$ [-58,58] = $\sqrt{2}$ ×{0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0} (7)

on the subcarriers of the OFDM signal. The ensuing long sequence for 40 MHz greenfield operation is defined by the sequence

$LS_{40GF}$ [-58..58] = {1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1} (8)

The ~~mixed mode~~mixed-mode training structures for 1TX, 2TX, and 3TX/4TX modes in 40 MHz are defined in Figure 012, 014, and 016 respectively. The additional short and long sequences used in these modes are defined by the following frequency domain sequences:

$SS_{40MM}$ [-58..58] = $\sqrt{7/3}$ ×{0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0} (9)

$LS_{40MM}$ [-58..58] = {1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 0, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1}. (10)

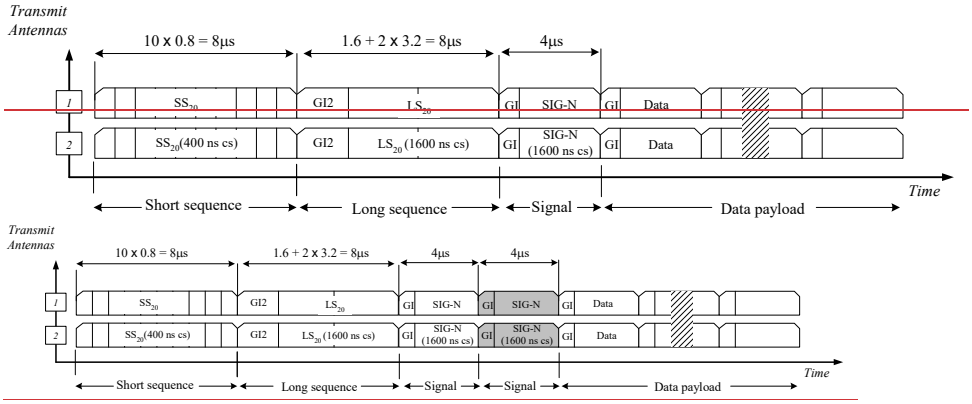



**Figure 007 – MIMO-OFDM Training structure for $N_{TX}$ = 2, 20 MHz, greenfield operation.** The shaded field indicates the optional duplicate SIG-N for extended range communication.

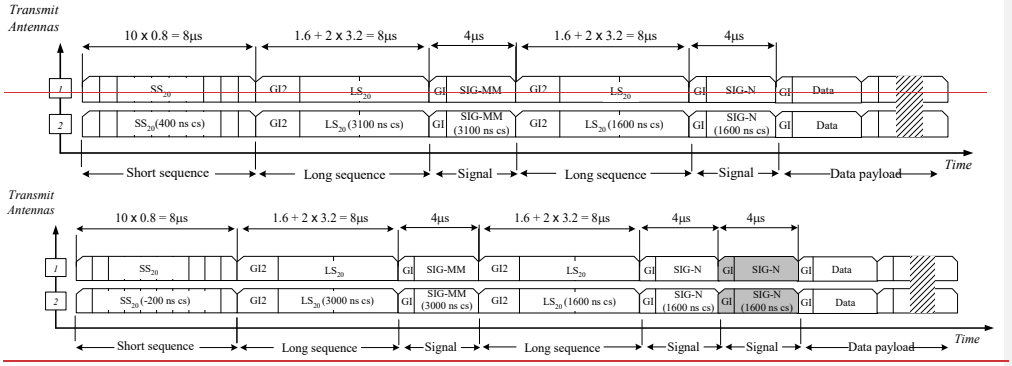



**Figure 008 – MIMO-OFDM Training structure for $N_{TX}$ = 2, 20 MHz, ~~mixed mode~~mixed-mode operation.** The shaded field indicates the optional duplicate SIG-N for extended range communication.

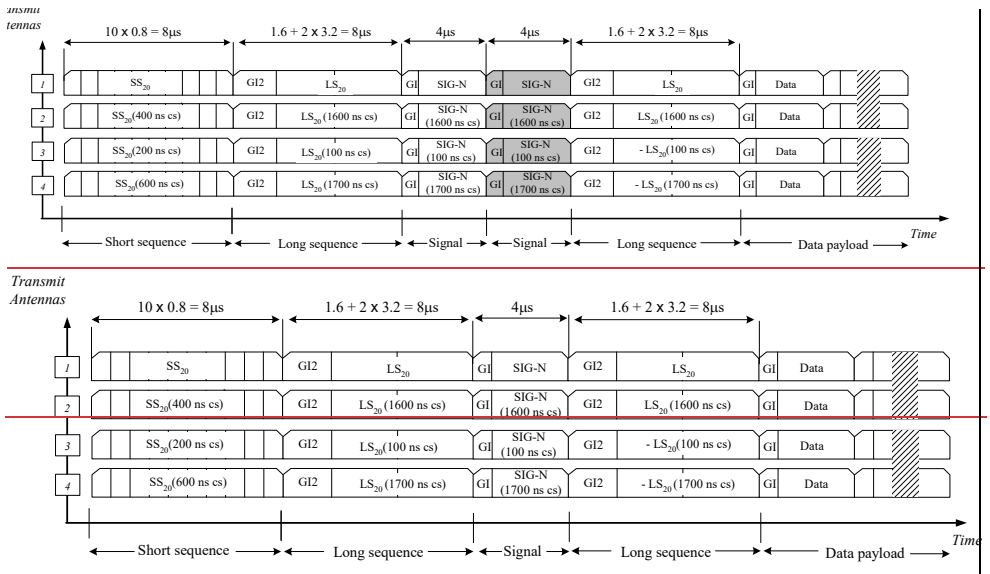



**Figure 009 – MIMO-OFDM Training structure for $N_{TX}$ = 3 and 4, 20 MHz, greenfield operation. The shaded field indicates the optional duplicate SIG-N for extended range communication.**

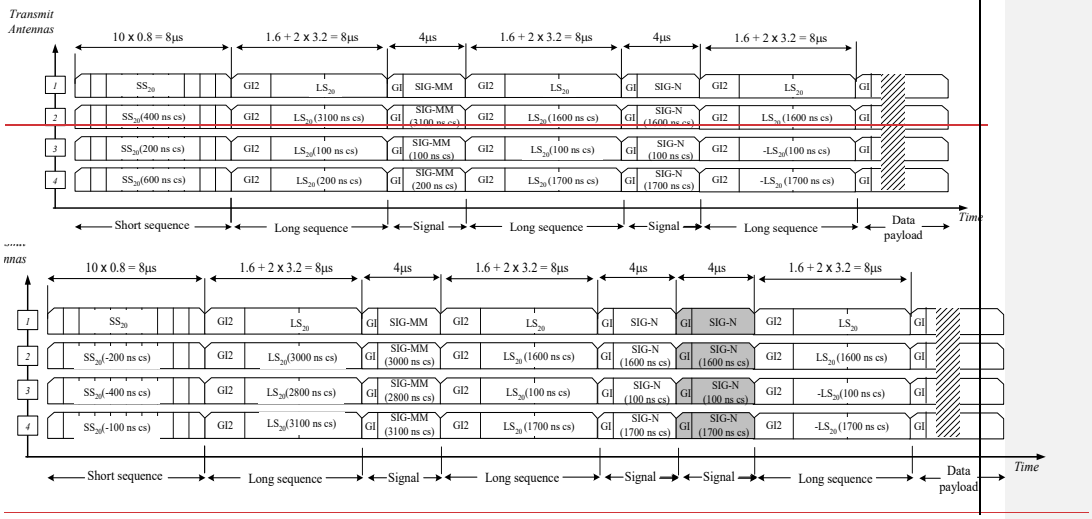






**Figure 010 – MIMO-OFDM Training structure for $N_{TX}$ = 3, 4, 20 MHz, ~~mixed mode~~mixed-mode operation. The shaded field indicates the optional duplicate SIG-N for extended range communication.**

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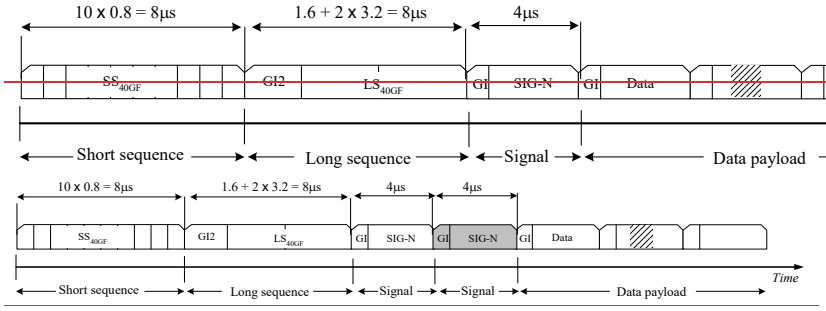



**Figure 011 – MIMO-OFDM Training structure for $N_{TX}$=1, 40 MHz, greenfield operation. The shaded field indicates the optional duplicate SIG-N for extended range communication.**

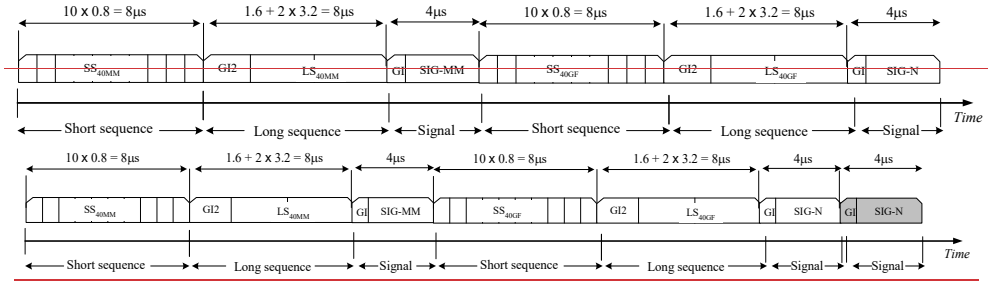



**Figure 012 – MIMO-OFDM Training structure for $N_{TX}$=1, 40 MHz, ~~mixed mode~~mixed-mode operation. The shaded field indicates the optional duplicate SIG-N for extended range communication.**

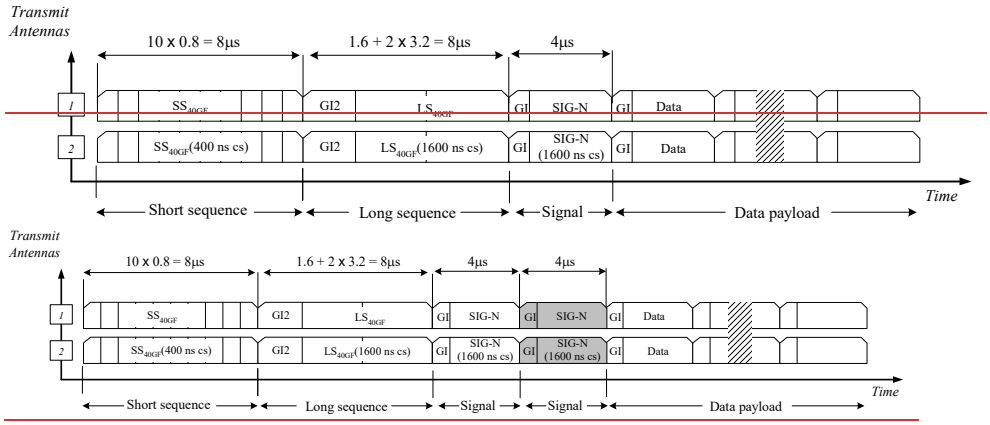
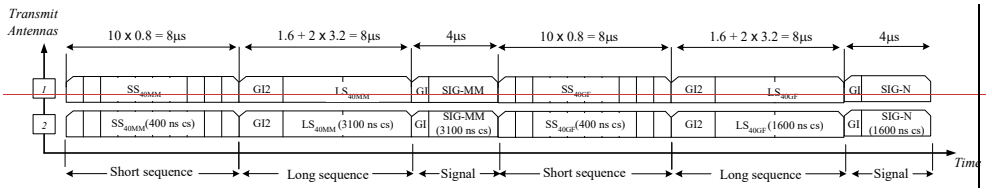


**Figure 013 – MIMO-OFDM Training structure for $N_{TX}$ = 2, 40 MHz, greenfield operation. The shaded field indicates the optional duplicate SIG-N for extended range communication.**



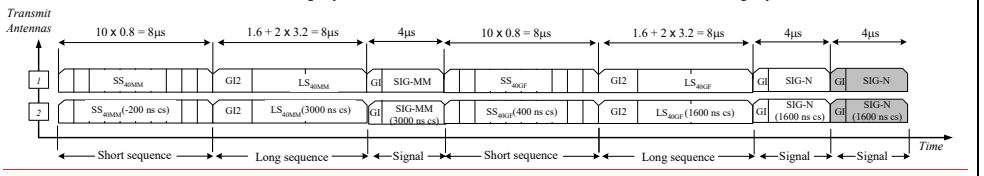
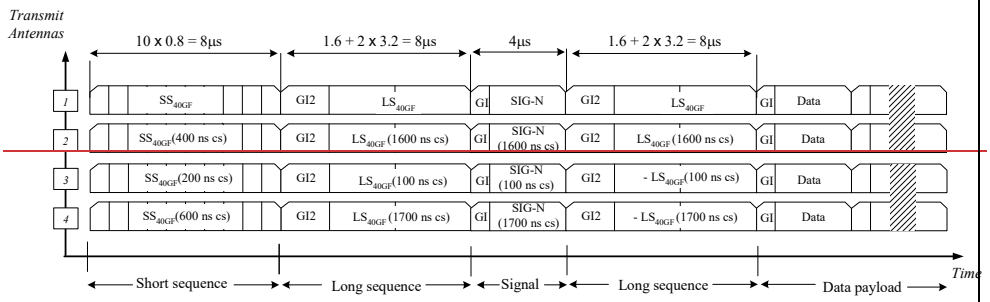




**Figure 014 – MIMO-OFDM Training structure for $N_{TX}$ = 2, 40 MHz, ~~mixed mode~~mixed-mode operation. The shaded field indicates the optional duplicate SIG-N for extended range communication.**



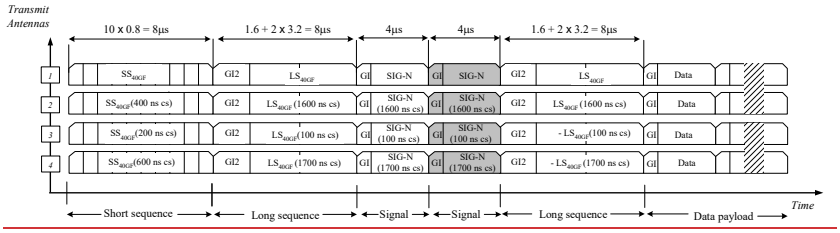




**Figure 015 – MIMO-OFDM Training structure for $N_{TX}$ = 3 and 4, 40 MHz, greenfield operation. The shaded field indicates the optional duplicate SIG-N for extended range communication.**

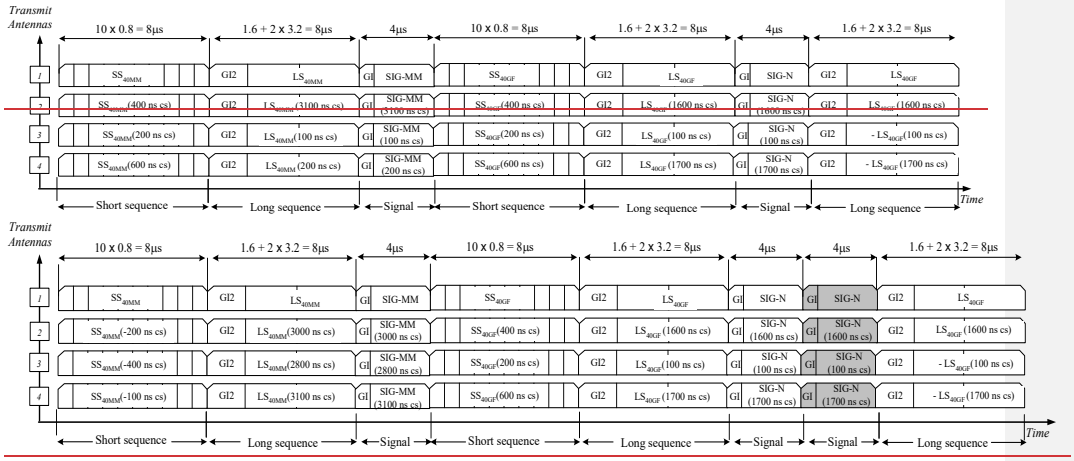



**Figure 016 – MIMO-OFDM Training structure for $N_{TX}$ = 3, 4, 40 MHz, ~~mixed mode~~mixed-mode operation.**
**The shaded field indicates the optional duplicate SIG-N for extended range communication.**

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### 20.3.4 Signal fields (SIG-N and SIG-MM)

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The SIGNAL-N field (SIG-N) is separately defined for a mandatory standard configuration and an optional "extended communication range" configuration described below.

In the mandatory standard configuration, SIG-N is composed of a single MIMO-OFDM symbol that provides all length and configuration parameters associated with a MIMO-OFDM PPDU.

In the extended communication range configuration, the corresponding SIG-N field is duplicated leading to a final length of two MIMO-OFDM symbols. The extended communication range configuration is only used with the optional NTX-STBC modes (described in subclause 20.3.5.10) and only with rate-1/2 encoding using BPSK modulation.

The SIGNAL-N field is composed of 54 bits, which shall be interpreted according to the bit assignment specified in Figure 017 and Table 011. The REXT bit, indicating extended range communication, can only be set in the optional NTX-STBC modes with rate-1/2 encoding and BPSK modulation.

~~The SIGNAL-N field (SIG-N) is composed of a single MIMO-OFDM symbol that provides all length and configuration parameters associated with a MIMO-OFDM PPDU. The SIGNAL-N field is composed of 54 bits, which shall be interpreted according to the bit assignment specified in Figure 017 and Table 011.~~

**Table 011—SIG-N field bit assignment**

| Bits | Field | Subfield | Parameter | Values |
|---|---|---|---|---|
| B0 : b5 | RSVD | | Reserved bits | 111111, Bits shall be ignored at the receiver |
| B6 : b21 | CONFIG | | Configuration | |
| B6 : b8 | | NSS | Number of spatial streams | 000: 1, 001: 2, 010: 3, 011: 4 |
| B9 : b11 | | NTX | Number of transmit antennas | 000: 1, 001: 2, 010: 3, 011: 4 |
| B12 : b13 | | BW | Bandwidth | 00: 20 MHz, 01: 40 MHz |
| B14: b16 | | R | Code rate | 000: 1/2, 001: 2/3, 010: 3/4, 011: 5/6 |
| B17 : b18 | | CT | ECC type | 00 : convolutional, 01 : LDPC |
| B19 : b21 | | CON | Constellation type | 000: BPSK, 001: QPSK, 010: 16-QAM, 011: 64-QAM |
| B22 : b34 | LEN | | Length | Number of bytes in the payload |
| b35 | LPI | | Last PSDU indicator | 1 indicates that this is the last PSDU to be aggregated into the current PPDU |
| b36 | REXT | | Standard or extended communication range configuration | 0 indicates the standard configuration, 1 indicates the extended communication range configuration |
| b37~~6~~ : b43 | RSVD | | Reserved | 00000000, Bits shall be ignored at the receiver |
| b44 : b47 | CRC | | Cyclic Redundancy Check | CRC calculated on bits 0-43 using generator polynomial $x^4+x+1$ |
| b48 : b53 | TAIL | | | 000000 |

In all 20 MHz modes, the encoding of the single SIG-N MIMO-OFDM symbol shall be performed with QPSK modulation of the subcarriers of the first antenna and shall use convolutional coding at R = 1/2. In all 40 MHz modes, the encoding of the single SIG-N MIMO-OFDM symbol shall be performed with BPSK modulation of the subcarriers of the first antenna and shall use using convolutional coding at R = 1/2. The contents of the SIG-N field are not scrambled.

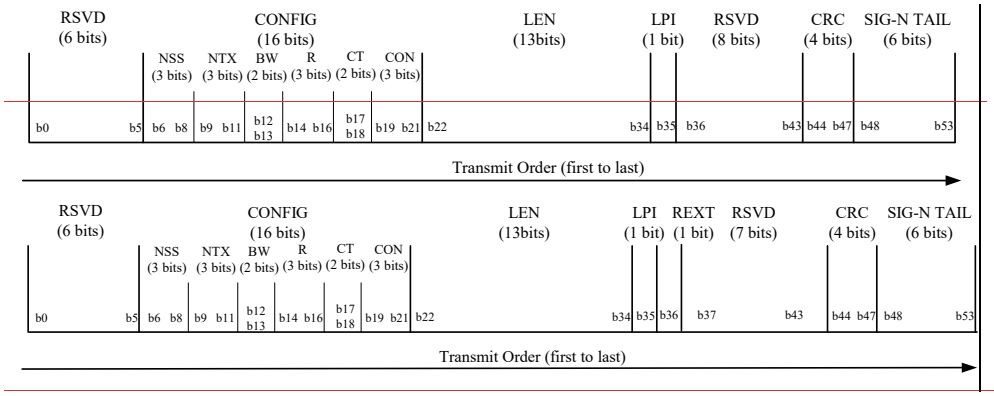



**Figure 017 – SIG-N field bit assignment**

The SIG-N MIMO-OFDM symbol is transmitted simultaneously from all TX antennas in all modes, with the same values of relative cyclic shift between antennas as are used to transmit the long training symbol preceding the SIG-N symbol. The value of the cyclic shift in each operating mode is specified in Figures 007 through 016 in subclause 20.3.3.

With mixed-mode access, another symbol, denoted as SIGNAL-MM (SIG-MM) is sent in the PLCP header. The SIG-MM field is encoded and transmitted from the first antenna as per IEEE 802.11a-1999 subclause 17.3.4. The remaining antennas simultaneously transmit the same OFDM symbol, with relative cyclic shifts defined in subclause 20.3.3. The reserved bit in the SIG-MM field shall be set to signal a MIMO-OFDM PPDU transmission. The duration for which the medium will be used by the MIMO-OFDM PPDU transmission is signaled to non MIMO-OFDM stations via the LENGTH and RATE fields of the SIG-MM symbol.

In 40 MHz mixed-mode operation, the SIG-MM field shall be transmitted such that it can be decoded by non-MIMO-OFDM stations operating in either the upper or the lower 20 MHz band.

### 20.3.5 DATA field

The DATA field contains the SERVICE field, the PSDU, the TAIL bits, and the PAD bits, if needed, as described in 20.3.5.2 and 20.3.5.4. All bits in the DATA field except the TAIL bits are scrambled, as described in 20.3.5.4.

#### 20.3.5.1 Service field (SERVICE)

The IEEE 802.11 SERVICE field has 16 bits, which shall be denoted as bits 0-15. The bit 0 shall be transmitted first in time. The bits 0-6 of the SERVICE field, which are transmitted first, are set to zeros and are used to synchronize the descrambler in the receiver. The remaining 9 bits (7-15) of the SERVICE field shall be reserved for future use. All reserved bits shall be set to zero. Refer to Figure 112, IEEE 802.11a-1999 subclause 17.3.5.1.

#### 20.3.5.2 PPDU tail bits

The PPDU tail bits shall follow IEEE 802.11a-1999 subclause 17.3.5.2.

#### 20.3.5.3 PAD bits

The number of bits in the DATA field shall be a multiple of $N_{CBPS}$, the number of coded bits in an OFDM symbol. To achieve that, the length of the message is extended so that it becomes a multiple of $N_{DBPS}$, the number of data bits per OFDM symbol. At least 6 bits per encoding stream ($N_{ES}$) are appended to the message, in order to accommodate the TAIL bits, as described in 20.3.5.2. The number of MIMO-OFDM symbols, $N_{SYM}$; the number of bits in the DATA field, $N_{DATA}$; and the number of pad bits, $N_{PAD}$, are computed from the length of the PSDU (LENGTH) as follows:

$$N_{SYM} = \text{Ceiling}\left((16 + 8 \times \text{LENGTH} + 6 \times N_{ES})/N_{DBPS}\right) \quad (11)$$

$$N_{DATA} = N_{SYM} \times N_{DBPS} \quad (12)$$

$$N_{PAD} = N_{DATA} - (16 + 8 \times \text{LENGTH} + 6 \times N_{ES}) \quad (13)$$

The appended bits ("pad bits") are set to "zeros" and are subsequently scrambled with the rest of the bits in the DATA field.

#### 20.3.5.4 PLCP data scrambler and descrambler

The PPDU data scrambler and descrambler shall follow IEEE 802.11a-1999 subclause 17.3.5.4.

#### 20.3.5.5 Convolutional encoder

The DATA field, composed of SERVICE, PSDU, tail, and pad parts, shall be coded with a convolutional encoder that conforms to IEEE 802.11a-1999 subclause 17.3.5.5 for code rates of R = 1/2, 2/3, and 3/4. Additionally, the code rate of R = 5/6 shall be implemented according to the puncturing pattern illustrated in Figure 018.

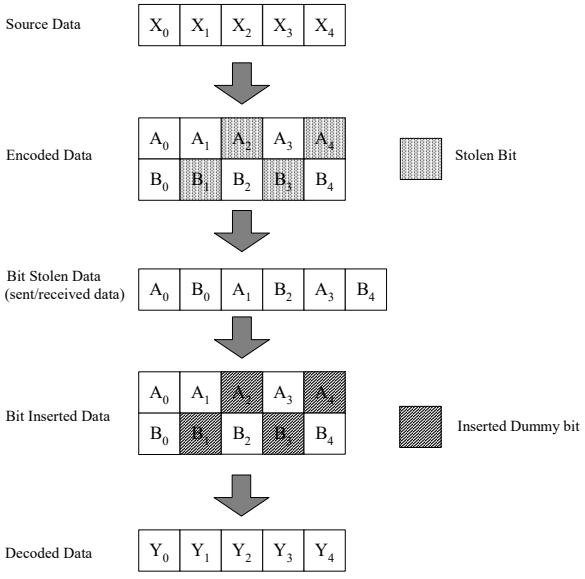



**Figure 018 – An illustration of the bit stealing and bit insertion procedure for R = 5/6**

### 20.3.5.6 Interleaver

All encoded bits shall be interleaved by a block interleaver with a block size equal to the number of bits in a single MIMO-OFDM symbol, $N_{CBPS}$. The interleaver is defined by the following series of permutations.

We shall denote by $k$ the index of the coded bits before interleaving, $k = 0, 1 \ldots N_{CBPS}-1$. $n = 0, 1 \ldots N_{SS}-1$ denotes the index of the spatial streams. The bits are first distributed across spatial streams by inputting the bit with index $k_n \times N_{SS} + n$ into the $n$th spatial stream. This is illustrated in Figure 019.

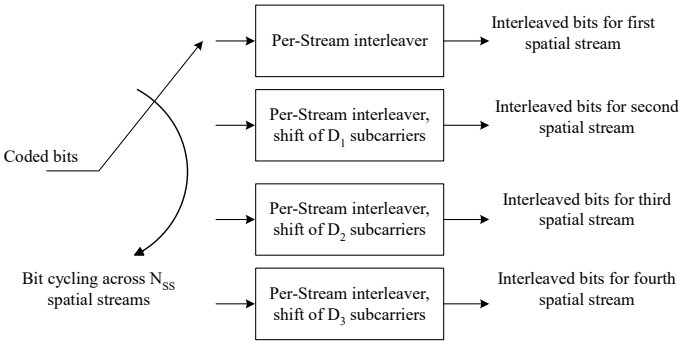



**Figure 019 – Illustration of the interleaver function**

The interleaver for spatial stream $n$ within its block of $N_{CBPS}/N_{SS}$ bits is defined by the following relations.

$$k = k_n \times N_{ss} + n$$

$$i = ((N_{CBPS}/N_{SS})/I_{DEPTH})\ (k_n \bmod I_{DEPTH}) + \text{floor}\ (k_n/I_{DEPTH}) \qquad k_n = 0, 1 \ldots (N_{CBPS}/N_{SS})-1$$

$$j = s \times \text{floor}(i/s) + (i + N_{CBPS}/N_{SS} - \text{floor}\ (I_{DEPTH} \times i / (N_{CBPS}/N_{SS}))) \bmod s \qquad s = \max(N_{BPSC}/2,1)$$

$$j_n = (j + N_{CBPS}/N_{SS} - N_{BPSC}\ D_n) \bmod (N_{CBPS}/N_{SS}). \qquad (14)$$

The parameter $D_n$ which denotes the shift in subcarriers for spatial stream $n$ is given by

$$D_n = 5n. \qquad (15)$$

The interleaving depth $I_{DEPTH}$ shall conform to the values given in Table 012.

**Table 012—Interleaving parameters**

| $N_{SS}$ | $N_{SD}$ | $I_{DEPTH}$ |
|---|---|---|
| 1, 2, 3, 4 | 54 | 6 |
| 2,3,4 | 108 | 6 |
| 1 | 108 | 12 |

The deinterleaver, which performs the inverse relation, is defined by the following series of permutations.

$$k_d = \bmod (k_n + N_{CBPS}/N_{SS} + 2sD_n) \bmod (N_{CBPS}/N_{SS})$$

$$i_d = s\ \text{floor}(k_d / s) + (k_d + \text{floor}\ (I_{DEPTH} \times k_d / (N_{CBPS}/N_{SS}))) \bmod s$$

$j_{dn} = I_{DEPTH} \times i_d - ((N_{CBPS}/N_{SS}) - 1) \times \text{floor}\ (I_{DEPTH} \times i_d / (N_{CBPS}/N_{SS}))$. (16)

where s and $D_n$ are as defined for the interleaver.

#### 20.3.5.7 Low density parity check codes (optional ECC)

This subclause describes the LDPCCs to be optionally used in the MIMO-OFDM system as high-performance ECC technique, instead of the convolutional code (20.3.5.5). The rate-dependent parameters in subclause 20.3.2.2 shall still apply.

When this subclause applies, the following clauses are to be considered no more applicable:

20.3.2.1: changes needed, as described in 20.3.5.7.3;
20.3.5.2: not used;
20.3.5.3: replaced by 20.3.5.7.3;
20.3.5.5: replaced by 20.3.5.7.4;
20.3.5.6: not used.

#### 20.3.5.7.1 LDPCC Code Rates and Block Sizes

The supported code rates, information block size, and coded block size are described in Table 013.

**Table 013— LDPCC parameters**

| Code rate (R) | LDPC information bits (bits) | LDPC codeword length (bits) |
|---|---|---|
| 1/2 | 972 | 1944 |
| 2/3 | 1296 | 1944 |
| 3/4 | 1458 | 1944 |
| 5/6 | 1620 | 1944 |

#### 20.3.5.7.3 LDPCC PPDU encoding process

a) Produce the PLCP preamble fields for each transmit antenna based on the TRANSMISSION_MODE field of the TXVECTOR. Refer to 20.3.3 for details.

b) Produce the PLCP header field from the LENGTH, DATARATE, and SERVICE fields of the TXVECTOR by filling the appropriate bit fields, as described in subclause 20.3.4 and subclause 20.3.5.1.

c) Compute the integer number of LDPCC codewords to be transmitted, $L_1$, and the possible remainder $K_1$.

$L_1 = \text{ceil}(\ (\text{LENGTH} \times 8 + 16)/1944/R)$,

$K_1 = \text{rem}(\ (\text{LENGTH} \times 8 + 16)\ ,1944 \times R)$. (17)

d) If $K_1 > 0$ compute the number of zeros for padding in order to encode the last codeword as

$N_{P1} = 1944 \times R - K_1$. (18)

These bits will not be transmitted nor scrambled. If $K_1 > 0$, the last frame has an effective information frame (i.e. information frame excluding padded zeros) of size $K_1$, generally less than *k.* The last codeword includes a fixed number of parity bits equal to $p = (1944 - k)$. This implies the code rate for the last codeword is different from the overall target code rate and is given by:

$$\frac{K_1}{K_1 + (1944 - k)}. \tag{19}$$

e) Compute the number of coded bits to be transmitted (including the shortened codeword) as

$$L_2 = \begin{cases} 1944 \times L_1, & K_1 = 0 \\ 1944 \times (L_1 - 1) + 1944 \times (1 - R) + K_1, & K_1 \neq 0 \end{cases} \tag{20}$$

f) Compute the integer number of MIMO-OFDM symbols $N_{S1}$ and the possible reminder $R_{S1}$:

$$N_{S1} = \text{ceil}(L_2/N_{CBPS}),$$

$$R_{S1} = \text{rem}(L_2, N_{CBPS}). \tag{21}$$

g) If $R_{S1} > 0$ append $N_{P2}$ zeros to info bits in order to fill an integer number of MIMO-OFDM symbols

$$N_{P2} = N_{CBPS} - R_{S1}. \tag{22}$$

h) The service field at the beginning of the resulting sequence is used to initialize a scrambler, which is then used to scramble the rest of the sequence including the zeros appended in step g).

k) The resulting PSDU is then coded by the LDPCC at the proper code rate (R) and block size (i.e. 1944 bits for all frames). The last codeword is encoded extending the info bits with $N_{P1}$ zeros; these $N_{P1}$ bits are not transmitted. The last $N_{P2}$ bits are not encoded.

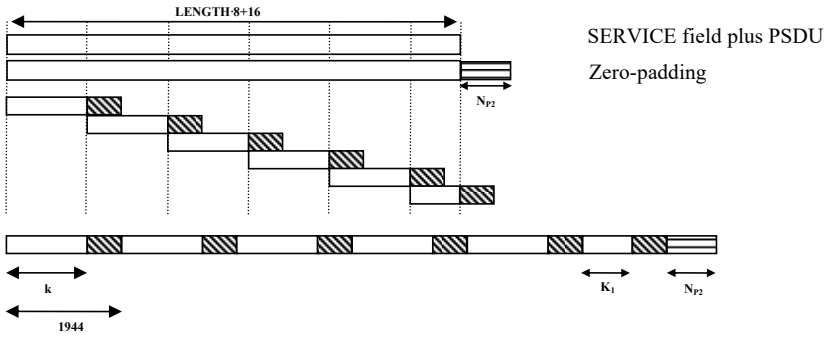



**Figure 020 – LDPC PPDU encoding.**

### 20.3.5.7.4 LDPCC Encoder

The proposed LDPCC supports rate-1/2, rate-2/3, rate-3/4 and rate-5/6 encoding. The LDPCC encoder is systematic, i.e. it encodes an information block of size $k$, $I=(i_0,i_1,\ldots i_{(k-1)})$ into a codeword $\mathbf{c}$ of size $n$, $\mathbf{c}=(i_0,i_1,\ldots i_{(k-1)}, p_0, p_1, \ldots, p_{(n-k-1)})$, by adding $n-k$ parity bits obtained so that $\mathbf{H}\cdot\mathbf{c}^T = \mathbf{0}$. The parameters $k$ and $n$ are defined in Table 013 according to the selected encoder rate.

The parity-check matrix for each encoder rate is "structured" (as opposed to "random") in the sense that it can be partitioned into square subblocks (submatrices) of size $Z$ x $Z$. These submatrices are either cyclic permutations of the diagonal identity matrix, null sub-matrices, or, in a few cases, a staircase matrix ("st") or a subdiagonal matrix ("D"). The submatrix types (except for the null submatrix) are illustrated in Figure 021. At each encoding rate, the structure of parity-check matrix allows a linear-complexity encoder (based on back substitution).

~~A characteristic feature of the considered LDPCCs is that combining rows of the parity check matrix (**H**) for the lowest rate code produces **H** for higher rates. This is equivalent to replacing a group of check nodes with a single check node that sums all the edges coming into each of the original check nodes. Direct consequences are that all code rates have the same block length and the same variable node degree distribution.~~

~~The LDPCC encoder is systematic, i.e. encodes an information block of size $k$, $I=(i_0,i_1,\ldots i_{(k-1)})$ into a codeword **C** of size $n$ $\mathbf{C}=(i_0,i_1,\ldots i_{(k-1)}, p_0, p_1, \ldots, p_{(n-k-1)})$ by adding $n-k$ parity bits obtained so that $\mathbf{H}\cdot\mathbf{c}^T = \mathbf{0}$.~~

~~$k$ and $n$ are defined in Table 013 according to the selected rate.~~

~~The parity check matrix used to generate all the code rates is rate 1/2 (i.e. number of rows $n-k = 972$, number of columns $n = 1944$). This belongs to the class of the so-called structured parity check matrices (compared to "random" generated codes). More specifically, the matrix can be partitioned into square sub-blocks of size 27x27 which are either cyclic permutations of the diagonal identity matrix or null sub-matrices. A few of them – specifically 2 in the rate 1/2 matrix described in Table A.1 – may contain two (cyclically shifted) diagonals.~~

~~In addition, in order to enable a simple encoding process, the parity-check matrices include a block lower triangular structure at the right hand side. This allows a linear complexity encoder (based on back substitution). More precisely, the parity-check matrix is of the type:~~

~~$$H_{(n-k)\times n} = [A_{(n-k)\times k}\ B_{(n-k)\times(n-k)}] \qquad (23)$$~~

~~where $B$ is block lower triangular, i.e. has the structure reported in Fig. 021.~~

~~$$B_{(n-k)\times(n-k)} = \begin{pmatrix} b_{11} & 0 & \cdots & 0 \\ b_{21} & b_{22} & 0 & \\ & b_{32} & \ddots & \vdots \\ \vdots & & \ddots & 0 \\ & & & 0 \\ b_{(n-k)1} & & \cdots & b_{(n-k)(n-k)} \end{pmatrix}$$~~

~~$b_{ij}$ = circulant permutation matrix; $(i,j)$ sub-matrix indexes.~~

~~**Figure 021 – lower triangular part of the parity check matrix**~~

~~In order to generate variable rate LDPCCs, the following criteria apply:~~

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~~a) Row-combining of rows who do not have a '1' in the same position (this implies a same resulting variable node degree distribution for all the code rates).~~
~~b) The selection of rows to be summed preserves the lower triangular structure of the right hand side of the matrix through all the rates.~~

~~Taking into account above-mentioned criteria, the code rates are obtained as follows:~~

~~- Code rate 2/3:~~
~~row *i* (the rows are enumerated from top to bottom) is generated by summing row *i* of **H** of rate 1/2 code and the row with index *i*+*M*/2 where *M* is the total number of check equations in rate 1/2 code, for all the rows where *i* < *M*/3.~~

~~- Code rate 3/4:~~
~~row *i* is generated by summing row *i* of **H** of rate 1/2 code and the row with index *i*+*M*/2 where *M* is the total number of **H** rows (i.e. check equations) in rate 1/2 code.~~

~~- Code rate 5/6:~~
~~Rows are summed three at a time as: row *i* plus the row with index *i*+*M*/3 plus the row with index *I* + 2*M*/3.~~

~~The codes are designed to avoid length 4 cycles and to avoid small stopping sets.~~

**20.3.5.7.5 Parity check matrix**

Most of the non-null subblocks of the parity-check matrices are cyclic permutation matrices. The cyclic permutation matrix $P_i$ is obtained from the identity matrix by cyclically shifting the rows to the right by $i$ elements. The matrix $P_0$ is the identity matrix. Figure 021 illustrates examples (for a subblock size of 8 x 8) of cyclic-permutation matrices $P_i$, as well as two other submatrix types, the "st"-matrix which has the staircase structure and the "$D$"-matrix which has the subdiagonal structure.

$$P_0=\begin{bmatrix}1&0&0&0&0&0&0&0\\0&1&0&0&0&0&0&0\\0&0&1&0&0&0&0&0\\0&0&0&1&0&0&0&0\\0&0&0&0&1&0&0&0\\0&0&0&0&0&1&0&0\\0&0&0&0&0&0&1&0\\0&0&0&0&0&0&0&1\end{bmatrix},P_1=\begin{bmatrix}0&1&0&0&0&0&0&0\\0&0&1&0&0&0&0&0\\0&0&0&1&0&0&0&0\\0&0&0&0&1&0&0&0\\0&0&0&0&0&1&0&0\\0&0&0&0&0&0&1&0\\0&0&0&0&0&0&0&1\\1&0&0&0&0&0&0&0\end{bmatrix},P_5=\begin{bmatrix}0&0&0&0&0&1&0&0\\0&0&0&0&0&0&1&0\\0&0&0&0&0&0&0&1\\1&0&0&0&0&0&0&0\\0&1&0&0&0&0&0&0\\0&0&1&0&0&0&0&0\\0&0&0&1&0&0&0&0\\0&0&0&0&1&0&0&0\end{bmatrix}$$

$$st=\begin{bmatrix}1&0&0&0&0&0&0&0\\1&1&0&0&0&0&0&0\\0&1&1&0&0&0&0&0\\0&0&1&1&0&0&0&0\\0&0&0&1&1&0&0&0\\0&0&0&0&1&1&0&0\\0&0&0&0&0&1&1&0\\0&0&0&0&0&0&1&1\end{bmatrix},D=st\oplus P_0=\begin{bmatrix}0&0&0&0&0&0&0&0\\1&0&0&0&0&0&0&0\\0&1&0&0&0&0&0&0\\0&0&1&0&0&0&0&0\\0&0&0&1&0&0&0&0\\0&0&0&0&1&0&0&0\\0&0&0&0&0&1&0&0\\0&0&0&0&0&0&1&0\end{bmatrix}$$

**Figure 021 – Types of subblock matrices. The matrix $P_i$ is produced by cyclically shifting the rows of the identity matrix to the right by *i* places.**

Table A.1 of Annex A displays the "matrix prototype" of the rate-1/2 parity-check matrix. The integer $i$ denotes the cyclic-permutation matrix $P_i$, "st" denotes the staircase matrix and $D$ denotes the subdiagonal matrix, as illustrated in Figure 021. Vacant entries of the table denote null (zero) submatrices.

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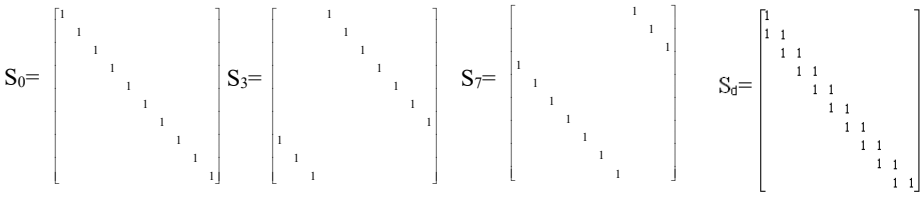
Table A.2 of Annex A displays the matrix prototype of the rate-2/3 parity-check matrix in the same fashion.

Table A.3 of Annex A displays the matrix prototype of the rate-3/4 parity-check matrix in the same fashion.
Table A.4 of Annex A displays the matrix prototype of the rate-5/6 parity-check matrix in the same fashion.

~~In Table A.1 in Annex A the rate 1/2 parity check matrix is reported. All the other rates can be derived by properly combining its rows as explained in 20.3.5.7.4.~~

~~The table describes the "matrix prototype", i.e. a structure of size 36x72 where the basic elements are squared sub-matrices whose size is 27x27. Each sub-matrix is either a null matrix or a cyclic permutation of the identity matrix (or the lower bidiagonal matrix at the right hand bottom of the matrix).~~

~~Figure 022 illustrates some examples (for a 10x10 matrix) of the basic circular permutation matrix $S_i$, clarifying how cyclic shift indexes *i* are to be interpreted. The last line in Table A.1, indicated as "st", indicates the staircase (or bi-diagonal) structure ($S_d$ in Fig. 021).~~




~~**Figure 022 – Structure of the cyclic permutations of the identity matrix. Matrix $S_i$ is produced by cyclically shifting the columns of the identity matrix to the right *i* places.**~~

~~Table A.1 follows the following format: Row number – Column number – Cyclic shift to the right (of columns). Rows are enumerated from top to bottom, columns from left to right.~~

### 20.3.5.8 Subcarrier modulation mapping

The subcarrier modulation mapping shall follow IEEE 802.11a-1999 clause 17.3.5.7 for each transmit antenna.

### 20.3.5.9 NTX-SDM (Spatial Data Multiplexing) Modes

The NTX-SDM modes are those modes in which $N_{TX}$, the number of TX antennas, is equal to $N_{SS}$, the number of transmitted spatial streams. Throughout the description of the MIMO signaling modes, we shall number the MIMO-OFDM symbols transmitted in a PSDU sequentially, with $n = 1$ denoting the first symbol that follows the PLCP preamble.

#### 20.3.5.9.1 Pilot tones for the NTX-SDM modes

The subcarriers with index -21 and +21 are dedicated in all 20 MHz NTX-SDM modes to transmit pilot signals during each OFDM symbol, in order to increase robustness against frequency offsets and phase noise. In the 40 MHz modes, 4 subcarriers are dedicated to transmitting pilots. These subcarriers have indices -42, -14, +14, and +42.

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The relative polarity of the pilots transmitted from various antennas shall be determined using the following relations. We shall use $p_n$ to denote the $n$th element of the sequence $p_{0\ldots126}$ specified in equation (25) of IEEE 802.11a-1999 subclause 17.3.5.9. We define the following matrices:

$$A=\begin{bmatrix}+1 & +1 & +1 & -1\\ +1 & -1 & +1 & +1\end{bmatrix},\quad B=\begin{bmatrix}+1 & +1 & -1 & -1\\ +1 & -1 & +1 & -1\\ -1 & +1 & +1 & -1\end{bmatrix},\quad C=\begin{bmatrix}+1 & +1 & +1 & -1\\ +1 & +1 & -1 & +1\\ +1 & -1 & +1 & +1\\ -1 & +1 & +1 & +1\end{bmatrix}, \qquad (24)$$

Furthermore, we define $a_{i,j}$, $b_{i,j}$, and $c_{i,j}$ as the element on the $i$th row and $j$th column of the matrices A, B, and C, respectively. For example, $i$ =0, 1, 2; $j$ = 0, 1, 2, 3 for matrix B. Then the pilot values sent from the $m$th antenna ($m$ = 1, 2, …4) during the $n$th OFDM symbol in the 20 MHz modes shall be given by the corresponding value in Table 014, multiplied with $p_{n \bmod 127}$. The function f( · ) in Table 014 is defined as f(0) = 0, f(1)=2, f(2)=1, f(3)=3.

~~Table 018~~The pilot value in the 40 MHz modes shall be given by the corresponding value in Table 015, multiplied with $p_{n \bmod 127}$.The value of the pilot signals sent from the first antenna during the SIG-N symbol shall be obtained by setting $n$ = 0 in this subclause. The pilot signals sent during the SIG-MM symbol in the mixed-mode preambles shall follow IEEE 802.11a-1999 subclause 17.3.5.9, and the polarity of the sequence $p_{0\ldots126}$ shall be reset after the SIG-MM symbol is transmitted.

**Table 014—Pilot value sent from *m*th antenna during *n*th OFDM symbol in 20 MHz $N_{TX}$-SDM modes.**

| Subcarrier index, *k* | 2TX-SDM mode | 3TX-SDM mode | 4TX-SDM mode |
|---|---|---|---|
| -21 | $a_{m-1,\, n \bmod 2}$ | $b_{m-1,\, f(n \bmod 4)}$ | $c_{m-1,\, f(n \bmod 4)}$ |
| +21 | $a_{m-1,\, (n+1) \bmod 2}$ | $b_{m-1,\, f((n+2) \bmod 4)}$ | $c_{m-1,\, f((n+2) \bmod 4)}$ |

**Table 015—Pilot value sent from *m*th antenna during *n*th OFDM symbol in 40 MHz $N_{TX}$-SDM modes.**

| Subcarrier index, *k* | 1TX-mode | 2TX-SDM mode | 3TX-SDM mode | 4TX-SDM mode |
|---|---|---|---|---|
| -42 | +1 | $a_{m-1,\, n \bmod 4}$ | $b_{m-1,\, n \bmod 4}$ | $c_{m-1,\, n \bmod 4}$ |
| -14 | +1 | $a_{m-1,\, (n+1) \bmod 4}$ | $b_{m-1,\, (n+1) \bmod 4}$ | $c_{m-1,\, (n+1) \bmod 4}$ |
| +14 | +1 | $a_{m-1,\, (n+2) \bmod 4}$ | $b_{m-1,\, (n+2) \bmod 4}$ | $c_{m-1,\, (n+2) \bmod 4}$ |
| +42 | -1 | $a_{m-1,\, (n+3) \bmod 4}$ | $b_{m-1,\, (n+3) \bmod 4}$ | $c_{m-1,\, (n+3) \bmod 4}$ |

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~~**20.3.5.9 Pilot tones**~~

~~The subcarriers with index -21 and +21 are dedicated in all 20 MHz modes to transmit pilot signals during each OFDM symbol, in order to increase robustness against frequency offsets and phase noise. In the 40 MHz modes, 4 subcarriers are dedicated to transmitting pilots. These subcarriers have indexes -42, -14, +14, and +42.~~

~~The relative polarity of the pilots transmitted from various antennas shall be determined using the following relations. We shall number the MIMO-OFDM symbols transmitted in a PSDU sequentially, with $n$ = 1 denoting the first symbol that follows the PLCP preamble. We shall use $p_n$ to denote the $n$th element of the sequence $p_{0\ldots126}$ specified in equation (25) of IEEE 802.11a-1999 subclause 17.3.5.9. We define the following matrices:~~

~~$$A=\begin{bmatrix}+1 & +1 & +1 & -1\\ +1 & -1 & +1 & +1\end{bmatrix}$$~~

$$B=\begin{bmatrix}+1 & +1 & -1 & -1\\ +1 & -1 & +1 & -1\\ -1 & +1 & +1 & -1\end{bmatrix}$$

$$C=\begin{bmatrix}+1 & +1 & +1 & -1\\ +1 & +1 & -1 & +1\\ +1 & -1 & +1 & +1\\ -1 & +1 & +1 & +1\end{bmatrix} \quad (24)$$

Furthermore, we define $a_{i,j}$, $b_{i,j}$, and $c_{i,j}$ as the element on the $i$th row and $j$th column of the matrices A, B, and C, respectively. For example, $i = 0, 1, 2$; $j = 0, 1, 2, 3$ for matrix B. Then the pilot values sent from the $m$th antenna ($m = 1, 2, \ldots 4$) during the $n$th OFDM symbol in the 20 MHz modes shall be given by the corresponding value in Table 014, multiplied with $p_{n \bmod 127}$. The function f(.) referred to in Table 014 is defined in Table 016. The pilot value in the 40 MHz modes shall be given by the corresponding value in Table 015, multiplied with $p_{n \bmod 127}$. The value of the pilot signals sent from the first antenna during the SIG-N symbol shall be obtained by setting $n = 0$ in this subclause. The pilot signals sent during the SIG-MM symbol in the mixed mode preambles shall follow IEEE 802.11a-1999 subclause 17.3.5.9, and the polarity of the sequence $p_{0\ldots126}$ shall be reset after the SIG-MM symbol is transmitted.

**Table 014—Pilot value sent from *m*th antenna during *n*th OFDM symbol in 20 MHz modes**

| Subcarrier index | 2TX mode | 3TX mode | 4TX mode |
|---|---|---|---|
| -21 | $a_{m-1,\, n \bmod 2}$ | $b_{m-1,\, f(n \bmod 4)}$ | $c_{m-1,\, f(n \bmod 4)}$ |
| +21 | $a_{m-1,\, (n+1) \bmod 2}$ | $b_{m-1,\, f((n+2) \bmod 4)}$ | $c_{m-1,\, f((n+2) \bmod 4)}$ |

**Table 015—Pilot value sent from *m*th antenna during *n*th OFDM symbol in 40 MHz modes**

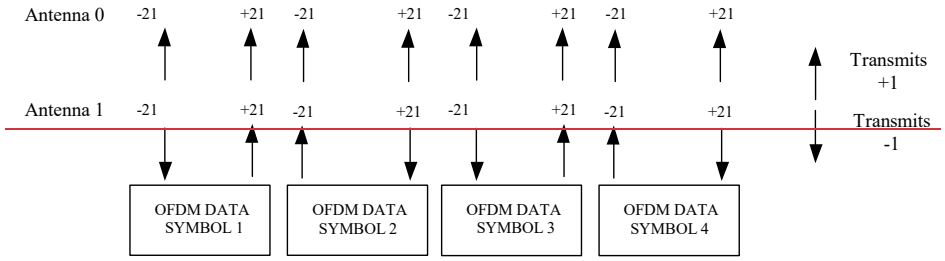
| Subcarrier index | 1TX mode | 2TX mode | 3TX mode | 4TX mode |
|---|---|---|---|---|
| -42 | +1 | $a_{m-1,\, n \bmod 4}$ | $b_{m-1,\, n \bmod 4}$ | $c_{m-1,\, n \bmod 4}$ |
| -14 | +1 | $a_{m-1,\, (n+1) \bmod 4}$ | $b_{m-1,\, (n+1) \bmod 4}$ | $c_{m-1,\, (n+1) \bmod 4}$ |
| +14 | +1 | $a_{m-1,\, (n+2) \bmod 4}$ | $b_{m-1,\, (n+2) \bmod 4}$ | $c_{m-1,\, (n+2) \bmod 4}$ |
| +42 | -1 | $a_{m-1,\, (n+3) \bmod 4}$ | $b_{m-1,\, (n+3) \bmod 4}$ | $c_{m-1,\, (n+3) \bmod 4}$ |

**Table 016—Definition of the function f(.)**

| *I* | *f(I)* |
|---|---|
| 0 | 0 |
| 1 | 2 |
| 2 | 1 |
| 3 | 3 |

Figure 023 provides an illustration of the relative polarity of pilot signals transmitted in the 2TX, 20 MHz mode of operation

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~~**Figure 023 – An illustration of the relative polarity of pilot signals in the 2TX, 20 MHz mode. "-21" and "+21" indicate the subcarrier indexes on which pilot signals are sent**~~

~~**20.3.5.10 Space-time block coding (STBC)**~~

Figure 022 provides an illustration of the relative polarity of pilot signals transmitted in the 20 MHz 2TX-SDM mode of operation.

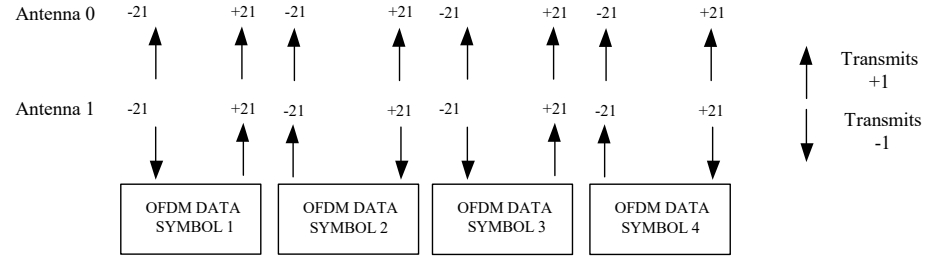



**Figure 022 – An illustration of the relative polarity of pilot signals in the 20 MHz 2TX-SDM mode. "-21" and "+21" indicate the subcarrier indices on which pilot signals are sent**

**20.3.5.9.2 Data tones in NTX-SDM modes**

The signaling on the data tones of the NTX-SDM modes is described in subclause 20.3.2.1., item (l).

**20.3.5.10 NTX-STBC (Space-Time Block Coding) Modes**

This subclause defines a set of robust transmission rates which are applicable when $N_{TX}$, the number of TX antennas, is greater than $N_{SS}$, the number of transmitted spatial streams. These rates are based on space time block coding. Implementation of all modes defined in this subclause is optional.

**20.3.5.10.1 $N_{TX}$-STBC modes with single spatial stream $N_{SS}$=1**

**20.3.5.10.1.1 Pilot tones in the NTX-STBC modes with $N_{SS}$=1**

The pilot structure of the optional NTX-STBC modes closely follows that of the 2TX-SDM modes. For 20 MHz operation, the subcarriers with indices $k$=-21,+21 are reserved for piloting. For 40 MHz operation, the subcarriers with indices $k$=-42,-14,+14,+42 are reserved for piloting.

In the NTX-STBC modes, only two antennas per pilot subcarrier transmit pilots on a given OFDM symbol. For $N_{TX}$=3 and $N_{TX}$=4, the active antennas on a given OFDM symbol are determined using the antenna selection functions $g$ and $h$ defined in the following. We define $g(m,n,p)$ via Table 016, and $h(m,n,p)$ via Table 017 below. The notation $[x]$ is used to denote $floor(x)$.

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**Table 016—The *g* function used in antenna selection for 3TX-STBC modes.**

| $\lfloor [n/2]+p \rfloor \bmod 3$ / $M$ | 0 | 1 | 2 |
|---|---|---|---|
| 1 | 1 | 0 | 1 |
| 2 | 0 | 1 | 2 |
| 3 | 2 | 2 | 0 |

**Table 017—The *h* function used in antenna selection for 4TX-STBC modes.**

| $\lfloor [n/2]+p \rfloor \bmod 4$ / $m$ | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 0 |
| 2 | 0 | 1 | 0 | 1 |
| 3 | 2 | 0 | 0 | 2 |
| 4 | 0 | 2 | 2 | 0 |

The pilot values sent from the $m$th antenna ($m$ = 1, …,$N_{TX}$) during the $n$th OFDM symbol in the 20 MHz-STBC modes shall be given by the corresponding value in Table 018, multiplied with $p_{n \bmod 127}$. The values $a_{i,j}$ with $i$ =-1 in Table 018 are interpreted as zero.

**Table 018—Pilot value sent from *m*th antenna during *n*th OFDM symbol in 20 MHz $N_{TX}$-STBC modes.**

| Subcarrier index, *k* | 2TX-STBC-mode with $N_{SS}$=1 | 3TX-STBC-mode with $N_{SS}$=1 | 4TX-STBC-mode with $N_{SS}$=1 |
|---|---|---|---|
| -21 | $a_{m-1,\, n \bmod 2}$ | $(3/2)^{1/2}\, a_{g(m,n,0)-1,\, n \bmod 2}$ | $2^{1/2}\, a_{h(m,n,0)-1,\, n \bmod 2}$ |
| +21 | $a_{m-1,\, (n+1) \bmod 2}$ | $(3/2)^{1/2}\, a_{g(m,n,1)-1,\, (n+1) \bmod 2}$ | $2^{1/2}\, a_{h(m,n,1)-1,\, (n+1) \bmod 2}$ |

The pilot values sent from the $m$th antenna ($m$ = 1, …,$N_{TX}$) during the $n$th OFDM symbol in the 40 MHz-STBC modes shall be given by the corresponding value in Table 019, multiplied with $p_{n \bmod 127}$. The values $a_{i,j}$ with $i$ =-1 in Table 019 are interpreted as zero.

**Table 019—Pilot value sent from *m*th antenna during *n*th OFDM symbol in 40 MHz $N_{TX}$-STBC modes.**

| Subcarrier index, *k* | 2TX-STBC-mode with $N_{SS}$=1 | 3TX-STBC-mode with $N_{SS}$=1 | 4TX-STBC-mode With $N_{SS}$=1 |
|---|---|---|---|
| -42 | $a_{m-1,\, n \bmod 4}$ | $(3/2)^{1/2}\, a_{g(m,n,0)-1,\, n \bmod 4}$ | $2^{1/2}\, a_{h(m,n,0)-1,\, n \bmod 4}$ |
| -14 | $a_{m-1,\, (n+1) \bmod 4}$ | $(3/2)^{1/2}\, a_{g(m,n,1)-1,\, n \bmod 4}$ | $2^{1/2}\, a_{h(m,n,1)-1,\, (n+1) \bmod 4}$ |
| +14 | $a_{m-1,\, (n+2) \bmod 4}$ | $(3/2)^{1/2}\, a_{g(m,n,2)-1,\, n \bmod 4}$ | $2^{1/2}\, a_{h(m,n,2)-1,\, (n+2) \bmod 4}$ |
| +42 | $a_{m-1,\, (n+3) \bmod 4}$ | $(3/2)^{1/2}\, a_{g(m,n,3)-1,\, n \bmod 4}$ | $2^{1/2}\, a_{h(m,n,3)-1,\, (n+3) \bmod 4}$ |

### 20.3.5.10.1.2 Data tones in the NTX-STBC modes with $N_{SS}$=1

The 2TX-STBC scheme for $N_{SS}$ =1 in 20 MHz and 40 MHz is defined as follows. The bits output from the interleaver of the (single) spatial stream are mapped to the subcarriers of the first antenna, according to subclause 20.3.5.8. We denote the pair of complex numbers transmitted on subcarrier $k$ from this antenna during the $n$th and $(n+1)$st OFDM symbols as $x_{k,n}$ and $x_{k,n+1}$ respectively, where $n$ is odd (subclause 20.3.5.9 noted that the first OFDM symbol following the PLCP preamble is labelled $n$=1). Then, the corresponding transmission from the second antenna, on the same subcarrier and during the same OFDM symbols, shall be $-x^*_{k,n+1}$ and $x^*_{k,n}$ where * denotes complex conjugation. This encoding scheme shall hereafter be referred to as the "basic STBC encoding rule". The basic STBC encoding rule is represented as

$$M(x_1, x_2) = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \qquad (27)$$

where $x_1$ and $x_2$ are complex quantities.

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~~Table 019~~Table 020—Rate-dependent parameters for 20 MHz, NTX-STBC modes with $N_{SS}$ = 1

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data sub-carriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 6 .75 | BPSK | 1/2 | 1 | 54 | 2 | 54 | 27 | 114 |
| 10.125 | BPSK | 3/4 | 1 | 54 | 2 | 54 | 40.5 | 115 |
| 13.5 | QPSK | 1/2 | 2 | 54 | 2 | 108 | 54 | 116 |
| 20.25 | QPSK | 3/4 | 2 | 54 | 2 | 108 | 81 | 117 |
| 27 | 16-QAM | 1/2 | 4 | 54 | 2 | 216 | 108 | 118 |
| 40.5 | 16-QAM | 3/4 | 4 | 54 | 2 | 216 | 162 | 119 |
| 54 | 64-QAM | 2/3 | 6 | 54 | 2 | 324 | 216 | 120 |
| 60.75 | 64-QAM | 3/4 | 6 | 54 | 2 | 324 | 243 | 121 |
| 67.5 | 64-QAM | 5/6 | 6 | 54 | 2 | 324 | 270 | 122 |

Since encoding takes place across pairs of MIMO-OFDM symbols in this subclause, the number of pad bits inserted in subclause 20.3.5.3 shall be sufficient to ensure that an even number of MIMO-OFDM symbols are transmitted in the PPDU.

The RATE-dependent parameters for 20 MHz, $N_{TX}$ = 2, $N_{SS}$ = 1 are defined in Table 020. The RATE-dependent parameters for 40 MHz, $N_{TX}$ = 2, $N_{SS}$ = 1 are defined in Table 006.

For $N_{TX}$ = 3, $N_{SS}$ = 1 modes, and for $N_{TX}$ = 4, $N_{SS}$ = 1 modes, each data subcarrier transmits on two consecutive OFDM symbol pairs using the basic STBC encoding rule on two of the transmit antennas. The selection of the two active antennas on each data subcarrier is achieved through a circulation pattern given by

$$cir(k_d) = ((k_d \bmod 9) + \text{floor}(k_d/9)) \bmod N_{TX}, \quad (28)$$

where $k_d$ is the "data tone index". For subcarrier indices $k$, Table 021~~Table 021~~ lists the corresponding data tone indices for 20 MHz modes. For subcarrier indices $k$, Table 022 lists the corresponding data tone indices for 40 MHz modes.

~~Table 021~~Table 021- Data tone indices as a function of subcarrier indices in 20 MHz modes.

| Subcarrier index, $k$ | Data tone index, $k_d$ |
|---|---|
| $-28 \le k \le -22$ | $k+28$ |
| $-20 \le k \le -1$ | $k+27$ |
| $1 \le k \le 20$ | $k+26$ |
| $22 \le k \le 28$ | $k+25$ |

Table 022— Data tone indices as a function of subcarrier indices in 40 MHz modes.

| Subcarrier index, $k$ | Data tone index, $k_d$ |
|---|---|
| $-58 \le k \le -43$ | $k+58$ |
| $-41 \le k \le -15$ | $k+57$ |
| $-13 \le k \le -3$ | $k+56$ |
| $3 \le k \le 13$ | $k+51$ |
| $15 \le k \le 41$ | $k+50$ |
| $43 \le k \le 58$ | $k+49$ |

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Table 023 displays the transmitted signals over two consecutive OFDM symbols in the NTX-STBC modes with $N_{SS}$=1, using the basic STBC encoding rule summarized in (27). For each data subcarrier $k$, the selection of the two antennas for the basic STBC encoding rule for 3TX and 4TX is achieved via the binary matrices $S_3(\text{cir}(k_d))$ and $S_4(\text{cir}(k_d))$, defined below, where $k_d$ is the data tone index corresponding to data subcarrier index $k$ (Table 021 ~~Table 021~~and Table 022).

**Table 023— NTX-STBC-mode encoding rules for $N_{TX}$=2, 3, 4 and $N_{SS}$=1**

| $N_{TX}$ | Signal over OFDM symbol pair ($n$, $n$+1), $n$ odd |
|---|---|
| 2 | $M(s_{k,n}, s_{k,n+1})$ |
| 3 | $(3/2)^{1/2}\, S_3(\text{cir}(k_d))\, M(s_{k,n}, s_{k,n+1})$ |
| 4 | $2^{1/2}\, S_4(\text{cir}(k_d))\, M(s_{k,n}, s_{k,n+1})$ |

Depending on the value of the data tone index $k_d$, the matrix $S_3(\text{cir}(k_d))$ assumes one of the three values shown in Figure 024. The values $S_3(0)$, $S_3(1)$, $S_3(2)$ indicate that the basic STBC encoding rule shall be applied to antenna pairs (1,3), (2,3) or (1,2), respectively. Similarly, depending on the values of $k_d$, the matrix $S_4(\text{cir}(k_d))$ takes on one of the four values shown in Figure 025. The values $S_4(0)$, $S_4(1)$, $S_4(2)$, $S4(2)$ indicate that the basic STBC encoding rule shall be applied to antenna pairs (1,3), (2,4) ,(1,4) or (2,3) respectively.

$$S_3(0)=\begin{bmatrix}1&0\\0&0\\0&1\end{bmatrix},\quad S_3(1)=\begin{bmatrix}0&0\\1&0\\0&1\end{bmatrix},\quad S_3(2)=\begin{bmatrix}1&0\\0&1\\0&0\end{bmatrix}$$

**Figure 024 – Antenna selection via $S_3$.**

$$S_4(0)=\begin{bmatrix}1&0\\0&0\\0&1\\0&0\end{bmatrix},\quad S_4(1)=\begin{bmatrix}0&0\\1&0\\0&0\\0&1\end{bmatrix},\quad S_4(2)=\begin{bmatrix}1&0\\0&0\\0&0\\0&1\end{bmatrix},\quad S_4(3)=\begin{bmatrix}0&0\\1&0\\0&1\\0&0\end{bmatrix}$$

**Figure 025 – Antenna selection via $S_4$.**

The RATE-dependent parameters for 20 MHz, $N_{TX}$ = 3, $N_{SS}$ = 1 are the same as those for the 20MHz, $N_{TX}$ = 2, $N_{SS}$ = 1, given by Table 022.
The RATE-dependent parameters for 20 MHz, $N_{TX}$ = 4, $N_{SS}$ = 1 are the same as those for the 20MHz, $N_{TX}$ = 2, $N_{SS}$ = 1, given by Table 022.
The RATE-dependent parameters for 40 MHz, $N_{TX}$ = 2, $N_{SS}$ = 1 are defined in Table 006.
The RATE-dependent parameters for 40 MHz, $N_{TX}$ = 3, $N_{SS}$ = 1 are the same as those for the 40MHz, $N_{TX}$ = 2, $N_{SS}$ = 1,given by Table 006.
The RATE-dependent parameters for 40 MHz, $N_{TX}$ = 4, $N_{SS}$ = 1 are the same as those for the 40MHz, $N_{TX}$ = 2, $N_{SS}$ = 1,given by Table 006.

### 20.3.5.10.2 NTX-STBC modes with more than one single spatial stream ($N_{SS}$≥ 2)

#### 20.3.5.10.2.1 Pilot tones in NTX-STBC modes with $N_{SS}$≥ 2

The pilot tones and their structure in NTX-STBC modes with $N_{SS}$≥ 2 follow those of the NTX-SDM modes described in subclause 20.3.5.9.1

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### 20.3.5.10.2.2 Data tones in NTX-STBC modes with $N_{SS} \geq 2$

The RATE-dependent parameters for 20 MHz, $N_{TX} = 3$, $N_{SS} = 2$ are defined in Table 003. In this configuration, the basic STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8.

The RATE-dependent parameters for 20 MHz, $N_{TX} = 4$, $N_{SS} = 2$ are defined in Table 003. In this configuration, the basic STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream, and on the third and fourth antennas using bits from the second spatial stream.

The RATE-dependent parameters for 20 MHz, $N_{TX} = 4$, $N_{SS} = 3$ are defined in Table 004. In this configuration, the basic STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8. Bits from the third spatial stream shall be mapped to subcarriers of the fourth transmit antenna, according to subclause 20.3.5.8.

The RATE-dependent parameters for 40 MHz, $N_{TX} = 2$, $N_{SS} = 1$ are defined in Table 006. In this configuration, the STBC encoding rule shall be applied on the first and second antennas.

The RATE-dependent parameters for 40 MHz, $N_{TX} = 3$, $N_{SS} = 2$ are defined in Table 007. In this configuration, the basic STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8.

The RATE-dependent parameters for 40 MHz, $N_{TX} = 4$, $N_{SS} = 2$ are defined in Table 007. In this configuration, the basic STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream, and on the third and fourth antennas using bits from the second spatial stream.

The RATE-dependent parameters for 40 MHz, $N_{TX} = 4$, $N_{SS} = 3$ are defined in Table 008. In this configuration, the basic STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8. Bits from the third spatial stream shall be mapped to subcarriers of the fourth transmit antenna, according to subclause 20.3.5.8.

~~The space-time block encoding scheme for $N_{TX} = 2$, $N_{SS} = 1$ in 20 MHz and 40 MHz is defined as follows. The bits output from the interleaver of the (single) spatial stream are mapped to the subcarriers of the first antenna, according to subclause 20.3.5.8. We denote the pair of complex numbers transmitted on subcarrier $k$ from this antenna during the $j-1$th and $j$th OFDM symbol as $s_{j-1}$ and $s_j$, respectively. Then the corresponding transmission from the second antenna, on the same subcarrier index and during the same OFDM symbols, shall be $-s^*_j$ and $s^*_{j-1}$ where * denotes complex conjugate. This encoding scheme shall hereafter be referred to as the "STBC encoding rule".~~

~~Since encoding takes place across pairs of MIMO-OFDM symbols in this subclause, the number of pad bits inserted in subclause 20.3.5.3 shall be sufficient to ensure that an even number of MIMO-OFDM symbols are transmitted in the PPDU.~~

~~Table 017—Rate-dependent parameters for 20 MHz, $N_{TX} = 2$, $N_{SS} = 1$~~

| ~~Data rate (Mbits/s)~~ | ~~Modulation~~ | ~~Code rate (R)~~ | ~~Coded bits per subcarrier per~~ | ~~Number of data subcarriers ($N_{SD}$)~~ | ~~Number of pilots ($N_{SP}$)~~ | ~~Coded bits per MIMO-OFDM~~ | ~~Data bits per MIMO-OFDM~~ | ~~Clause 10.4.4.2 rate code~~ |
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| | | | antenna ($N_{BPSC}$) | | | symbol ($N_{CBPS}$) | symbol ($N_{DBPS}$) | |
|---|---|---|---|---|---|---|---|---|
| 6 .75 | BPSK | 1/2 | 1 | 54 | 2 | 54 | 27 | 114 |
| 10.125 | BPSK | 3/4 | 1 | 54 | 2 | 54 | 40.5 | 115 |
| 13.5 | QPSK | 1/2 | 2 | 54 | 2 | 108 | 54 | 116 |
| 20.25 | QPSK | 3/4 | 2 | 54 | 2 | 108 | 81 | 117 |
| 27 | 16-QAM | 1/2 | 4 | 54 | 2 | 216 | 108 | 118 |
| 40.5 | 16-QAM | 3/4 | 4 | 54 | 2 | 216 | 162 | 119 |
| 54 | 64-QAM | 2/3 | 6 | 54 | 2 | 324 | 216 | 120 |
| 60.75 | 64-QAM | 3/4 | 6 | 54 | 2 | 324 | 243 | 121 |
| 67.5 | 64-QAM | 5/6 | 6 | 54 | 2 | 324 | 270 | 122 |

The RATE-dependent parameters for 20 MHz, $N_{TX}$ = 3, $N_{SS}$ = 2 are defined in Table 003. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8.

The RATE-dependent parameters for 20 MHz, $N_{TX}$ = 4, $N_{SS}$ = 2 are defined in Table 003. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream, and on the third and fourth antennas using bits from the second spatial stream.

The RATE-dependent parameters for 20 MHz, $N_{TX}$ = 4, $N_{SS}$ = 3 are defined in Table 004. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8. Bits from the third spatial stream shall be mapped to subcarriers of the fourth transmit antenna, according to subclause 20.3.5.8.

The RATE-dependent parameters for 40 MHz, $N_{TX}$ = 2, $N_{SS}$ = 1 are defined in Table 006. In this configuration, the STBC encoding rule shall be applied on the first and second antennas.

The RATE-dependent parameters for 40 MHz, $N_{TX}$ = 3, $N_{SS}$ = 2 are defined in Table 007. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8.

The RATE-dependent parameters for 40 MHz, $N_{TX}$ = 4, $N_{SS}$ = 2 are defined in Table 007. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream, and on the third and fourth antennas using bits from the second spatial stream.

The RATE-dependent parameters for 40 MHz, $N_{TX}$ = 4, $N_{SS}$ = 3 are defined in Table 008. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8. Bits from the third spatial stream shall be mapped to subcarriers of the fourth transmit antenna, according to subclause 20.3.5.8.

### 20.3.6 Clear channel assessment

PLCP shall provide the capability to perform CCA and report the result to the MAC. The CCA mechanism shall detect a “medium busy” condition with a performance specified in 20.3.10.5. This medium status report is indicated by the primitive PHY_CCA.indicate.

### 20.3.7 PLCP data modulation and modulation rate change

The PLCP preamble shall be transmitted using a set of OFDM-modulated fixed waveforms, specified in subclause 20.3.3 for each transmit antenna for each mode of operation defined in the MIMO-OFDM PHY. The SIG-N field, composed of 54 bits, shall indicate the bandwidth, modulation, code rate, code type, number of TX antennas, and number of spatial streams that shall be used to transmit the MPDU. The transmitter (receiver) shall initiate the modulation constellation, code rate, code type, and other configuration parameters according to the CONFIG indicated in the SIG-N field. The MPDU transmission rate shall be set by the DATARATE parameter in the TXVECTOR, issued with the PHY-TXSTART.request primitive described in 20.2.

### 20.3.8 PMD operating specifications

Subclauses 20.3.8.1 through 20.3.8.8 provide general specifications for the various modes and options defined in the MIMO-OFDM PMD sublayer. These specifications apply to both the receive and transmit functions and general operation of the MIMO-OFDM PHY.

#### 20.3.8.1 TX Block diagram

The general block diagram of the transmitter for the MIMO-OFDM PHY is shown in Figure 024. The blocks that are shaded in the figure may be replicated $N_{TX}$ times in a MIMO-OFDM system with $N_{TX}$ transmit antennas.

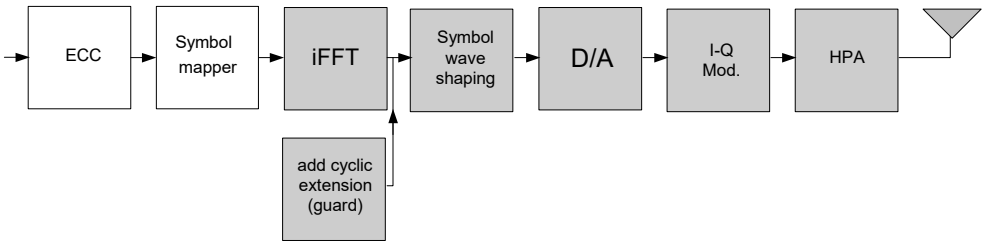



**Figure 024 – Transmitter block diagram for the MIMO-OFDM PHY**

#### 20.3.8.2 Regulatory requirements

All systems shall comply with the local regulatory requirements for operation in the band in which they are implemented. For 2.4 GHz operation, refer to FCC 15.247, 15.249, 15.205, and 15.209 for the USA; ETS 300-328 for Europe; and MPHPT article 49-20 for Japan. For 5 GHz operation in the USA, refer to FCC CFR47, Part 15, sections 15.205 and 15.209; and Subpart E, sections 15.401-15.407.

The documents listed here are provided for information only, and are subject to change or revision at any time.

#### 20.3.8.3 Operating channel frequencies

The range of operating frequencies for the MIMO-OFDM PHY shall be 2400-2497 MHz and 4920-5805 MHz. The channel numbering shall be as defined in IEEE 802.11b-1999 clause 18.4.6.2, and clause 17.3.8.3.2 of IEEE

P802.11j/D1.5, May 2004. The relationship between center frequency and channel number is given by the following equations:

Channel center frequency = 5000 + (channel number) × 5 (MHz) for center frequency > 5000 MHz (25)

Channel center frequency = 4000 + (channel number) × 5 (MHz) for 4900 ≤ center frequency ≤ 5000 MHz (26)

40 MHz operation shall be restricted to the 5 GHz band only. Each 40 MHz channel shall occupy two 20 MHz channels, with the center frequency of the 40 MHz transmission selected to be midway between the center frequencies of the two occupied 20 MHz channels. For example, if the two occupied 20 MHz channels are centered at channel number 149 and 153, then the 40 MHz transmission shall be centered at channel number 151.

#### 20.3.8.4 Spurious emissions

The spurious emissions shall conform to IEEE 802.11a-1999 subclause 17.3.8.4

#### 20.3.8.5 TX RF delay

The TX RF delay shall follow IEEE 802.11a-1999 subclause 17.3.8.5.

#### 20.3.8.6 Slot time

The slot time shall follow IEEE 802.11a-1999 subclause 17.3.8.6 for 5 GHz bands and IEEE 802.11g-1999 subclause 19.4.4 for 2.4 GHz bands.

#### 20.3.8.7 Transmit and receive antenna port impedance

The transmit and receive antenna port impedance for each transmit and receive antenna shall follow IEEE 802.11a-1999 subclause 17.3.8.7.

#### 20.3.8.8 Transmit and receive operating temperature range

The transmit and receive temperature range shall follow IEEE 802.11a-1999 subclause 17.3.8.8.

### 20.3.9 PMD TX specifications

Subclauses 20.3.9.1 through 20.3.9.7 describe the transmit specifications associated with the PMD sublayer. In general, these are specified by primitives from the PLCP, and the transmit PMD entity provides the actual means by which the signals required by the PLCP primitives are imposed into the medium.

#### 20.3.9.1 TX power levels

The maximum allowable output power shall conform to national regulatory constraints on the maximum radiated power allowed in any frequency band.

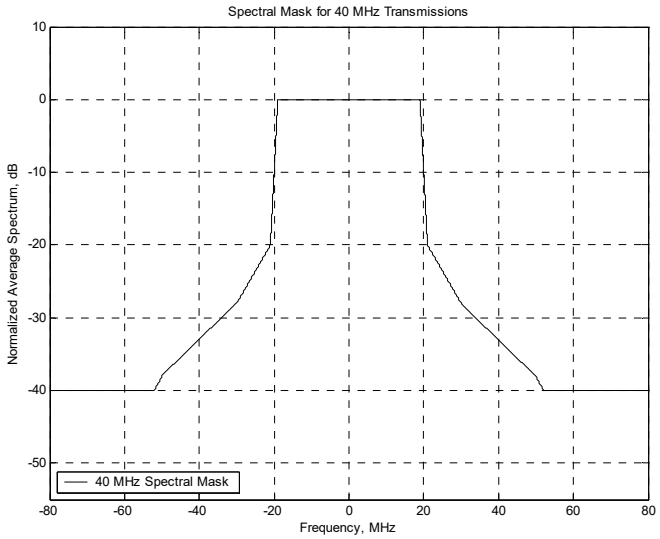



**Figure 025 –Transmit spectrum mask for 40 MHz transmissions**

### 20.3.9.2 TX spectrum mask

The transmitted spectral density of the transmitted signal shall conform to subclause IEEE 802.11a-1999 17.3.9.2 for all 20 MHz transmissions. The transmitted spectrum for 40 MHz transmissions shall have a 0 dBr bandwidth not exceeding 38 MHz, -20 dBr at 21 MHz frequency offset, -28 dBr at 30 MHz frequency offset, -38 dBr at 50 MHz frequency offset, and -40 dBr at 52 MHz frequency offset and above. The transmitted spectral density of the 40 MHz transmitted signal shall fall within the spectral mask shown in Figure 025. The measurements shall be made using a 100 kHz resolution bandwidth and a 30 kHz video bandwidth.

### 20.3.9.3 TX spurious

Spurious transmissions from Clause 20 compliant devices shall conform to national regulations.

### 20.3.9.4 TX center frequency tolerance

The transmitted center frequency tolerance shall be ±20 ppm maximum for 5 GHz bands and ±25 ppm for 2.4 GHz bands. The transmit center frequency and the symbol clock frequency for all transmit antennas shall be derived from the same reference oscillator.

.

### 20.3.9.5 TX symbol clock frequency tolerance

The symbol clock frequency tolerance shall be ±20 ppm maximum for 5 GHz bands and ±25 ppm for 2.4 GHz bands. The transmit center frequency and the symbol clock frequency for all transmit antennas shall be derived from the same reference oscillator.

### 20.3.9.6 Modulation accuracy

Transmit modulation accuracy specifications are described in this subclause. The test method is described in 20.3.9.7.

#### 20.3.9.6.1 TX center frequency leakage

TX center frequency leakage shall follow IEEE 802.11a-1999 subclause 17.3.9.6.1 for all 20 MHz modes of transmission. For 40 MHz modes, the center frequency leakage shall not exceed -18 dB relative to overall transmitted power, or,equivalently, +2 dB relative to the average energy of the rest of the subcarriers.

#### 20.3.9.6.2 TX spectral flatness

For 20 MHz transmissions, the average energy of the constellation in each of the spectral lines -16…-1 and +1…+16 will deviate no more than ±2 dB of their average energy. The average energy of the constellations in each of the spectral lines -28…-17 and +17…+28 will deviate no more than +2/-4 dB from the average energy of the spectral lines -16…-1 and +1…+16.

For 40 MHz transmissions, the average energy of the constellation in each of the spectral lines -32…-3 and +3…+32 will deviate no more than ±2 dB of their average energy. The average energy of the constellations in each of the spectral lines -58…-33 and +33…+58 will deviate no more than +2/-4 dB from the average energy of the spectral lines -32…-3 and +3…+32.

#### 20.3.9.6.3 TX constellation error

The relative constellation RMS error, averaged over subcarriers, transmit spatial streams, OFDM frames, and packets, shall not exceed a constellation and code rate dependent value according to Table 020 for the all modes in which the number of spatial streams is equal to the number of transmit antennas.

**Table 020—Allowed relative constellation error versus constellation type and code rate**

| Constellation size | Code Rate | Relative constellation error (dB) |
|---|---|---|
| 16-QAM | 1/2 | -17 |
| 16-QAM | 3/4 | -20 |
| 64-QAM | 2/3 | -24 |
| 64-QAM | 3/4 | -26 |
| 64-QAM | 5/6 | -27 |

#### 20.3.9.7 TX modulation accuracy (EVM) test

The transmit modulation accuracy test shall be performed by instrumentation capable of converting the transmitted signals into a stream of complex samples at 20 Msamples/s or more for 20 MHz modes, and 40 Msamples/s or more for 40 MHz modes, with sufficient accuracy in terms of I/Q arm amplitude and phase balance, DC offsets, phase noise, etc. A possible embodiment of such a setup is converting the signals to a low IF frequency with a microwave synthesizer, sampling the signals with a digital oscilloscope, and decomposing them digitally into quadrature components.

The test procedure for this requirement is as follows: Matrices $H_{1TX}$, $H_{2TX}$, $H_{3TX}$, and $H_{4TX}$ are defined to give the connections from the transmit antennas to the receive antennas for the 1TX, 2TX, 3TX, and 4TX cases respectively. They are specified as follows:

$$H_{1TX} = \alpha \cdot 1$$

$$H_{2TX} = \alpha \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

$$H_{3TX} = \alpha \begin{bmatrix} -1 & 2 & 2 \\ 2 & -1 & 2 \\ 2 & 2 & -1 \end{bmatrix}$$

$$H_{4TX} = \alpha \begin{bmatrix} -1 & 1 & 1 & 1 \\ 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \end{bmatrix} \quad (27)$$

The elements of the above matrices $h_{ij}$ specify the connection from the $j^{th}$ transmitter to the $i^{th}$ receiver, where $h_{ij}$ is the element of the $i^{th}$ row and $j^{th}$ column where $i = 1,\ldots, N_{RX}$ and $j = 1,\ldots, N_{TX}$. The attenuation $\alpha$ is chosen to ensure an appropriate received signal power at the test equipment. Figure 026 shows an example test setup for a 2TX mode.

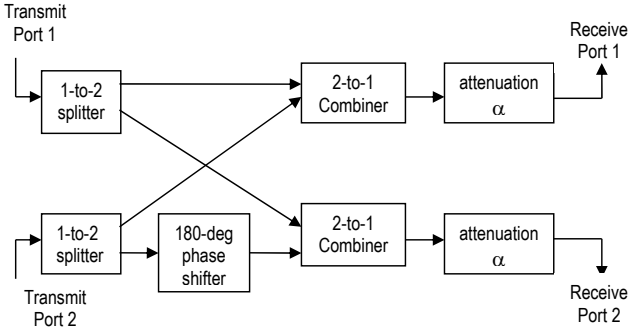



**Figure 026 –EVM test setup**

The 180 degree phase shifter shall be 180 +/- 10 degrees. The relative amplitudes of the connections $h_{ij}$ shall be within +/-1 dB of the relative values specified in the H matrices above.

The sampled signals shall be processed in a manner similar to an actual receiver, according to the following steps, or an equivalent procedure:

a) Start of frame shall be detected.
b) Transition from short sequences to channel estimation sequences shall be detected, and fine timing (with one sample resolution) shall be established.
c) Coarse and fine frequency offsets shall be estimated.
d) The packet shall be derotated according to estimated frequency offset.
e) The complex channel response coefficients shall be estimated for each of the subcarriers.
f) For each of the data OFDM symbols: transform the symbol into subcarrier received values, estimate the phase from the pilot subcarriers, derotate the subcarrier values according to estimated phase, and apply an

MMSE channel equalizer to each vector of received subcarrier values based on complex estimated channel response coefficients found in (e).

g) For each data-carrying subcarrier of each transmitted stream, find the closest constellation point and compute the Euclidean distance from it.

h) Compute the RMS average of all errors in a packet. It is given by:

$$Error_{RMS} = \frac{\sum_{i=1}^{N_f} \sqrt{\frac{\sum_{l=1}^{N_{SS}} \sum_{j=1}^{L_P} \sum_{k=1}^{N_{ST}} \{(I(i,j,k,l) - I_0(i,j,k,l))^2 + (Q(i,j,k,l) - Q_0(i,j,k,l))^2\}}{N_{ST} L_P P_0 N_{SS}}}}{N_f} \quad (28)$$

where

$L_P$ is the length of the packet;

$N_{SS}$ is the number of spatial streams;

$N_f$ is the number of frames for the measurement;

$N_{ST}$ is the total number of subcarriers (data and pilots) per OFDM symbol;

($I_0(i,j,k,l)$, $Q_0(i,j,k,l)$) denotes the ideal symbol point of the $i^{th}$ frame, $j^{th}$ OFDM symbol of the frame, $k^{th}$ subcarrier, and $l^{th}$ spatial stream of the OFDM symbol in the complex plane;

($I(i,j,k,l)$, $Q(i,j,k,l)$) denotes the observed point of the $i^{th}$ frame, $j^{th}$ OFDM symbol of the frame, $k^{th}$ subcarrier, and $l^{th}$ spatial stream of the OFDM symbol in the complex plane;

$P_0$ is the average power of the constellation.

The vector error on a phase plane is shown in Figure 121 in IEEE 802.11a-1999 subclause 17.3.9.7.

The test shall be performed over at least 20 frames ($N_f$), and the RMS average shall be taken. The packets under test shall be at least 16 OFDM symbols long. Random data shall be used for the symbols.

### 20.3.10 PMD RX specifications

Subclauses 20.3.10.1 through 20.3.10.5 describe the receive specifications associated with the PMD sublayer.

#### 20.3.10.1 RX minimum input level sensitivity

The packet error rate (PER) shall be less than 10% at a PSDU length of 1000 bytes for rate-dependent input levels shall be the numbers listed in Table 021 or less. The minimum input levels are measured at the antenna connectors and are referenced as the average power per receive antenna.

**Table 021—Receiver minimum input level sensitivity**

| Constellation size | Code Rate | Minimum sensitivity (dBm) |
|---|---|---|
| BPSK | ½ | -82 |
| BPSK | ¾ | -81 |
| QPSK | ½ | -79 |
| QPSK | ¾ | -77 |
| 16-QAM | ½ | -74 |
| 16-QAM | ¾ | -70 |

| | | |
|---|---|---|
| 64-QAM | 2/3 | -66 |
| 64-QAM | ¾ | -65 |
| 64-QAM | 5/6 | -64 |

#### 20.3.10.2 RX maximum input level

The RX maximum input level shall be defined as the maximum at any or all antennas, and shall follow IEEE 802.11a-1999 subclause 17.3.10.4 for the 4920-5805 MHz band, and follow IEEE 802.11g-2003 subclause 19.5.3 for the 2400-2497 MHz band.

#### 20.3.10.3 CCA sensitivity

The CCA sensitivity of all Clause 20 compliant devices shall conform to IEEE 802.11a-2003 subclause 17.3.10.5. When operating in 40 MHz mode, the receiver shall also provide a secondary channel carrier sense. The start of a valid OFDM transmission at a receive level equal to or greater than the minimum 6 Mbit/s sensitivity (-82 dBm) shall cause the secondary channel CCA to indicate busy with a probability of >90% within 4us. The receiver shall hold the secondary channel CCA busy for any signal 20 dB above the minimum 6 Mbit/s sensitivity (-62 dBm).

### 20.3.11 PLCP TX procedure

The transmit PLCP is shown in Figure 029. In order to transmit data, PHY-TXSTART.request shall be enabled so that the PHY entity shall be in the transmit state. Further, the PHY shall be set to operate at the appropriate frequency through station management via the PLME. Other transmit parameters, such as DATARATE, TRANSMISSION_MODE, NUM_STREAMS, and TXPWR_LEVEL, are set via the PHY-SAP with the PHY-TXSTART.request(TXVECTOR), as described in 20.2.

A clear channel shall be indicated by PHY-CCA.indicate(IDLE). The MAC considers this indication before issuing the PHY-TXSTART.request. Transmission of the PPDU or A-PPDU shall be initiated after receiving the PHYTXSTART. request(TXVECTOR) primitive. The TXVECTOR elements for the PHY-TXSTART.request are the PLCP header parameters LENGTH, DATARATE, TRANSMISSION_MODE, NUM_STREAMS, CODE_TYPE, SERVICE, LPI, and BURST_DURATION, and the PMD parameter TXPWR_LEVEL.

The PLCP shall issue PMD_TXPWRLVL, PMD_RATE, PMD_NUM_STREAMS, and PMD_TRANSMISSION_MODE, primitives to configure the PHY. The PLCP shall then issue a PMD_TXSTART.request, and transmission of the PLCP preamble and PLCP header, based on the parameters passed in the PHY-TXSTART.request primitive will begin. Once PLCP preamble transmission is started, the PHY entity shall immediately initiate data scrambling and data encoding. The scrambled and encoded data shall then be exchanged between the MAC and the PHY through a series of PHYDATA.request(DATA) primitives issued by the MAC, and PHY-DATA.confirm primitives issued by the PHY. The modulation rate change, if any, shall be initiated from the SERVICE field data of the PLCP header, as described in 20.3.2. The PHY proceeds with PSDU transmission through a series of data octet transfers from the MAC. The PLCP header parameter, SERVICE, and PSDU are encoded by the convolutional encoder with the bit-stealing function described in 20.3.5.5. At the PMD layer, the data octets are sent in bit 0–7 order and presented to the PHY through PMD_DATA.request primitives. In the PMD, the GI shall be inserted in every OFDM symbol as a countermeasure against severe delay spread.

Transmission of a PSDU can be prematurely terminated by the MAC through the primitive PHY-TXEND.request. PHY-TXSTART shall be disabled by the issuance of the PHY-TXEND.request. Normal transmission of a PSDU occurs after the transmission of the final bit of the last PSDU octet, according to the number of bytes supplied in the PLCP header LENGTH.

Each PHY-TXEND.request is acknowledged with a PHY-TXEND.confirm primitive from the PHY. If the coded PSDU (C-PSDU) is not multiples of the OFDM symbol, bits shall be stuffed to make the C-PSDU length multiples of the OFDM symbol.

If an aggregated PPDU (A-PPDU) is being transmitted as indicated by the TXVECTOR LPI parameter, the PHY will wait for the next PHY_TXSTART.request from the MAC. The process of transmitting the subsequent MPDUs as part of the A-PPDU is identical to the first MPDU except that the PLCP will not issue PMD primitives to configure the PHY.

Normal termination of the A-PPDU occurs at the termination of the transmission of the last PSDU, indicated by the PHY PLCP header LPI field. A permaturely terminated PSDU transmission from the MAC will prematurely terminate the transmission of the A-PPDU.

The A-PPDU transmission shall be completed and the PHY entity shall enter the receive state (i.e., PHY-TXSTART shall be disabled).

A typical state machine implementation of the transmit PLCP is provided in Figure 027. Requests (.req) and confirmations (.confirm) are issued once with designated states.

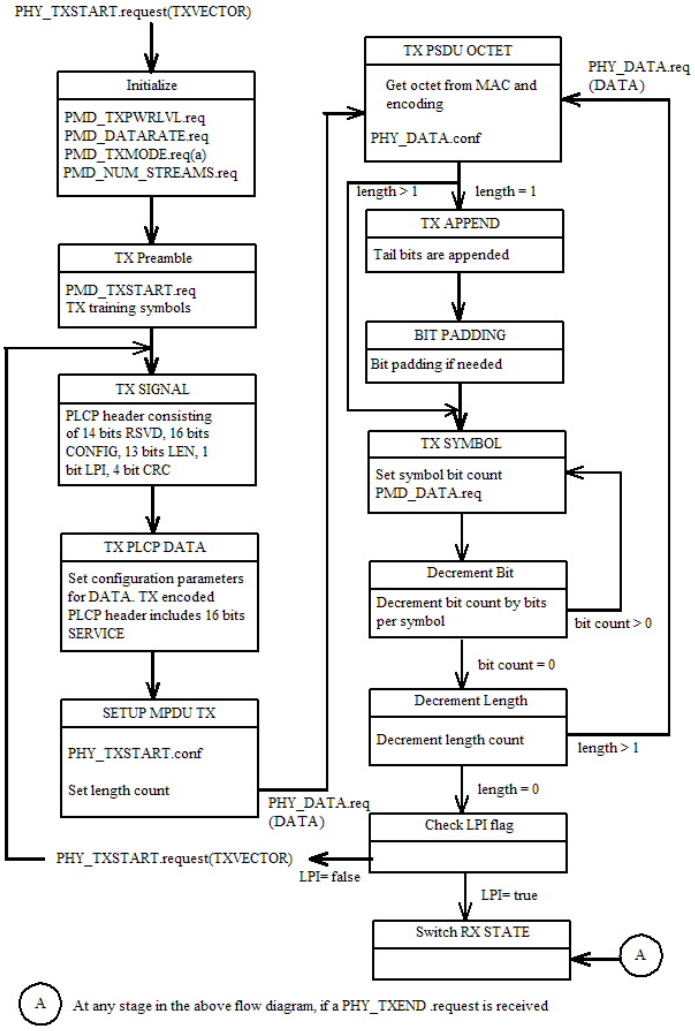



**Figure 027 –PLCP transmit state machine**

### 20.3.12 PLCP RX procedure

The receive PLCP is shown in Figure 030. In order to receive data, PHY-TXSTART.request shall be disabled so that the PHY entity is in the receive state. Further, through station management (via the PLME) the PHY is set to the appropriate frequency. Other receive parameters, such as RSSI and indicated DATARATE, TRANSMISSION_MODE, NUM_STREAMS, CODE_TYPE, LPI, and BURST_DURATION may be accessed via the PHY-SAP.

Upon receiving the transmitted PLCP preamble, PMD_RSSI.indicate shall report a significant received signal strength level to the PLCP. This indicates activity to the MAC via PHY_CCA.indicate.
PHY_CCA.indicate(BUSY) shall be issued for reception of a signal prior to correct reception of the PLCP frame. The PMD primitive PMD_RSSI is issued to update the RSSI and parameter reported to the MAC.

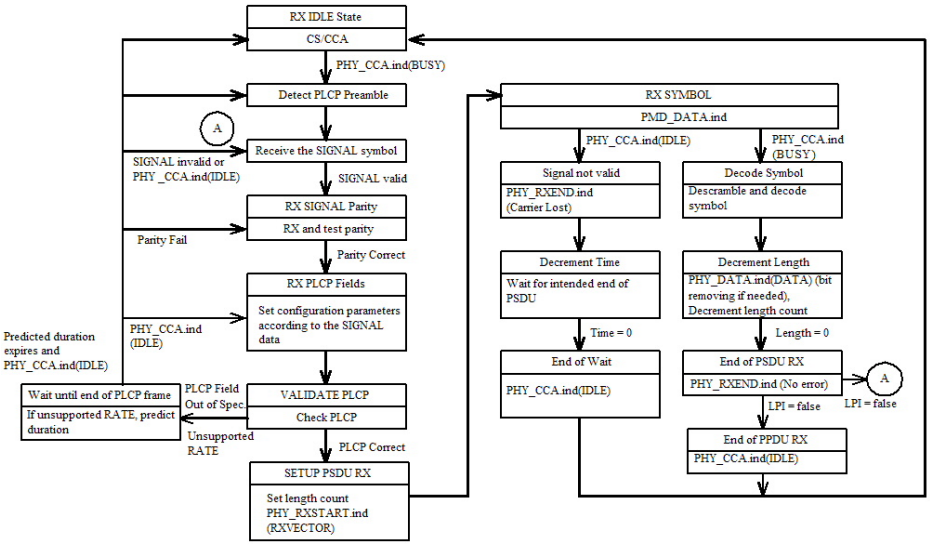



**Figure 028 – PLCP receive state machine**

After PHY-CCA.indicate is issued, the PHY entity shall begin receiving the training symbols and searching for the SIGNAL in order to set the length of the data stream, the demodulation type, and the decoding rate. Once the SIGNAL is detected without any errors detected by the CRC checker, FEC decode shall be initiated and the PLCP SERVICE fields and data shall be received, and decoded. Should the status of CCA return to the IDLE state during reception prior to completion of the full PLCP processing, the PHY receiver shall return to the RX IDLE state.

If the PLCP header reception is successful (and the SIGNAL field is completely recognizable and supported), a PHY-RXSTART.indicate(RXVECTOR) shall be issued. The RXVECTOR associated with this primitive includes the SIGNAL fields, the SERVICE field, the PSDU length in bytes, and the RSSI. Also, in this case, the HT PHY will ensure that the CCA shall indicate a busy medium for the intended duration of the transmitted frame, as indicated by the LENGTH field. The received PSDU bits are assembled into octets, decoded, and presented to the MAC using a series of PHY-DATA.indicate(DATA) primitive exchanges. The rate change indicated in the SIGNAL field shall be initiated from the SERVICE field data of the PLCP header, as described in 20.3.2. The PHY shall proceed with PSDU reception. After the reception of the final bit of the last PSDU octet indicated by the PLCP header LENGTH field, the receiver shall transition to the RX IDLE state if LPI is 1 or to the RX SIGNAL state if LPI is 0 in the RXVECTOR associated with this primitive, as shown in Figure 030. If the LPI is 1 in the RXVECTOR, a PHY-RXEND.indicate(NoError) primitive shall also be issued.

In the event that a change in the RSSI causes the status of the CCA to return to the IDLE state before the complete reception of the PSDU, as indicated by the PLCP LENGTH field, the error condition PHYRXEND.indicate(CarrierLost) shall be reported to the MAC. The HT PHY will ensure that the CCA

indicates a busy medium for the intended duration of the transmitted packet. If the indicated rate in the SIGNAL field is not receivable, a PHY-RXSTART.indicate will not be issued. The PHY shall issue the error condition PHY-RXEND.indicate(UnsupportedRate). If the PLCP header is receivable, but the FCS check of the PLCP header is not valid, a PHY-RXSTART.indicate will not be issued. The PHY shall issue the error condition PHY-RXEND.indicate(FormatViolation). Any data received after the indicated data length are considered pad bits (to fill out an OFDM symbol) and should be discarded. A typical state machine implementation of the receive PLCP is given in Figure 028.

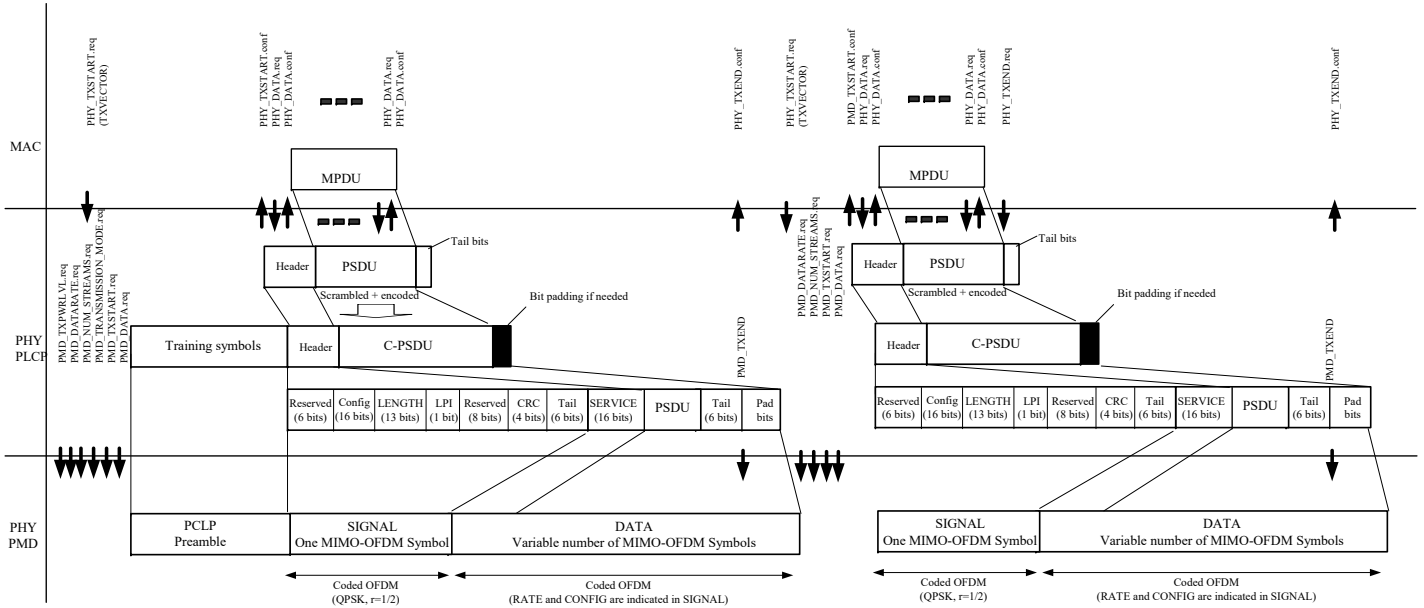



**Fig. 029 PLCP transmit procedure for A-PPDU transmission in greenfield 20 MHz modes**

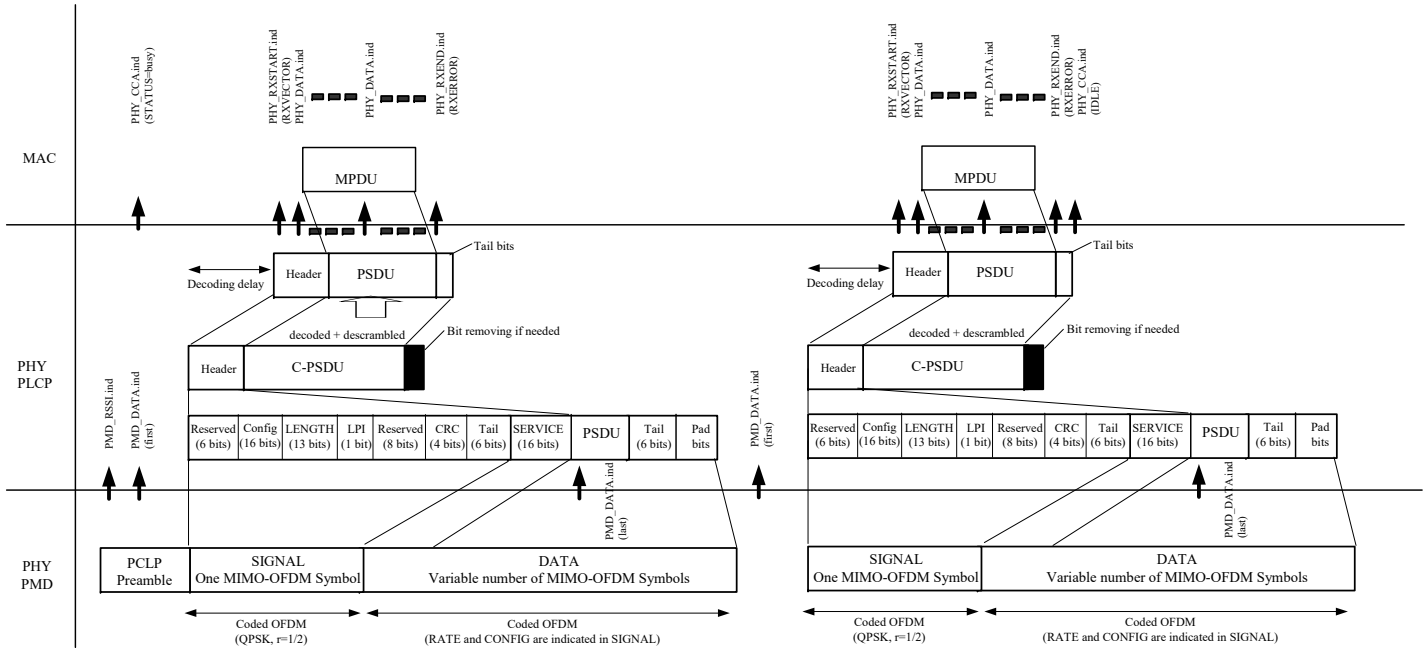



**Fig. 030 PLCP receive procedure for A-PPDU reception in greenfield 20 MHz modes**

# 20.4 MIMO-OFDM PMD operating specifications

### 20.4.1 PLME_SAP sublayer management primitives

Table 20.4.2T1 lists the MIB attributes that may be accessed by the PHY entities and the intralayer of higher level LMEs. These attributes are accessed via the PLME-GET, PLME-SET, PLME-RESET, and PLME-CHARACTERISTICS primitives defined in 10.4.

### 20.4.2 MIMO-OFDM management information base

All MIMO-OFDM PHY MIB attributes are defined in Clause 13, with specific values defined in Table 20.4.2.T1. The column titled "Operational semantics" in Table 20.4.2.T1 contains two types: static and dynamic. Static MIB attributes are fixed and cannot be modified for a given PHY implementation. Dynamic MIB attributes can be modified by some management entity.

**Table 20.4.2T1 MIB attribute default values/ranges**

| Managed Object | Default Value / Range | Operational Semantics |
|---|---|---|
| dot11 PHY Operation Table | | |
| dot11PHYtype | HTP (Value to be assigned) | Static |
| dot11CurrentRegDomain | Implementation dependent | Static |
| dot11TempType | Implementation dependent | Static |
| **dot11 PHY Antenna Table** | | |
| dot11CurrentTxAntenna | Implementation dependent | Dynamic |
| dot11DiversitySupport | Implementation dependent | Static |
| dot11CurrentRxAntenna | Implementation dependent | Dynamic |
| **Dot11 PHY Tx Power Table** | | |
| dot11NumberSupportedPowerLevels | Implementation dependent | Static |
| dot11TxPowerLevel1 | Implementation dependent | Static |
| dot11TxPowerLevel2 | Implementation dependent | Static |
| dot11TxPowerLevel3 | Implementation dependent | Static |
| dot11TxPowerLevel4 | Implementation dependent | Static |
| dot11TxPowerLevel5 | Implementation dependent | Static |
| dot11TxPowerLevel6 | Implementation dependent | Static |
| dot11TxPowerLevel7 | Implementation | Static |

| | | |
|---|---|---|
| | dependent | |
| dot11TxPowerLevel8 | Implementation dependent | Static |
| dot11CurrentTxPowerLevel | Implementation dependent | Dynamic |
| **dot11 Phy DSSS Table** | | |
| dot11CurrentChannel | Implementation dependent | Dynamic |
| **dot11 Reg Domains Supported Table** | | |
| dot11RegDomainsSupportedValue(s) | Implementation dependent | Static |
| **dot11 PHY Antennas List Table** | | |
| dot11SupportedTxAntenna | Implementation dependent | Static |
| dot11SupportedRxAntenna | Implementation dependent | Static |
| dot11DiversitySelectionRx | Implementation dependent | Dynamic |
| **dot11 Supported Data Rates Tx Table** | | |
| dot11SupportedDataratesTxValue | See Clause 10.4.4.2 rate code columns of Tables 003-009 and Table 018 | Static |
| **dot11 Supported Data Rates Rx Table** | | |
| dot11SupportedDataRatesRxValue | See Clause 10.4.4.2 rate code columns of Tables 003-009 and Table 018 | Static |
| **dot11 PHY HTP Table** | | |
| dot11CurrentFrequency | Implementation dependent | Dynamic |
| dot11SupportedTransmissionModes | Assign optional types in TRANSMISSION_MODE of Table 001 to bits in bit mask | Static |
| dot11SupportedNumStreams | X'0' = Support 1 and 2 streams<br>X'1' = Support 1, 2, and 3 streams<br>X'2' = Support 1, 2, and 4 streams<br>X'3' = Support 1, 2, 3, and 4 streams | Static |
| dot11SupportedCodeTypes | X'0' = convolutional only<br>X'1' = convolutional and LDPC | Static |

### 20.4.3 MIMO-OFDM TXTIME calculation

The value of the TXTIME parameter returned by the PLME-TXTIME.confirm primitive shall be calculated according to the following equation:

TXTIME = $TXTIME_{CONV}$ if CODE_TYPE is convolutional and $TXTIME_{LDPC}$ if CODE_TYPE is LDPC

where

$TXTIME_{CONV} = T_{MIXED} + T_{PREAMBLE} + T_{SIGNAL} + T_{SYM} \times \text{Ceiling}((16 + 8 \times LENGTH + 6 \times N_{ES})/N_{DBPS})$

$TXTIME_{LDPC} = T_{MIXED} + T_{PREAMBLE} + T_{SIGNAL} + T_{SYM} \cdot N_{S1}$

$T_{MIXED}$ is 20μs if TRANSMISSION_MODE is a ~~mixed mode~~mixed-mode and 0μs if it is a greenfield mode

$T_{PREAMBLE}$ is 16μs if TRANSMISSION_MODE specifies $N_{TX} = 2$ and 28μs if TRANSMISSION_MODE specifies $N_{TX} = 3$ or 4

$T_{SIGNAL}$ is 4μs

$N_{DBPS}$ is derived from the DATARATE parameter (Ceiling is a function that returns the smallest integer value greater than or equal to its argument value)

$N_{S1}$ is defined in subclause 20.3.5.7.3.

### 20.4.4 MIMO-OFDM PHY characteristics

**Table 20.4.4.1—MIMO-OFDM PHY characteristics**

| Characteristic | Value |
|---|---|
| aSlotTime | 9 μs |
| aSIFSTime | 16 μs |
| aRIFSTime | 2 μs |
| aCCATime | <4 μs |
| aRxTxTurnaroundTime | Implementation dependent as long as the requirements of aSIFSTime are met. |
| aTxRxTurnaroundTime | Implementation dependent as long as the requirements of aSIFSTime are met. |
| aTxPLCPDelay | Implementation dependent as long as the requirements of aRxTxTurnaroundTime are met. |
| aRxPLCPDelay | Implementation dependent as long as the requirements of aSIFSTime and aCCATime are met |
| aRxTxSwitchTime | Implementation dependent |
| aTxRampOnTime | Implementation dependent as long as the requirements of aRxTxTurnaroundTime are met |
| aTxRampOffTime | Implementation dependent as long as the requirements of aSIFSTime are met |
| ATxRFDelay | Implementation dependent as long as the requirements of aRxTxTurnaroundTime are met |
| ARxRFDelay | Implementation dependent as long as the requirements of aSIFSTime and aCCATime are met |
| aAirPropagationTime | <<1 μs |
| aMACProcessingDelay | <2 μs |
| aPreambleLength | 16 μs |
| aPLCPHeaderLength | 4 μs |

| | |
|---|---|
| aMPDUMaxLength | 8191 |
| aCWmin | 15 |
| aCWmax | 1023 |

## 20.5 MIMO-OFDM operating specifications

### 20.5.1 Scope and field of application

This subclause describes the PMD services provided to the PLCP for the MIMO-OFDM PHY.

### 20.5.2 Overview of service

The MIMO-OFDM sublayer accepts PLCP sublayer service primitives and provides the actual means by which data is transmitted or received from the medium. The combined functions of the MIMO-OFDM PMD sublayer primitives and parameters for the receive function result in a data stream, timing information, and associated received signal parameters being delivered to the PLCP sublayer. A similar functionality is provided for data transmission.

### 20.5.3 Overview of interactions

The primitives associated with the PLCP sublayer to the MIMO-OFDM fall into two basic categories

a) Service primitives that support PLCP peer-to-peer interactions;
b) Service primitives that have local significance and that support sublayer-to-sublayer interactions.

### 20.5.4 Basic services and options

All of the service primitives described in this subclause are considered mandatory, unless otherwise specified.

#### 20.5.4.1 PMD_SAP peer-to-peer service primitives

Table 20.5.4.1 indicates the primitives for peer-to-peer interactions.

**Table 20.5.4.1 PMD_SAP peer-to-peer services**

| Primitive | Request | Indicate | Confirm | Response |
|---|---|---|---|---|
| PMD_Data | X | X | | |

#### 20.5.4.2 PMD_SAP sublayer-to-sublayer service primitives

Table 19.9.4.2 indicates the primitives for sublayer-to-sublayer interactions.

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**Table 19.9.4.2 PMD_SAP sublayer-to-sublayer services**

| Primitive | Request | Indicate | Confirm | Response |
|---|---|---|---|---|
| PMD_TXSTART | X | | | |
| PMD_TXEND | X | | | |
| PMD_ANTSEL | X | | | |
| PMD_TXPWRLVL | X | | | |
| PMD_TRANSMISSION_MODE | X | | | |
| PMD_NUM_STREAMS | X | | | |
| PMD_DATARATE | X | | | |
| PMD_RSSI | | X | | |

### 20.5.4.3 PMD_SAP service primitive parameters

Table 19.9.4.3 shows the parameters used by one or more of the PMD_SAP service primitives.

**Table 20.5.4.3 List of parameters for the PMD primitives**

| Parameter | Associated primitive | Value | Description |
|---|---|---|---|
| TXD_UNIT | PMD_DATA.request | 0 to (2^n)-1, where n is the number of bits per symbol for the transmission mode, number of streams, and data rate specified in PMD_TRANSMISSION_MODE.request, PMD_NUM_STREAMS.request, and PMD_DATARATE.request primitives. | This parameter represents a single block of data, which, in turn, is used by the PMD to be encoded into a transmitted symbol. |
| RXD_UNIT | PMD_DATA.indicate | 0 to (2^n)-1, where n is the number of bits per symbol for the transmission mode, number of streams, and data rate specified in PMD_TRANSMISSION_MODE.request, PMD_NUM_STREAMS.request, and PMD_DATARATE.request primitives. | This parameter represents a single symbol that has been demodulated by the PMD entity. |
| TRANSMISSION_MODE | PMD_TRANSMISSION_MODE.request | See Table 001 in 20.2 | This parameter specifies to the PMD layer, which transmission mode is used. |
| ANT_STATE | PMD_ANTSEL.request | 1 to 256 | ANT_STATE selects which of the available antennas is used for transmission. |

| | | | |
|---|---|---|---|
| | | | The number of available antennas is determined from the MIB table parameters. |
| TXPWR_LEVEL | PMD_TXPWRLVL.request | 1-8 | TXPWR_LEVEL selects which of the optional transmit power levels should be used for the current PPDU transmission. The number of available power levels is determined from the MIB table parameters. |
| DATARATE | PMD_DATARATE.request | See Clause 10.4.4.2 rate code columns of Tables 003-009 and Table 018 | DATARATE selects which of the data rates is used for PSDU transmission. |
| RSSI | PMD_RSSI.indicate | 8 bits of RSSI (256 levels) | The RSSI is a measure of the RF energy received. Mapping of the RSSI values to actual received power is implementation dependent. |

### 20.5.5 PMD_SAP detailed service specification

The following subclauses describe the services provided by each PMD primitive.

#### 20.5.5.1 PMD_DATA.request

This primitive is the same as that defined in 17.5.5.1 and 18.4.5.1 except that the parameter TXD_UNIT is expanded in scope to reflect the supported transmission formats defined in 20.5.4.3.

#### 20.5.5.2 PMD_DATA.indicate

This primitive is the same as that defined in 17.5.5.2 and 18.4.5.2 except that the parameter RXD_UNIT is expanded in scope to reflect the supported transmission formats defined in 20.5.4.3.

#### 20.5.5.3 PMD_TRANSMISSION_MODE.request

This primitive is the same as that defined in 18.4.5.3 except that the parameter MODULATION of that section is expanded in scope to reflect the supported transmission formats defined in 20.5.4.3.

#### 20.5.5.4 PMD_TXSTART.request

This primitive is the same as that defined in 17.5.5.3 and 18.4.5.6.

#### 20.5.5.5 PMD_TXEND.request

This primitive is the same as that defined in 17.5.5.4 and 18.4.5.7.

#### 20.5.5.6 PMD_ANTSEL.request

This primitive is the same as that defined in 18.4.5.8, including the definition of the parameter ANT_STATE.

#### 20.5.5.7 PMD_TXPRWLVL.request

This primitive is the same as that defined in 17.5.5.5, including the definition of the parameter TXPWR_LEVEL.

#### 20.5.5.8 PMD_DATARATE.request

This primitive is the same as that defined in 17.5.5.6 and 18.4.5.10, except that the parameter DATARATE is expanded in scope to reflect the supported MIMO-OFDM transmission modes as defined in 20.5.4.3.

#### 20.5.5.9 PMD_RSSI.indicate

This primitive is the same as that defined in 17.5.5.7 and 18.4.5.11, including the parameter RSSI. This primitive is used to aid in link optimization algorithms such as roaming decisions.

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# Annex A – LDPC matrix definitions

(normative)

**Table A.1 – Description of the matrix prototype of the rate 1/2 parity check matrix**

| Row | Col | Shift |
|---|---|---|
| 0 | 3 | 9 |
| 0 | 7 | 15 |
| 0 | 16 | 5 |
| 0 | 22 | 23 |
| 0 | 32 | 6 |
| 0 | 35 | 12 |
| 0 | 36 | 23 |
| 1 | 2 | 12 |
| 1 | 6 | 16 |
| 1 | 10 | 19 |
| 1 | 26 | 12 |
| 1 | 31 | 23 |
| 1 | 36 | 5 |
| 1 | 37 | 24 |
| 2 | 2 | 9 |
| 2 | 9 | 15 |
| 2 | 16 | 2 |
| 2 | 29 | 15 |
| 2 | 37 | 8 |
| 2 | 37 | 9 |
| 2 | 38 | 2 |
| 3 | 1 | 11 |
| 3 | 5 | 15 |
| 3 | 14 | 17 |

| | | |
|---|---|---|
| 3 | 22 | 7 |
| 3 | 36 | 12 |
| 3 | 38 | 19 |
| 3 | 39 | 25 |
| 4 | 4 | 15 |
| 4 | 8 | 3 |
| 4 | 10 | 15 |
| 4 | 26 | 16 |
| 4 | 34 | 6 |
| 4 | 39 | 6 |
| 4 | 40 | 10 |
| 5 | 4 | 20 |
| 5 | 10 | 24 |
| 5 | 11 | 17 |
| 5 | 23 | 4 |
| 5 | 33 | 25 |
| 5 | 40 | 24 |
| 5 | 41 | 15 |
| 6 | 1 | 14 |
| 6 | 5 | 17 |
| 6 | 13 | 0 |
| 6 | 28 | 14 |
| 6 | 35 | 16 |
| 6 | 41 | 24 |
| 6 | 42 | 5 |
| 7 | 1 | 7 |
| 7 | 9 | 7 |
| 7 | 11 | 3 |
| 7 | 21 | 12 |
| 7 | 30 | 18 |

| | | |
|---|---|---|
| 7 | 42 | 15 |
| 7 | 43 | 21 |
| 8 | 2 | 9 |
| 8 | 7 | 25 |
| 8 | 10 | 4 |
| 8 | 18 | 15 |
| 8 | 34 | 15 |
| 8 | 43 | 18 |
| 8 | 44 | 18 |
| 9 | 4 | 13 |
| 9 | 9 | 5 |
| 9 | 18 | 6 |
| 9 | 20 | 3 |
| 9 | 39 | 8 |
| 9 | 44 | 14 |
| 9 | 45 | 15 |
| 10 | 0 | 3 |
| 10 | 7 | 11 |
| 10 | 11 | 10 |
| 10 | 23 | 21 |
| 10 | 33 | 17 |
| 10 | 45 | 13 |
| 10 | 46 | 12 |
| 11 | 1 | 11 |
| 11 | 9 | 9 |
| 11 | 11 | 15 |
| 11 | 29 | 6 |
| 11 | 38 | 11 |
| 11 | 46 | 9 |
| 11 | 47 | 5 |

| | | |
|---|---|---|
| 12 | 5 | 16 |
| 12 | 5 | 22 |
| 12 | 10 | 9 |
| 12 | 24 | 0 |
| 12 | 45 | 5 |
| 12 | 47 | 7 |
| 12 | 48 | 10 |
| 13 | 3 | 13 |
| 13 | 10 | 0 |
| 13 | 13 | 20 |
| 13 | 20 | 23 |
| 13 | 42 | 7 |
| 13 | 48 | 21 |
| 13 | 49 | 14 |
| 14 | 3 | 8 |
| 14 | 7 | 1 |
| 14 | 11 | 3 |
| 14 | 25 | 24 |
| 14 | 46 | 3 |
| 14 | 49 | 3 |
| 14 | 50 | 7 |
| 15 | 0 | 8 |
| 15 | 9 | 0 |
| 15 | 11 | 5 |
| 15 | 19 | 26 |
| 15 | 31 | 8 |
| 15 | 50 | 5 |
| 15 | 51 | 2 |
| 16 | 4 | 4 |
| 16 | 8 | 6 |

| | | |
|---|---|---|
| 16 | 15 | 4 |
| 16 | 19 | 11 |
| 16 | 43 | 20 |
| 16 | 51 | 5 |
| 16 | 52 | 16 |
| 17 | 1 | 10 |
| 17 | 5 | 24 |
| 17 | 10 | 13 |
| 17 | 27 | 3 |
| 17 | 32 | 26 |
| 17 | 52 | 7 |
| 17 | 53 | 24 |
| 18 | 4 | 10 |
| 18 | 8 | 8 |
| 18 | 12 | 10 |
| 18 | 30 | 21 |
| 18 | 48 | 7 |
| 18 | 53 | 16 |
| 18 | 54 | 17 |
| 19 | 4 | 23 |
| 19 | 6 | 15 |
| 19 | 14 | 14 |
| 19 | 28 | 4 |
| 19 | 50 | 5 |
| 19 | 54 | 13 |
| 19 | 55 | 11 |
| 20 | 3 | 9 |
| 20 | 6 | 18 |
| 20 | 15 | 16 |
| 20 | 25 | 5 |

| | | |
|---|---|---|
| 20 | 40 | 0 |
| 20 | 55 | 12 |
| 20 | 56 | 8 |
| 21 | 0 | 4 |
| 21 | 6 | 20 |
| 21 | 11 | 6 |
| 21 | 24 | 9 |
| 21 | 55 | 20 |
| 21 | 56 | 24 |
| 21 | 57 | 12 |
| 22 | 2 | 10 |
| 22 | 8 | 12 |
| 22 | 12 | 12 |
| 22 | 27 | 4 |
| 22 | 53 | 3 |
| 22 | 57 | 0 |
| 22 | 58 | 19 |
| 23 | 0 | 2 |
| 23 | 9 | 17 |
| 23 | 17 | 17 |
| 23 | 21 | 9 |
| 23 | 49 | 14 |
| 23 | 58 | 22 |
| 23 | 59 | 23 |
| 24 | 1 | 16 |
| 24 | 7 | 5 |
| 24 | 17 | 7 |
| 24 | 29 | 12 |
| 24 | 56 | 19 |
| 24 | 59 | 23 |

| | | |
|---|---|---|
| 24 | 60 | 4 |
| 25 | 0 | 8 |
| 25 | 8 | 13 |
| 25 | 18 | 1 |
| 25 | 28 | 25 |
| 25 | 44 | 1 |
| 25 | 60 | 26 |
| 25 | 61 | 13 |
| 26 | 4 | 1 |
| 26 | 9 | 1 |
| 26 | 21 | 10 |
| 26 | 26 | 12 |
| 26 | 52 | 3 |
| 26 | 61 | 6 |
| 26 | 62 | 18 |
| 27 | 3 | 21 |
| 27 | 5 | 8 |
| 27 | 22 | 13 |
| 27 | 27 | 17 |
| 27 | 59 | 21 |
| 27 | 62 | 21 |
| 27 | 63 | 12 |
| 28 | 1 | 13 |
| 28 | 8 | 26 |
| 28 | 20 | 18 |
| 28 | 32 | 11 |
| 28 | 58 | 21 |
| 28 | 63 | 23 |
| 28 | 64 | 3 |
| 29 | 2 | 16 |

| | | |
|---|---|---|
| 29 | 5 | 6 |
| 29 | 19 | 10 |
| 29 | 25 | 17 |
| 29 | 54 | 20 |
| 29 | 64 | 16 |
| 29 | 65 | 8 |
| 30 | 3 | 16 |
| 30 | 7 | 15 |
| 30 | 16 | 1 |
| 30 | 31 | 0 |
| 30 | 41 | 13 |
| 30 | 65 | 15 |
| 30 | 66 | 17 |
| 31 | 0 | 20 |
| 31 | 6 | 8 |
| 31 | 15 | 4 |
| 31 | 34 | 1 |
| 31 | 51 | 22 |
| 31 | 66 | 4 |
| 31 | 67 | 8 |
| 32 | 2 | 11 |
| 32 | 7 | 17 |
| 32 | 13 | 3 |
| 32 | 33 | 12 |
| 32 | 57 | 20 |
| 32 | 67 | 7 |
| 32 | 68 | 3 |
| 33 | 0 | 19 |
| 33 | 6 | 22 |
| 33 | 14 | 8 |

| | | |
|---|---|---|
| 33 | 30 | 14 |
| 33 | 35 | 18 |
| 33 | 68 | 16 |
| 33 | 69 | 0 |
| 34 | 3 | 6 |
| 34 | 6 | 0 |
| 34 | 17 | 16 |
| 34 | 24 | 19 |
| 34 | 47 | 12 |
| 34 | 69 | 1 |
| 34 | 70 | 21 |
| 35 | 2 | 22 |
| 35 | 8 | 22 |
| 35 | 12 | 26 |
| 35 | 23 | 1 |
| 35 | 70 | 5 |
| 35 | 71 | st |

**Table A.2 – Description of the matrix prototype of the rate 2/3 parity check matrix**

| Row | Col | Shift |
|---|---|---|
| 0 | 5 | 16 |
| 0 | 5 | 22 |
| 0 | 10 | 9 |
| 0 | 24 | 0 |
| 0 | 45 | 5 |
| 0 | 47 | 7 |
| 0 | 48 | 10 |

| | | |
|---|---|---|
| 1 | 3 | 13 |
| 1 | 10 | 0 |
| 1 | 13 | 20 |
| 1 | 20 | 23 |
| 1 | 42 | 7 |
| 1 | 48 | 21 |
| 1 | 49 | 14 |
| 2 | 3 | 8 |
| 2 | 7 | 1 |
| 2 | 11 | 3 |
| 2 | 25 | 24 |
| 2 | 46 | 3 |
| 2 | 49 | 3 |
| 2 | 50 | 7 |
| 3 | 0 | 8 |
| 3 | 9 | 0 |
| 3 | 11 | 5 |
| 3 | 19 | 26 |
| 3 | 31 | 8 |
| 3 | 50 | 5 |
| 3 | 51 | 2 |
| 4 | 4 | 4 |
| 4 | 8 | 6 |
| 4 | 15 | 4 |
| 4 | 19 | 11 |
| 4 | 43 | 20 |
| 4 | 51 | 5 |

| | | |
|---|---|---|
| 4 | 52 | 16 |
| 5 | 1 | 10 |
| 5 | 5 | 24 |
| 5 | 10 | 13 |
| 5 | 27 | 3 |
| 5 | 32 | 26 |
| 5 | 52 | 7 |
| 5 | 53 | 24 |
| 6 | 3 | 9 |
| 6 | 4 | 10 |
| 6 | 7 | 15 |
| 6 | 8 | 8 |
| 6 | 12 | 10 |
| 6 | 16 | 5 |
| 6 | 22 | 23 |
| 6 | 30 | 21 |
| 6 | 32 | 6 |
| 6 | 35 | 12 |
| 6 | 36 | 23 |
| 6 | 48 | 7 |
| 6 | 53 | 16 |
| 6 | 54 | 17 |
| 7 | 2 | 12 |
| 7 | 4 | 23 |
| 7 | 6 | 15 |
| 7 | 6 | 16 |
| 7 | 10 | 19 |

| | | |
|---|---|---|
| 7 | 14 | 14 |
| 7 | 26 | 12 |
| 7 | 28 | 4 |
| 7 | 31 | 23 |
| 7 | 36 | 5 |
| 7 | 37 | 24 |
| 7 | 50 | 5 |
| 7 | 54 | 13 |
| 7 | 55 | 11 |
| 8 | 2 | 9 |
| 8 | 3 | 9 |
| 8 | 6 | 18 |
| 8 | 9 | 15 |
| 8 | 15 | 16 |
| 8 | 16 | 2 |
| 8 | 25 | 5 |
| 8 | 29 | 15 |
| 8 | 37 | 8 |
| 8 | 37 | 9 |
| 8 | 38 | 2 |
| 8 | 40 | 0 |
| 8 | 55 | 12 |
| 8 | 56 | 8 |
| 9 | 0 | 4 |
| 9 | 1 | 11 |
| 9 | 5 | 15 |
| 9 | 6 | 20 |

| | | |
|---|---|---|
| 9 | 11 | 6 |
| 9 | 14 | 17 |
| 9 | 22 | 7 |
| 9 | 24 | 9 |
| 9 | 36 | 12 |
| 9 | 38 | 19 |
| 9 | 39 | 25 |
| 9 | 55 | 20 |
| 9 | 56 | 24 |
| 9 | 57 | 12 |
| 10 | 2 | 10 |
| 10 | 4 | 15 |
| 10 | 8 | 3 |
| 10 | 8 | 12 |
| 10 | 10 | 15 |
| 10 | 12 | 12 |
| 10 | 26 | 16 |
| 10 | 27 | 4 |
| 10 | 34 | 6 |
| 10 | 39 | 6 |
| 10 | 40 | 10 |
| 10 | 53 | 3 |
| 10 | 57 | 0 |
| 10 | 58 | 19 |
| 11 | 0 | 2 |
| 11 | 4 | 20 |
| 11 | 9 | 17 |

| | | |
|---|---|---|
| 11 | 10 | 24 |
| 11 | 11 | 17 |
| 11 | 17 | 17 |
| 11 | 21 | 9 |
| 11 | 23 | 4 |
| 11 | 33 | 25 |
| 11 | 40 | 24 |
| 11 | 41 | 15 |
| 11 | 49 | 14 |
| 11 | 58 | 22 |
| 11 | 59 | 23 |
| 12 | 1 | 14 |
| 12 | 1 | 16 |
| 12 | 5 | 17 |
| 12 | 7 | 5 |
| 12 | 13 | 0 |
| 12 | 17 | 7 |
| 12 | 28 | 14 |
| 12 | 29 | 12 |
| 12 | 35 | 16 |
| 12 | 41 | 24 |
| 12 | 42 | 5 |
| 12 | 56 | 19 |
| 12 | 59 | 23 |
| 12 | 60 | 4 |
| 13 | 0 | 8 |
| 13 | 1 | 7 |

| | | |
|---|---|---|
| ~~13~~ | ~~8~~ | ~~13~~ |
| ~~13~~ | ~~9~~ | ~~7~~ |
| ~~13~~ | ~~11~~ | ~~3~~ |
| ~~13~~ | ~~18~~ | ~~1~~ |
| ~~13~~ | ~~21~~ | ~~12~~ |
| ~~13~~ | ~~28~~ | ~~25~~ |
| ~~13~~ | ~~30~~ | ~~18~~ |
| ~~13~~ | ~~42~~ | ~~15~~ |
| ~~13~~ | ~~43~~ | ~~21~~ |
| ~~13~~ | ~~44~~ | ~~1~~ |
| ~~13~~ | ~~60~~ | ~~26~~ |
| ~~13~~ | ~~61~~ | ~~13~~ |
| ~~14~~ | ~~2~~ | ~~9~~ |
| ~~14~~ | ~~4~~ | ~~1~~ |
| ~~14~~ | ~~7~~ | ~~25~~ |
| ~~14~~ | ~~9~~ | ~~1~~ |
| ~~14~~ | ~~10~~ | ~~4~~ |
| ~~14~~ | ~~18~~ | ~~15~~ |
| ~~14~~ | ~~21~~ | ~~10~~ |
| ~~14~~ | ~~26~~ | ~~12~~ |
| ~~14~~ | ~~34~~ | ~~15~~ |
| ~~14~~ | ~~43~~ | ~~18~~ |
| ~~14~~ | ~~44~~ | ~~18~~ |
| ~~14~~ | ~~52~~ | ~~3~~ |
| ~~14~~ | ~~61~~ | ~~6~~ |
| ~~14~~ | ~~62~~ | ~~18~~ |
| ~~15~~ | ~~3~~ | ~~21~~ |

| | | |
|---|---|---|
| ~~15~~ | ~~4~~ | ~~13~~ |
| ~~15~~ | ~~5~~ | ~~8~~ |
| ~~15~~ | ~~9~~ | ~~5~~ |
| ~~15~~ | ~~18~~ | ~~6~~ |
| ~~15~~ | ~~20~~ | ~~3~~ |
| ~~15~~ | ~~22~~ | ~~13~~ |
| ~~15~~ | ~~27~~ | ~~17~~ |
| ~~15~~ | ~~39~~ | ~~8~~ |
| ~~15~~ | ~~44~~ | ~~14~~ |
| ~~15~~ | ~~45~~ | ~~15~~ |
| ~~15~~ | ~~59~~ | ~~21~~ |
| ~~15~~ | ~~62~~ | ~~21~~ |
| ~~15~~ | ~~63~~ | ~~12~~ |
| ~~16~~ | ~~0~~ | ~~3~~ |
| ~~16~~ | ~~1~~ | ~~13~~ |
| ~~16~~ | ~~7~~ | ~~11~~ |
| ~~16~~ | ~~8~~ | ~~26~~ |
| ~~16~~ | ~~11~~ | ~~10~~ |
| ~~16~~ | ~~20~~ | ~~18~~ |
| ~~16~~ | ~~23~~ | ~~21~~ |
| ~~16~~ | ~~32~~ | ~~11~~ |
| ~~16~~ | ~~33~~ | ~~17~~ |
| ~~16~~ | ~~45~~ | ~~13~~ |
| ~~16~~ | ~~46~~ | ~~12~~ |
| ~~16~~ | ~~58~~ | ~~21~~ |
| ~~16~~ | ~~63~~ | ~~23~~ |
| ~~16~~ | ~~64~~ | ~~3~~ |

| | | |
|---|---|---|
| 17 | 1 | 11 |
| 17 | 2 | 16 |
| 17 | 5 | 6 |
| 17 | 9 | 9 |
| 17 | 11 | 15 |
| 17 | 19 | 10 |
| 17 | 25 | 17 |
| 17 | 29 | 6 |
| 17 | 38 | 11 |
| 17 | 46 | 9 |
| 17 | 47 | 5 |
| 17 | 54 | 20 |
| 17 | 64 | 16 |
| 17 | 65 | 8 |
| 18 | 3 | 16 |
| 18 | 7 | 15 |
| 18 | 16 | 1 |
| 18 | 31 | 0 |
| 18 | 41 | 13 |
| 18 | 65 | 15 |
| 18 | 66 | 17 |
| 19 | 0 | 20 |
| 19 | 6 | 8 |
| 19 | 15 | 4 |
| 19 | 34 | 1 |
| 19 | 51 | 22 |
| 19 | 66 | 4 |

| | | |
|---|---|---|
| ~~19~~ | ~~67~~ | ~~8~~ |
| ~~20~~ | ~~2~~ | ~~11~~ |
| ~~20~~ | ~~7~~ | ~~17~~ |
| ~~20~~ | ~~13~~ | ~~3~~ |
| ~~20~~ | ~~33~~ | ~~12~~ |
| ~~20~~ | ~~57~~ | ~~20~~ |
| ~~20~~ | ~~67~~ | ~~7~~ |
| ~~20~~ | ~~68~~ | ~~3~~ |
| ~~21~~ | ~~0~~ | ~~19~~ |
| ~~21~~ | ~~6~~ | ~~22~~ |
| ~~21~~ | ~~14~~ | ~~8~~ |
| ~~21~~ | ~~30~~ | ~~14~~ |
| ~~21~~ | ~~35~~ | ~~18~~ |
| ~~21~~ | ~~68~~ | ~~16~~ |
| ~~21~~ | ~~69~~ | ~~0~~ |
| ~~22~~ | ~~3~~ | ~~6~~ |
| ~~22~~ | ~~6~~ | ~~0~~ |
| ~~22~~ | ~~17~~ | ~~16~~ |
| ~~22~~ | ~~24~~ | ~~19~~ |
| ~~22~~ | ~~47~~ | ~~12~~ |
| ~~22~~ | ~~69~~ | ~~1~~ |
| ~~22~~ | ~~70~~ | ~~21~~ |
| ~~23~~ | ~~2~~ | ~~22~~ |
| ~~23~~ | ~~8~~ | ~~22~~ |
| ~~23~~ | ~~12~~ | ~~26~~ |
| ~~23~~ | ~~23~~ | ~~1~~ |
| ~~23~~ | ~~70~~ | ~~5~~ |

| | | |
|---|---|---|
| 23 | 71 | st |

Table A.3 – Description of the matrix prototype of the rate 3/4 parity check matrix

| Row | Col | Shift |
|---|---|---|
| 0 | 3 | 9 |
| 0 | 4 | 10 |
| 0 | 7 | 15 |
| 0 | 8 | 8 |
| 0 | 12 | 10 |
| 0 | 16 | 5 |
| 0 | 22 | 23 |
| 0 | 30 | 21 |
| 0 | 32 | 6 |
| 0 | 35 | 12 |
| 0 | 36 | 23 |
| 0 | 48 | 7 |
| 0 | 53 | 16 |
| 0 | 54 | 17 |
| 1 | 2 | 12 |
| 1 | 4 | 23 |
| 1 | 6 | 15 |
| 1 | 6 | 16 |
| 1 | 10 | 19 |
| 1 | 14 | 14 |
| 1 | 26 | 12 |
| 1 | 28 | 4 |

| | | |
|---|---|---|
| 1 | 31 | 23 |
| 1 | 36 | 5 |
| 1 | 37 | 24 |
| 1 | 50 | 5 |
| 1 | 54 | 13 |
| 1 | 55 | 11 |
| 2 | 2 | 9 |
| 2 | 3 | 9 |
| 2 | 6 | 18 |
| 2 | 9 | 15 |
| 2 | 15 | 16 |
| 2 | 16 | 2 |
| 2 | 25 | 5 |
| 2 | 29 | 15 |
| 2 | 37 | 8 |
| 2 | 37 | 9 |
| 2 | 38 | 2 |
| 2 | 40 | 0 |
| 2 | 55 | 12 |
| 2 | 56 | 8 |
| 3 | 0 | 4 |
| 3 | 1 | 11 |
| 3 | 5 | 15 |
| 3 | 6 | 20 |
| 3 | 11 | 6 |
| 3 | 14 | 17 |
| 3 | 22 | 7 |

| | | |
|---|---|---|
| 3 | 24 | 9 |
| 3 | 36 | 12 |
| 3 | 38 | 19 |
| 3 | 39 | 25 |
| 3 | 55 | 20 |
| 3 | 56 | 24 |
| 3 | 57 | 12 |
| 4 | 2 | 10 |
| 4 | 4 | 15 |
| 4 | 8 | 3 |
| 4 | 8 | 12 |
| 4 | 10 | 15 |
| 4 | 12 | 12 |
| 4 | 26 | 16 |
| 4 | 27 | 4 |
| 4 | 34 | 6 |
| 4 | 39 | 6 |
| 4 | 40 | 10 |
| 4 | 53 | 3 |
| 4 | 57 | 0 |
| 4 | 58 | 19 |
| 5 | 0 | 2 |
| 5 | 4 | 20 |
| 5 | 9 | 17 |
| 5 | 10 | 24 |
| 5 | 11 | 17 |
| 5 | 17 | 17 |

| | | |
|---|---|---|
| ~~5~~ | ~~21~~ | ~~9~~ |
| ~~5~~ | ~~23~~ | ~~4~~ |
| ~~5~~ | ~~33~~ | ~~25~~ |
| ~~5~~ | ~~40~~ | ~~24~~ |
| ~~5~~ | ~~41~~ | ~~15~~ |
| ~~5~~ | ~~49~~ | ~~14~~ |
| ~~5~~ | ~~58~~ | ~~22~~ |
| ~~5~~ | ~~59~~ | ~~23~~ |
| ~~6~~ | ~~1~~ | ~~14~~ |
| ~~6~~ | ~~1~~ | ~~16~~ |
| ~~6~~ | ~~5~~ | ~~17~~ |
| ~~6~~ | ~~7~~ | ~~5~~ |
| ~~6~~ | ~~13~~ | ~~0~~ |
| ~~6~~ | ~~17~~ | ~~7~~ |
| ~~6~~ | ~~28~~ | ~~14~~ |
| ~~6~~ | ~~29~~ | ~~12~~ |
| ~~6~~ | ~~35~~ | ~~16~~ |
| ~~6~~ | ~~41~~ | ~~24~~ |
| ~~6~~ | ~~42~~ | ~~5~~ |
| ~~6~~ | ~~56~~ | ~~19~~ |
| ~~6~~ | ~~59~~ | ~~23~~ |
| ~~6~~ | ~~60~~ | ~~4~~ |
| ~~7~~ | ~~0~~ | ~~8~~ |
| ~~7~~ | ~~1~~ | ~~7~~ |
| ~~7~~ | ~~8~~ | ~~13~~ |
| ~~7~~ | ~~9~~ | ~~7~~ |
| ~~7~~ | ~~11~~ | ~~3~~ |

| | | |
|---|---|---|
| 7 | 18 | 1 |
| 7 | 21 | 12 |
| 7 | 28 | 25 |
| 7 | 30 | 18 |
| 7 | 42 | 15 |
| 7 | 43 | 21 |
| 7 | 44 | 1 |
| 7 | 60 | 26 |
| 7 | 61 | 13 |
| 8 | 2 | 9 |
| 8 | 4 | 1 |
| 8 | 7 | 25 |
| 8 | 9 | 1 |
| 8 | 10 | 4 |
| 8 | 18 | 15 |
| 8 | 21 | 10 |
| 8 | 26 | 12 |
| 8 | 34 | 15 |
| 8 | 43 | 18 |
| 8 | 44 | 18 |
| 8 | 52 | 3 |
| 8 | 61 | 6 |
| 8 | 62 | 18 |
| 9 | 3 | 21 |
| 9 | 4 | 13 |
| 9 | 5 | 8 |
| 9 | 9 | 5 |

| | | |
|---|---|---|
| 9 | 18 | 6 |
| 9 | 20 | 3 |
| 9 | 22 | 13 |
| 9 | 27 | 17 |
| 9 | 39 | 8 |
| 9 | 44 | 14 |
| 9 | 45 | 15 |
| 9 | 59 | 21 |
| 9 | 62 | 21 |
| 9 | 63 | 12 |
| 10 | 0 | 3 |
| 10 | 1 | 13 |
| 10 | 7 | 11 |
| 10 | 8 | 26 |
| 10 | 11 | 10 |
| 10 | 20 | 18 |
| 10 | 23 | 21 |
| 10 | 32 | 11 |
| 10 | 33 | 17 |
| 10 | 45 | 13 |
| 10 | 46 | 12 |
| 10 | 58 | 21 |
| 10 | 63 | 23 |
| 10 | 64 | 3 |
| 11 | 1 | 11 |
| 11 | 2 | 16 |
| 11 | 5 | 6 |

| | | |
|---|---|---|
| 11 | 9 | 9 |
| 11 | 11 | 15 |
| 11 | 19 | 10 |
| 11 | 25 | 17 |
| 11 | 29 | 6 |
| 11 | 38 | 11 |
| 11 | 46 | 9 |
| 11 | 47 | 5 |
| 11 | 54 | 20 |
| 11 | 64 | 16 |
| 11 | 65 | 8 |
| 12 | 3 | 16 |
| 12 | 5 | 16 |
| 12 | 5 | 22 |
| 12 | 7 | 15 |
| 12 | 10 | 9 |
| 12 | 16 | 1 |
| 12 | 24 | 0 |
| 12 | 31 | 0 |
| 12 | 41 | 13 |
| 12 | 45 | 5 |
| 12 | 47 | 7 |
| 12 | 48 | 10 |
| 12 | 65 | 15 |
| 12 | 66 | 17 |
| 13 | 0 | 20 |
| 13 | 3 | 13 |

| | | |
|---|---|---|
| 13 | 6 | 8 |
| 13 | 10 | 0 |
| 13 | 13 | 20 |
| 13 | 15 | 4 |
| 13 | 20 | 23 |
| 13 | 34 | 1 |
| 13 | 42 | 7 |
| 13 | 48 | 21 |
| 13 | 49 | 14 |
| 13 | 51 | 22 |
| 13 | 66 | 4 |
| 13 | 67 | 8 |
| 14 | 2 | 11 |
| 14 | 3 | 8 |
| 14 | 7 | 1 |
| 14 | 7 | 17 |
| 14 | 11 | 3 |
| 14 | 13 | 3 |
| 14 | 25 | 24 |
| 14 | 33 | 12 |
| 14 | 46 | 3 |
| 14 | 49 | 3 |
| 14 | 50 | 7 |
| 14 | 57 | 20 |
| 14 | 67 | 7 |
| 14 | 68 | 3 |
| 15 | 0 | 8 |

| | | |
|---|---|---|
| 15 | 0 | 19 |
| 15 | 6 | 22 |
| 15 | 9 | 0 |
| 15 | 11 | 5 |
| 15 | 14 | 8 |
| 15 | 19 | 26 |
| 15 | 30 | 14 |
| 15 | 31 | 8 |
| 15 | 35 | 18 |
| 15 | 50 | 5 |
| 15 | 51 | 2 |
| 15 | 68 | 16 |
| 15 | 69 | 0 |
| 16 | 3 | 6 |
| 16 | 4 | 4 |
| 16 | 6 | 0 |
| 16 | 8 | 6 |
| 16 | 15 | 4 |
| 16 | 17 | 16 |
| 16 | 19 | 11 |
| 16 | 24 | 19 |
| 16 | 43 | 20 |
| 16 | 47 | 12 |
| 16 | 51 | 5 |
| 16 | 52 | 16 |
| 16 | 69 | 1 |
| 16 | 70 | 21 |

| | | |
|---|---|---|
| 17 | 1 | 10 |
| 17 | 2 | 22 |
| 17 | 5 | 24 |
| 17 | 8 | 22 |
| 17 | 10 | 13 |
| 17 | 12 | 26 |
| 17 | 23 | 1 |
| 17 | 27 | 3 |
| 17 | 32 | 26 |
| 17 | 52 | 7 |
| 17 | 53 | 24 |
| 17 | 70 | 5 |
| 17 | 71 | st |

Table A.4 – Description of the matrix prototype of the rate 5/6 parity check matrix

| Row | Col | Shift |
|---|---|---|
| 0 | 1 | 16 |
| 0 | 3 | 9 |
| 0 | 5 | 16 |
| 0 | 5 | 22 |
| 0 | 7 | 5 |
| 0 | 7 | 15 |
| 0 | 10 | 9 |
| 0 | 16 | 5 |
| 0 | 17 | 7 |
| 0 | 22 | 23 |

Formatted Table

| | | |
|---|---|---|
| 0 | 24 | 0 |
| 0 | 29 | 12 |
| 0 | 32 | 6 |
| 0 | 35 | 12 |
| 0 | 36 | 23 |
| 0 | 45 | 5 |
| 0 | 47 | 7 |
| 0 | 48 | 10 |
| 0 | 56 | 19 |
| 0 | 59 | 23 |
| 0 | 60 | 4 |
| 1 | 0 | 8 |
| 1 | 2 | 12 |
| 1 | 3 | 13 |
| 1 | 6 | 16 |
| 1 | 8 | 13 |
| 1 | 10 | 0 |
| 1 | 10 | 19 |
| 1 | 13 | 20 |
| 1 | 18 | 1 |
| 1 | 20 | 23 |
| 1 | 26 | 12 |
| 1 | 28 | 25 |
| 1 | 31 | 23 |
| 1 | 36 | 5 |
| 1 | 37 | 24 |
| 1 | 42 | 7 |

| | | |
|---|---|---|
| 1 | 44 | 1 |
| 1 | 48 | 21 |
| 1 | 49 | 14 |
| 1 | 60 | 26 |
| 1 | 61 | 13 |
| 2 | 2 | 9 |
| 2 | 3 | 8 |
| 2 | 4 | 1 |
| 2 | 7 | 1 |
| 2 | 9 | 1 |
| 2 | 9 | 15 |
| 2 | 11 | 3 |
| 2 | 16 | 2 |
| 2 | 21 | 10 |
| 2 | 25 | 24 |
| 2 | 26 | 12 |
| 2 | 29 | 15 |
| 2 | 37 | 8 |
| 2 | 37 | 9 |
| 2 | 38 | 2 |
| 2 | 46 | 3 |
| 2 | 49 | 3 |
| 2 | 50 | 7 |
| 2 | 52 | 3 |
| 2 | 61 | 6 |
| 2 | 62 | 18 |
| 3 | 0 | 8 |

| | | |
|---|---|---|
| 3 | 1 | 11 |
| 3 | 3 | 21 |
| 3 | 5 | 8 |
| 3 | 5 | 15 |
| 3 | 9 | 0 |
| 3 | 11 | 5 |
| 3 | 14 | 17 |
| 3 | 19 | 26 |
| 3 | 22 | 7 |
| 3 | 22 | 13 |
| 3 | 27 | 17 |
| 3 | 31 | 8 |
| 3 | 36 | 12 |
| 3 | 38 | 19 |
| 3 | 39 | 25 |
| 3 | 50 | 5 |
| 3 | 51 | 2 |
| 3 | 59 | 21 |
| 3 | 62 | 21 |
| 3 | 63 | 12 |
| 4 | 1 | 13 |
| 4 | 4 | 4 |
| 4 | 4 | 15 |
| 4 | 8 | 3 |
| 4 | 8 | 6 |
| 4 | 8 | 26 |
| 4 | 10 | 15 |

| | | |
|---|---|---|
| 4 | 15 | 4 |
| 4 | 19 | 11 |
| 4 | 20 | 18 |
| 4 | 26 | 16 |
| 4 | 32 | 11 |
| 4 | 34 | 6 |
| 4 | 39 | 6 |
| 4 | 40 | 10 |
| 4 | 43 | 20 |
| 4 | 51 | 5 |
| 4 | 52 | 16 |
| 4 | 58 | 21 |
| 4 | 63 | 23 |
| 4 | 64 | 3 |
| 5 | 1 | 10 |
| 5 | 2 | 16 |
| 5 | 4 | 20 |
| 5 | 5 | 6 |
| 5 | 5 | 24 |
| 5 | 10 | 13 |
| 5 | 10 | 24 |
| 5 | 11 | 17 |
| 5 | 19 | 10 |
| 5 | 23 | 4 |
| 5 | 25 | 17 |
| 5 | 27 | 3 |
| 5 | 32 | 26 |

| | | |
|---|---|---|
| 5 | 33 | 25 |
| 5 | 40 | 24 |
| 5 | 41 | 15 |
| 5 | 52 | 7 |
| 5 | 53 | 24 |
| 5 | 54 | 20 |
| 5 | 64 | 16 |
| 5 | 65 | 8 |
| 6 | 1 | 14 |
| 6 | 3 | 16 |
| 6 | 4 | 10 |
| 6 | 5 | 17 |
| 6 | 7 | 15 |
| 6 | 8 | 8 |
| 6 | 12 | 10 |
| 6 | 13 | 0 |
| 6 | 16 | 1 |
| 6 | 28 | 14 |
| 6 | 30 | 21 |
| 6 | 31 | 0 |
| 6 | 35 | 16 |
| 6 | 41 | 13 |
| 6 | 41 | 24 |
| 6 | 42 | 5 |
| 6 | 48 | 7 |
| 6 | 53 | 16 |
| 6 | 54 | 17 |

| | | |
|---|---|---|
| 6 | 65 | 15 |
| 6 | 66 | 17 |
| 7 | 0 | 20 |
| 7 | 1 | 7 |
| 7 | 4 | 23 |
| 7 | 6 | 8 |
| 7 | 6 | 15 |
| 7 | 9 | 7 |
| 7 | 11 | 3 |
| 7 | 14 | 14 |
| 7 | 15 | 4 |
| 7 | 21 | 12 |
| 7 | 28 | 4 |
| 7 | 30 | 18 |
| 7 | 34 | 1 |
| 7 | 42 | 15 |
| 7 | 43 | 21 |
| 7 | 50 | 5 |
| 7 | 51 | 22 |
| 7 | 54 | 13 |
| 7 | 55 | 11 |
| 7 | 66 | 4 |
| 7 | 67 | 8 |
| 8 | 2 | 9 |
| 8 | 2 | 11 |
| 8 | 3 | 9 |
| 8 | 6 | 18 |

| | | |
|---|---|---|
| 8 | 7 | 17 |
| 8 | 7 | 25 |
| 8 | 10 | 4 |
| 8 | 13 | 3 |
| 8 | 15 | 16 |
| 8 | 18 | 15 |
| 8 | 25 | 5 |
| 8 | 33 | 12 |
| 8 | 34 | 15 |
| 8 | 40 | 0 |
| 8 | 43 | 18 |
| 8 | 44 | 18 |
| 8 | 55 | 12 |
| 8 | 56 | 8 |
| 8 | 57 | 20 |
| 8 | 67 | 7 |
| 8 | 68 | 3 |
| 9 | 0 | 4 |
| 9 | 0 | 19 |
| 9 | 4 | 13 |
| 9 | 6 | 20 |
| 9 | 6 | 22 |
| 9 | 9 | 5 |
| 9 | 11 | 6 |
| 9 | 14 | 8 |
| 9 | 18 | 6 |
| 9 | 20 | 3 |

| | | |
|---|---|---|
| 9 | 24 | 9 |
| 9 | 30 | 14 |
| 9 | 35 | 18 |
| 9 | 39 | 8 |
| 9 | 44 | 14 |
| 9 | 45 | 15 |
| 9 | 55 | 20 |
| 9 | 56 | 24 |
| 9 | 57 | 12 |
| 9 | 68 | 16 |
| 9 | 69 | 0 |
| 10 | 0 | 3 |
| 10 | 2 | 10 |
| 10 | 3 | 6 |
| 10 | 6 | 0 |
| 10 | 7 | 11 |
| 10 | 8 | 12 |
| 10 | 11 | 10 |
| 10 | 12 | 12 |
| 10 | 17 | 16 |
| 10 | 23 | 21 |
| 10 | 24 | 19 |
| 10 | 27 | 4 |
| 10 | 33 | 17 |
| 10 | 45 | 13 |
| 10 | 46 | 12 |
| 10 | 47 | 12 |

| | | |
|---|---|---|
| 10 | 53 | 3 |
| 10 | 57 | 0 |
| 10 | 58 | 19 |
| 10 | 69 | 1 |
| 10 | 70 | 21 |
| 11 | 0 | 2 |
| 11 | 1 | 11 |
| 11 | 2 | 22 |
| 11 | 8 | 22 |
| 11 | 9 | 9 |
| 11 | 9 | 17 |
| 11 | 11 | 15 |
| 11 | 12 | 26 |
| 11 | 17 | 17 |
| 11 | 21 | 9 |
| 11 | 23 | 1 |
| 11 | 29 | 6 |
| 11 | 38 | 11 |
| 11 | 46 | 9 |
| 11 | 47 | 5 |
| 11 | 49 | 14 |
| 11 | 58 | 22 |
| 11 | 59 | 23 |
| 11 | 70 | 5 |
| 11 | 71 | st |

# Annex A – LDPC Matrix Definitions

(normative)

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**Table A.1 The matrix prototype of the rate-1/2 parity-check matrix. Subblock size is Z = 81 bits.**

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 36 | | | 17 | | | 21 | 46 | 68 | 0 | | | | | | | | | | 6 |
| 1 | | | | | 11 | | | | 2 | 64 | 17 | 0 | 0 | | | | | | | | | |
| | | 38 | | | 29 | | | | 1 | 57 | 44 | | 0 | 0 | | | | | | | | |
| | | | | 13 | | | | 39 | 72 | 26 | 43 | | | 0 | 0 | 0 | | | | | | 44 |
| | 20 | | | 33 | | | | | 20 | 27 | 25 | | | | 0 | 0 | | | | | | |
| | | | 64 | | | | 26 | | 4 | 8 | 26 | | | | | 0 | 0 | | | | | |
| 21 | | | 42 | | | | | 55 | 13 | | 73 | | | | | | 0 | 0 | | | | |
| | | 19 | | | | 13 | | | 60 | 37 | 80 | | | | | | | 0 | 0 | | | |
| | | 5 | | | | | 11 | | 35 | 69 | 68 | | | | | | | | 0 | 0 | | 57 |
| | 70 | | | | 71 | | | 68 | | 61 | 43 | | | | | | | | | 0 | 0 | |
| | 38 | | | | | 69 | | 51 | 24 | 26 | | | | | | | | | | | 0 | 0 |
| 42 | | | | 49 | | | 13 | | 28 | 4 | 9 | | | | | | | | | | | 0 |

**Table A.2 The matrix prototype of the rate-2/3 parity-check matrix. Subblock size Z = 27 bits.**

columns 1-24

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | 25 | | 20 | | | 25 | | | | | | | | | | 0 | | 19 | | | |
| 18 | 0 | 24 | 13 | | | | | | | 5 | 13 | | | | | | | 0 | | | 10 | |
| | | 0 | | 19 | 19 | 7 | 14 | | 20 | | | | | | | | | | 0 | | 7 | |
| | | | 0 | 11 | | 11 | | | | | 14 | | | | | | | | | 0 | | |
| | 3 | | 23 | 0 | | 10 | | | | | 22 | 15 | | | | | | 22 | | | 0 | |
| | 2 | | | | 0 | 20 | | | 17 | | | | | 9 | 24 | | | | | | | 0 |
| 17 | | | 16 | 8 | 4 | | | 17 | | | | 0 | | | | | | | | | | |
| | 10 | 8 | | | | | | | | 23 | | | 0 | | | | 25 | | | | | |
| | | 7 | 12 | | 2 | | | | | | | | | 0 | | | 25 | 4 | | | | |
| | 11 | 20 | | | | 5 | | | | 13 | 12 | | | | 0 | | | | | | | |
| | | | 6 | | 26 | | 20 | 13 | | | | | | | | 0 | | | | | | |
| | | | | | | 3 | 6 | 2 | 8 | 22 | | | | | | | 0 | | | 13 | | |
| | 26 | | | | | 0 | | 25 | | 20 | | | 2 | | | 4 | | | | | | 17 |
| | | | | 6 | 14 | 18 | 0 | 24 | 13 | | | | | | | | | | | | | |
| 8 | 15 | | 21 | | | | | 0 | | 19 | 19 | | | | | | | | | | | |
| 12 | | | | | 15 | | | | 0 | 11 | | | 4 | 20 | | | | | | | | |
| 11 | | | | | 23 | | 3 | | 23 | 0 | | | | | | | | | | | | |
| 21 | | | 18 | | | | 2 | | | | 0 | | | | | | | | | | | |
| | | 18 | | | | 17 | | | 16 | 8 | 4 | | | | | | | | | 16 | | |
| | | | | 24 | | | 10 | 8 | | | | | | | | 8 | 14 | | | | | |
| | | | | | | | | 7 | 12 | | 2 | | | | 7 | | | | 20 | | | |
| 6 | | | | 14 | 13 | | 11 | 20 | | | | | | | | | | | | | | |
| | 21 | 14 | | | | | | | 6 | | 26 | 13 | | | | | | | | 5 | | |
| 4 | 7 | 3 | 9 | 23 | | | | | | | | | | | | | | | | | | 9 |

columns 25-48

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 1 | | | 3 | | | | | | | 16 | | | | | | |
| | 15 | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | 8 | | | | |
| 6 | | | | | | | 3 | 19 | | | | | | | | | | | | 4 | | |
| | | | | | | | | | | | | | | | | | | | | 1 | | |
| 17 | | | | 19 | | | | | | | | | | | | | | | | | | |
| 0 | | | | | | | | | | | | | | | 15 | | | | 23 | | | |
| | 0 | | | | 7 | | | | | 7 | 13 | | | | | | | | | | | |
| | | 0 | | | | | | | 6 | | | | 19 | | | | | | | | | |
| | | | 0 | 26 | 1 | | | | | | | | | | | | | | | | | |
| | | 11 | | 0 | | 12 | | | | | | | | 4 | | | | | | | | |
| | | | | | 0 | | | | | | | | | | | | 8 | | | | | |
| | | | | | | | | | | | | 0 | | 19 | | | | | | | | |
| | | | | | | | | | | | | | 0 | | | 10 | | 15 | | | | |
| | 9 | | | | | | | | | | | | | 0 | | 7 | | | | | | |
| | | | 5 | | | | | | | | | | | | 0 | | | 6 | | | | |
| | | | 2 | | | 15 | | | | | | | 22 | | | 0 | | | | | | |
| | | | | | | | | 9 | 24 | | | | | | | | 0 | 17 | | | 19 | |
| | | 24 | | | | 0 | | | | | | | | | | | | 0 | | | | |
| | | | | | | | 0 | | | | | 25 | | | | | | | 0 | | | 7 | |
| | | | | | | | | 0 | | | 25 | 4 | | | | | | | | 0 | | | |
| | | | | | | | | | 0 | | | | | | | | | | | | 0 | 26 | 1 |
| | | | | | | | | | | 0 | | | | | | | | | | 11 | | 0 | |
| | | | | | | | | | | | 0 | | | | 13 | | | | | | | | 0 |

columns 49-72

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | | | | | | | | | | | | | | | | | | | | | | D |
| 0 | 0 | | | | | | | | | | | | | | | | | | | | | | |
| | 0 | 0 | | | | | | | | | | | | | | | | | | | | | |
| | | 0 | 0 | | | | | | | | | | | | | | | | | | | | |
| | | | 0 | 0 | | | | | | | | | | | | | | | | | | | |
| | | | | 0 | 0 | | | | | | | | | | | | | | | | | | |
| | | | | | 0 | 0 | | | | | | | | | | | | | | | | | |
| | | | | | | 0 | 0 | | | | | | | | | | | | | | | | |
| | | | | | | | 0 | 0 | | | | | | | | | | | | | | | |
| | | | | | | | | 0 | 0 | | | | | | | | | | | | | | |
| | | | | | | | | | 0 | 0 | | | | | | | | | | | | | |
| | | | | | | | | | | 0 | 0 | | | | | | | | | | | | |
| | | | | | | | | | | | 0 | 0 | | | | | | | | | | | |
| | | | | | | | | | | | | 0 | 0 | | | | | | | | | | |
| | | | | | | | | | | | | | 0 | 0 | | | | | | | | | |
| | | | | | | | | | | | | | | 0 | 0 | | | | | | | | |
| | | | | | | | | | | | | | | | 0 | 0 | | | | | | | |
| | | | | | | | | | | | | | | | | 0 | 0 | | | | | | |
| | | | | | | | | | | | | | | | | | 0 | 0 | | | | | |
| | | | | | | | | | | | | | | | | | | 0 | 0 | | | | |
| | | | | | | | | | | | | | | | | | | | 0 | 0 | | | |
| | | | | | | | | | | | | | | | | | | | | 0 | 0 | | |
| | | | | | | | | | | | | | | | | | | | | | 0 | 0 | |
| | | | | | | | | | | | | | | | | | | | | | | 0 | 0 |

**Table A.3 The matrix prototype of the rate-3/4 parity-check matrix. Subblock size is Z = 54 bits.**

columns 1-18

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 14 | | 34 | 44 | 43 | 0 | | | | | 24 | | 46 | | | 16 | 35 |
| 31 | | 17 | 31 | | 30 | 10 | | | 52 | 23 | | 38 | | | 41 | | |
| 49 | 41 | | 6 | | 47 | 10 | | 9 | | | | | | 8 | 8 | | |
| | | 29 | 50 | 30 | | 0 | | 40 | 5 | | 46 | | 35 | | | | 43 |
| | | 34 | 2 | 12 | 9 | | | 15 | 36 | | | 40 | | 33 | | | |
| | | 52 | 48 | | 36 | 23 | | 53 | | | 1 | | | 45 | 5 | | |
| 53 | | 6 | | 5 | 3 | | 41 | | 30 | | 6 | | | 26 | | | 53 |
| 24 | 50 | | | 38 | 43 | 38 | 43 | | 42 | | | | | | | 25 | |
| 12 | | 21 | 25 | 29 | | 16 | 4 | | | | | 52 | | | 21 | | |

columns 19-36

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | | | | | | | 8 | 45 | 36 | | | | | | | | |
| 45 | 53 | | | | | | | 51 | 15 | 31 | | | | | | | |
| 7 | 36 | 26 | | | | | | | 38 | 18 | 13 | | | | | | |
| | | | 34 | 47 | 18 | | | | | | | 19 | 53 | | | | |
| | | 51 | | 19 | 45 | | | | | | | 22 | 36 | 33 | | | |
| 40 | | | | | 19 | 29 | | | | | 52 | | | 36 | 26 | | |
| | | 48 | | | 13 | 46 | | | | | | | | 17 | 35 | | |
| | | | 7 | | 34 | 34 | 40 | | | | | | | | 43 | 30 | |
| | | | | | | 21 | 40 | 16 | | | | | | | | 41 | st |

Formatted: Normal

**Table A.4 The matrix prototype of the rate-5/6 parity-check matrix. Subblock size is Z = 54.**

columns 1-18

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 53 | 14 | 50 | 34 | 5 | 43 | 0 | 41 | | | 46 | 24 | 35 | | 26 | | 16 | 35 |
| 24 | 34 | 17 | 12 | 38 | 30 | 10 | 43 | 36 | 42 | 23 | | | 33 | | 41 | | |
| 12 | 41 | 48 | 6 | 29 | 23 | 16 | 53 | 9 | | | | 52 | | 5 | 8 | | |
| 16 | 29 | 6 | 30 | 44 | 3 | 0 | 40 | 5 | 30 | | 6 | | 46 | | | 43 | 53 |
| 31 | 50 | 2 | 31 | 9 | 43 | 38 | 15 | | 52 | | 40 | 38 | | | | 25 | |
| 49 | 52 | 21 | 25 | 36 | 47 | 10 | 4 | | | 1 | | | 45 | 8 | 21 | | 40 |

columns 19-36

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | | 48 | | 18 | 13 | 46 | | | | | 19 | 53 | | | | | |
| 45 | 53 | | 7 | | | 34 | 40 | | | | 22 | 36 | 33 | | | | |
| 7 | 36 | 26 | | | | 21 | 40 | 16 | | 52 | | | 36 | 26 | | | |
| | | 34 | 47 | | | | 8 | 45 | 36 | | | | | 17 | 35 | | |
| | 51 | | 19 | 45 | 34 | | | 51 | 15 | 31 | | | | | 43 | 30 | |
| | | | | 19 | 29 | | | | 38 | 18 | 13 | | | | | 41 | st |

# Annex B – Closed Loop Information Exchange

Text in this section is informative.

Closed loop methods that improve transmission by providing feedback information from receiver to transmitter are compatible with this amendment. Specific management frames to feedback information are given in sections 7.4.5. These management frames enable both transmission mode feedback and channel feedback.

Transmission mode feedback allows a receiving station to inform a transmitting station of the preferred mode for the current channel conditions. The particular choice of mode is determined by the receiving station. The transmitting station may or may not use the particular mode, depending on its capabilities. A receiving station may also decline to provide a preferred mode.

Channel feedback provides a mechanism for a transmitting station to learn the precise channel seen at the receiver. This information may either be used as part of a calibration, for systems that assume channel reciprocity, or as direct channel feedback. The usage of channel feedback information is implementation dependent. Receiving stations may either provide a complete channel estimate or a null response.

# APPENDIX G

# IEEE P802.11
# Wireless LANs

## WWiSE Proposal: High throughput extension to the 802.11 Standard

**Date:** 2005-03-18


| Author(s): | | | | |
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## Abstract


Changes and additions to IEEE Std. 802.11-1999 (Reaff 2003), as amended by published amendments IEEE802.11a, IEEE802.11g, IEEE802.11h and IEEE802.11i and by IEEE draft standard 802.11e/D9.0 are provided to support a new high throughput physical layer (PHY) for operation in the 2.4 and 5 GHz bands.

The content of this document is identical to 11-05-0149-01-000n-WWiseProposal except for the following revisions:

- Explicit matrix descriptions have been added to describe optional STBC modes.
- Additon of PSAD and HTBlock Ack scheme
- Addition of ER protection
- Modification of optional robust SIGN field
- Improved optional LDPC codes are presented.



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# Draft Amendment to IEEE Standard for Information technology-
# Telecommunications and information exchange between systems -
# Local and metropolitan area networks -
# Specific Requirements -

# Part 20: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications:

# High throughput extension for the 2.4 GHz and 5 GHz Bands

[This amendment is based on IEEE Std 802.11™, 1999 Edition (Reaff 2003), as amended by IEEE Std 802.11a™-1999 and IEEE Std 802.11g™-2003, and Draft Amendment IEEE P802.11e/D9.0]

## 3. Definitions

***Insert the following new definitions in alphabetical order, renumbering as necessary:***

**20 MHz transmission:** A frame transmission in which the modulation spans only one of the 20 MHz channels of a 40 MHz Channel Pair.

**40 MHz channel pair:** A pair of 20 MHz channels whose centre frequencies are separated by 20 MHz and which can be treated as a single channel for 40 MHz transmissions by a BSS, and where one of the 20 MHz channels will also be used for (non-overlapping) 20 MHz transmissions by the BSS.

**40 MHz transmission:** A frame transmission in which the modulation spans both 20 MHz channels of a 40 MHz channel pair.

**aggregated MSDU (A-MSDU):** A MSDU that encapsulates one or more MSDUs to be transmitted to the same destination.

**aggregated PPDU (A-PPDU):** A PPDU that contains one or more pairs of PLCP headers and PSDUs.

**HTP burst transmission:** A sequence of frames transmitted by a single high-throughput station in a single medium access. The frames may be transmitted as part of an A-PPDU, or with reduced interfame spacing to enhance medium efficiency.

**IEEE 802.11n-based Dynamic Frequency Selection (N-DFS):** Facilities mandated to sastisfy requirements in some regulatory domains for radar detetion and uniform channel spreading in the 5GHz band. N-DFS applies to both primary and secondary channels.

**primary channel:** The channel in a 40 MHz channel pair that will be used for 20 MHz transmissions as well as being part of the 40 MHz channel for 40 MHz transmissions.

**secondary channel:** The channel in a 40 MHz channel pair that is used only as part of the 40 MHz channel for 40 MHz transmissions, and which is not used for 20 MHz transmissions.

**HTP rate group:** A group of rates supported by an HTP STA that use the same transmit bandwidth, the same number of transmit antennas, and the number of spatial streams.

**HTP STA:** A STA which conforms to the minimum mandatory requirements set forth in clause 20.

**40MHz HTP rate:** Any rate supported by an HTP STA that uses 40MHz of transmit bandwidth.

**20MHz HTP STA:** An HTP STA which does not support any 40MHz HTP rate.

**40MHz HTP STA:** An HTP STA which supports the ability to receive at least one 40MHz HTP rate.

**MIMO-OFDM:** Multiple input multiple output orthogonal frequency division multiplexing

**PSAD:** Power Save Aggregation Descriptor is a MAC control frame that provides a schedule of TXOPs to be used by the PSAD transmitter and PSAD receivers. The scheduled TXOPs begin immediately subsequent to the transmission of the PSAD frame.

**PSA:** Power Save Aggregation is the name of the mechanism for scheduling TXOPs which employs the PSAD frame. HT STA that can use PSAD information indicates it's capability to do so by Power Save Aggregation (PSA) bit in its ERP IE.

**PAP:** PSA Access Phase is a period of controlled access with duration equal to the DUR field value of a transmitted PSAD frame and beginning immediately after the transmission of that PSAD frame. Access during the PAP is determined by the parameters of the transmitted PSAD frame.

**HT Block Ack:** A type of Block Ack frame which can accommodate the block acknowledgement status for multiple TID simultaneously.

**HT Block Ack Request:** A type of Block Ack Request frame which can accommodate block acknowledgement requests for multiple TID simultaneously.

**HT ADDBA:** A management frame which is used to negotiate the use of HT Block Ack.

**Implicit Block Ack:** A variant of Block Ack which does not require the transmission of Block Ack request frames. The trigger condition which elicits the transmission of Block Ack frames when using implicit Block Ack is specifieid within the HT ADDBA message exchange.

**DLT:** A Downlink transmission is period of time described by a PSAD frame and which is intended to be used for the transmission of frames from the PSAD transmitter to one of the PSAD receivers.

**ULT:** An Uplink transmission is period of time described by a PSAD frame and which is intended to be used for the transmission of frames by a PSAD receiver.

# 4. Abbreviations and acronyms

***Insert the following acronyms alphabetically in the list in Clause 4:***

| | |
|---|---|
| A-MSDU | aggregated MSDU |
| A-PPDU | aggregated PPDU |
| BRS | Basic Rate Set |
| ECC | error correction code |
| ER | Extended Range |
| HT | high throughput |
| HTP | high-throughput PHY conforming to Clause 20 |
| LDPCC | low density parity check code |
| MCS | Modulation and Coding Scheme |
| MIMO | multiple input multiple output |
| N-DFS | IEEE 802.11n-based Dynamic Frequency Selection |
| NR | Normal Range |
| nHTP | non HTP PHY conforming to Clause 15 or Clause 17 or Clause 18 or Clause 19, but not to Clause 20 |
| RIFS | reduced interframe space |
| SDM | spatial data multiplexing |
| STBC | space time block code |
| ITS | Inter TXOP Spacing<br>The idle gap between any two adjacent ULTs which are indicated within a single PSAD control frame |

# 6. MAC Service Definition

## 6.1 Overview of MAC services

### 6.1.4 Data service architecture (informative)

***Change the paragraph in 6.1.4 (.11e) as shown:***

The MAC data plane architecture (i.e., processes that involve transport of all or part of an MSDU) is shown in Figure 11g. During transmission, an MSDU goes through some or all of the following processes: frame delivery deferral during power save mode, aggregation, sequence number assignment, fragmentation, encryption, integrity

protection, and frame formatting. IEEE 802.1X may block the MSDU at the Controlled Port. At some point the Data frames that contain all or part of the MSDU are queued per access category/TS. This queuing may be at any of the three points indicated in Figure 11g.

During reception, a received data frame goes through processes of MPDU header + cyclic redundancy codecheck (CRC) validation, duplicate removal, possible reordering if the Block Ack mechanism is used, decryption, defragmentation, integrity checking, de-aggregation, and replay detection. After replay detection (or defragmentation if security is used), the MSDU is delivered to the MAC_SAP or to the DS. The IEEE 802.1X Controlled/ Uncontrolled Ports discards the MSDU if the Controlled Port is not enabled or if the MSDU does not represent an IEEE 802.1X frame. TKIP and CCMP MPDU frame order enforcement occurs after decryption, but prior to MSDU defragmentation; therefore, defragmentation will fail if MPDUs arrive out of order.

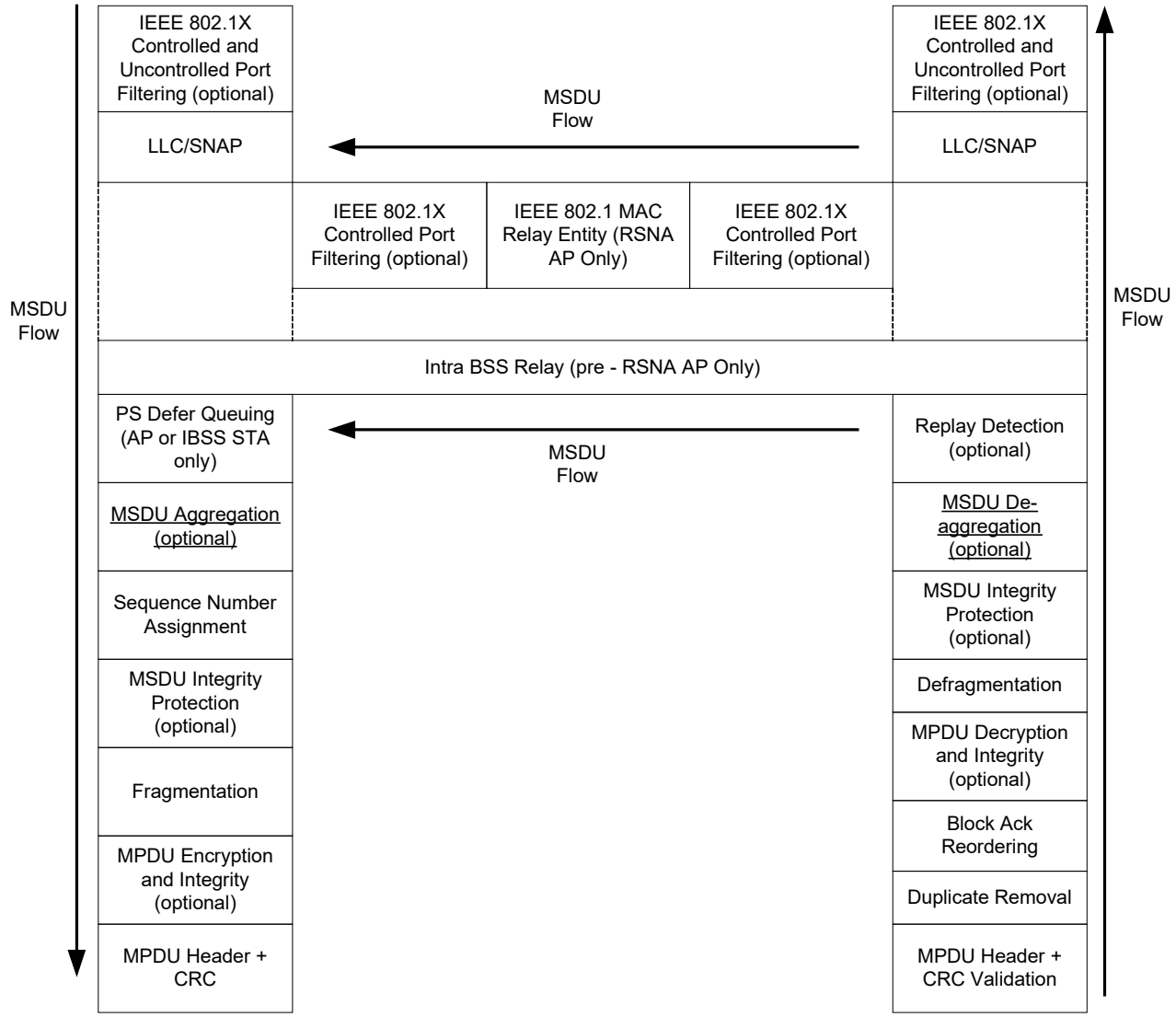



**Figure 11g – MAC data plane architecture**

# 6.2 Detailed service specification

## 6.2.1 MAC data services

### 6.2.1.1 MA-UNITDATA.request

#### 6.2.1.1.2 Semantics of the service primitive

***Change the third from the last paragraph as follows:***

The data parameter specifies the MSDU to be transmitted by the MAC sublayer entity. For IEEE 802.11, the length of the MSDU ~~must~~shall be less than or equal to ~~2304~~ 8100 octets when a PHY defined in Clause 20 is employed or 4000 when a PHY defined in Clause 17 is employed.

# 7. Frame Formats

## 7.1 MAC frame formats

### 7.1.2 General frame format

***Change Figure 12(.11e) as follows:***

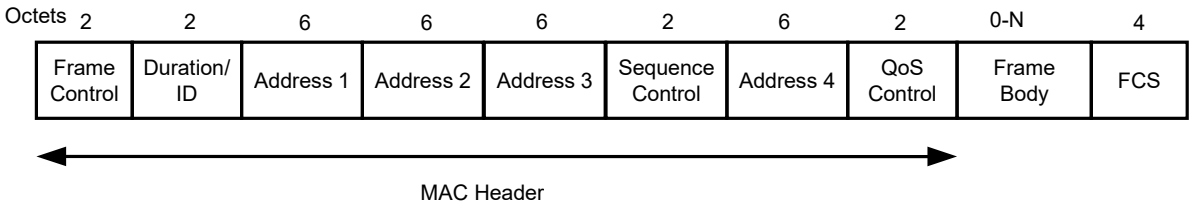



**Figure 12 – MAC frame format**

The maximum frame body length, N, is 8100 when a Clause 20 PHY is employed, and 4000 when a Clause 17 PHY is employed.

### 7.1.3 Frame fields

7.1.3.1.2 Type and Subtype Fields

***Insert the following entries in the appropriate location in Table 1.***

| Type value b3 b2 | Type Description | Subtype Value b7 b6 b5 b4 | Subtype Description |
|---|---|---|---|
| 01 | Control | 0111 | Power Saving Aggregation Descriptor |
| 01 | Control | 0000-0110 | Reserved |

### 7.1.3.5 QoS Control field

*Change Table 3.1 in 7.1.3.5 (.11e) to appear as follows:*

**Table 3.1 – QoS Control field**

| Applicable Frame (sub) Types | Bits 0-3 | Bit 4 | Bit 5-6 | Bit 7 | Bits 8-15 |
|---|---|---|---|---|---|
| QoS (+)CF-Poll frames sent by HC | TID | EOSP | Ack Policy | Reserved | TXOP limit |
| QoS Data and QoS Data+CF-Ack frames sent by HC | TID | EOSP | Ack Policy | Aggregated MSDU Present | QAP PS Buffer State |
| QoS Null, QoS CFAck frames sent by HC | TID | EOSP | Ack Policy | Reserved | QAP PS Buffer State |
| QoS data type frames sent by non-AP QSTAs | TID | 0 | Ack Policy | Aggregated MSDU Present | TXOP duration requested |
| | TID | 1 | Ack Policy | Aggregated MSDU Present | Queue size |

### 7.1.4 Duration/ID field in Data and Management frames

*Add the following to the end of clause 7.1.4:*

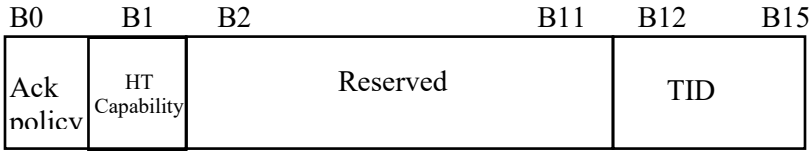
Within all data or management type frames sent within a PAP, the Duration/ID field is set to the remaining duration of the PAP.

## 7.2 Format of individual frame types

### 7.2.1 Control Frames

### 7.2.1.7 Block Acknowledgement Request (BlockAckReq) frame format

*Change the diagram of the BAR control field of 7.2.1.7 to appear as follows:*




The content of B2-B15 changes when HT Capability bit is set to 1. Refer to section 7.2.1.7.1 for details.

**Figure 21.2– BAR Control Field**

*Insert the following text and table immediately after Figure 21.2 within clause 7.2.1.7:*

The ACK Policy subfield of the BAR Control field contains the ACK policy for the BlockAckReq frame. The ACK policy subfield bits shall have the meaning indicated in table 3.3:

| Bits in BAR Control field | Meaning |
|---|---|
| **Bit 0** | |
| 0 | Normal acknowledgement.<br>The addressed recipient returns an ACK as defined in 9.2.8 or a Block Acknowledgement frame after a SIFS period, according to the previously negotiated block ack policy as described in 11.5. The Ack Policy field is set to this value in all directed Block Ack Request frames in which the sender requires immediate acknowledgement, including those requiring an immediate Block Acknowledgement. |
| 1 | No Acknowledgement<br>The addressed recipient performs no immediate response action upon receipt of the frame. More details are provided in 9.11. The Ack Policy is set to this value in all BlockAckReq frames in which the sender does not require immediate, explicit acknowledgement. |
| Bit 1 | |
| 0 | Block ACK structure as in 802.11e |
| 1 | High Throughput Block ACK Request<br>This is described in section 7.2.1.7.1 |

**Table 3.3**

### 7.2.1.7.1 HT Block ACK Request

The frame format of the HT Block Ack Request is defined in Figure x.y1

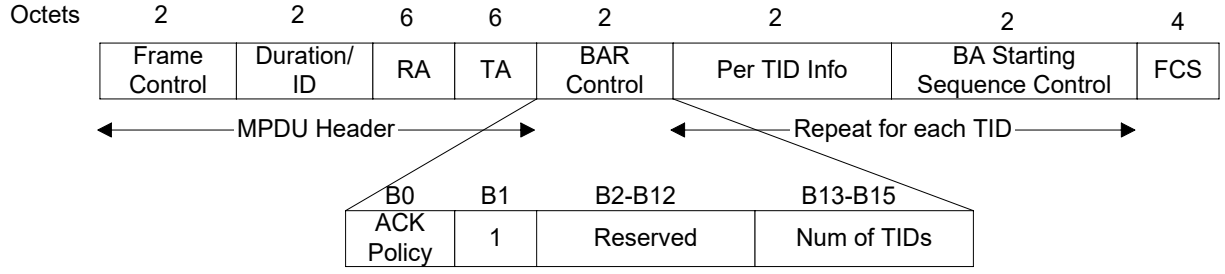



Figure x.y1 – HT Block ACK Request Frame Format

The duration value is greater than or equal to the time, in microseconds, required to transmit one ACK or BlockAck frame plus one SIFS interval, or is ZERO, or is the remaining time in the TXOP or CAP or PAP, as applicable. If the calculated duration includes a fractional microsecond, that value is rounded up to the next highest integer.

The RA field is the address of the recepient QSTA.

The TA field is the address of the QSTA transmitting the Block ACK Request frame.

The BAR Control field consists of the following subfields.
The Num of TIDs subfield contains the number of TID info fieds

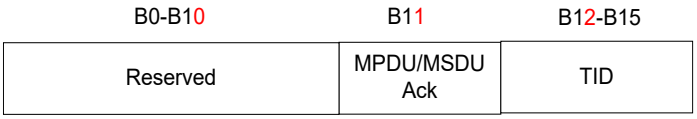



**Figure x.y3 – Per TID Information**

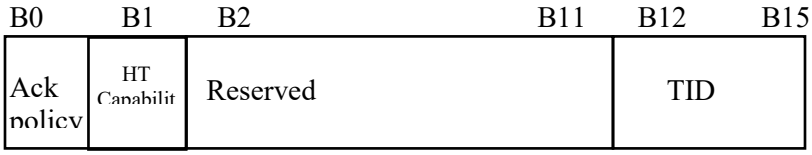
The MPDU/MSDU Ack bit indicates requested bitmap for MPDUs (0) or MSDUs (1). The TID sub-field indicates the requested TID.

***Insert the following two subclauses after clause 7.2.1.8 (.11e)***

## 7.2.1.8 Block Acknowledgement (BlockAck) frame format

***Change the diagram of the BA control field of 7.2.1.8 to appear as follows:***

The BA control field defined in Figure 21.5 consists of the TID and Ack Policy subfields as shown in figure 21.5.




The content of B2-B15 changes when HT Capability bit is set to 1. Refer to section 7.2.1.8.1 for details.

**Figure 21.5 – BA Control Field**

***Insert the following text and table immediately after Figure 21.5 within clause 7.2.1.8:***

The ACK Policy subfield of the BA Control field contains the ACK policy for the Block Acknowledgement frame. The ACK policy subfield bits shall have the meaning indicated in table 3.4:

| **Bits in BAR Control field** | **Meaning** |
|---|---|
| **Bit 0** | |
| 0 | Normal acknowledgement.<br>The addressed recipient returns an ACK as defined in 9.2.8 after a SIFS period. The Ack Policy field is set to this value in all directed Block Acknowledgement frames in which the sender requires immediate acknowledgement. |
| 1 | No Acknowledgement<br>The addressed recipient performs no immediate response action upon receipt of the frame. More details are provided in 9.11. The Ack Policy is set to this value in all Block Acknowledgement frames in which the sender does not |

| | require immediate, explicit acknowledgement. |
|---|---|
| Bit 1 | |
| 0 | Block ACK structure as in Section 7.2.1.7 (802.11e) |
| 1 | High Throughput Block ACK<br>This is described in section 7.2.1.8.1 |

**Table 3.4**

### 7.2.1.8.1 HT Block ACK

The frame format of the HT Block Ack is defined in Figure x.y3

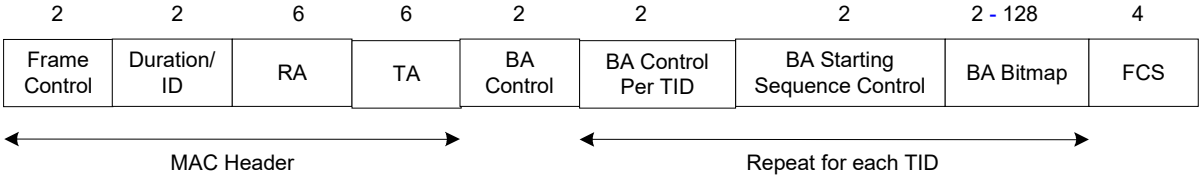



**Figure x.y3 – HT Block ACK Frame Format**

The duration value is greater than or equal to the time, in microseconds, required to transmit one ACK frame plus one SIFS interval, or is ZERO, or is the remaining time in the TXOP or CAP or PAP, as applicable. If the calculated duration includes a fractional microsecond, that value is rounded up to the next highest integer.

The RA field is the address of the recepient QSTA.

The TA field is the address of the QSTA transmitting the Block ACK frame.

The BA control field consists of the following subfields.

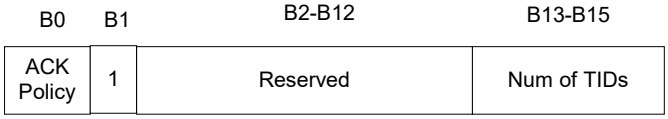



**Figure x.y4 – BA Control Field for HT Block ACK**

The BA Control per TID field consists of the following subfields.

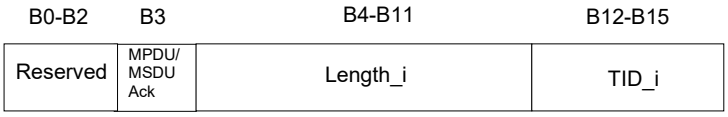



Figure x.y5 – BA Control Field Per TID for HT Block ACK

The MPDU/MSDU Ack bit indicates presence of bitmap for MPDUs (0) or MSDUs (1).
The Length_i field carries the length of the BA Bitmap corresponding to the TID_i in bytes.
The explicit HT BA frame covers only TIDs requested in the HT BAR frame. The implict HT BA frame only includes TIDs configured to use the implict Block Ack technique set up during the HT ADDBA exchange.

### 7.2.1.9 PSAD frame format

The Duration/ID field of the PSAD frame indicates the total time duration of all of the DLT and ULT TXOPs which are described in the STA INFO portion of the frame.

The frame body of a control frame (Type=0b01) of subtype PSAD (0b0111), Power Saving Aggregation Descriptor, contains the information shown in Table x.y2.

**Table x.y2 – PSAD Frame Body**

| Order | Information | Notes |
|---|---|---|
| 1 | PSAD Parameter Set | Describes the PAP which follows the PSAD frame |

The PSAD parameter set is used to describe the PAP which immediately follows the PSAD frame.

| | Reserved | More PSAD Indicator | Descriptor End | STA Info |
|---|---|---|---|---|
| Bits: | 5 | 1 | 10 | 64*m |

**Figure 000n- PSAD Parameter Set format**

The More PSAD Indicator bit is set to 1 to indicate the presence of a subsequent PSAD in the same TXOP and is set to 0 to indicate that there is no additional PSAD in the TXOP.

The Descriptor End field indicates the duration of the PAP which is described by the PSAD frame. The value of the Descriptor End field is an integer number of 2 OFDM symbols. Therefore, this field can describe a PAP of up to 8 msecs in duration.

The 'm' represents number of STAs included in the PSAD descriptor.

| | Rsrvd | STA ID | DLT Start Offset | DLT Duration | ULT Start Offset | ULT Duration |
|---|---|---|---|---|---|---|
| Bits: | 2 | 14 | 12 | 12 | 12 | 12 |

**Figure 000n- STA Info format**

The STA ID field indicates 14 LSBs (bits) of the receiving STA's MAC address. In case of infrastructure BSS mode, STA ID indicates 14 bits of AID.

The DLT Start Offset field indicates the start of a DLT for a STA relative to the end of the PSAD frame. It is given as an integer number of 1/2 OFDM symbols. If no DLT is scheduled for a STA, but a ULT is scheduled for that STA, then the DLT End Offset is set to null (0).

The DLT Duration field indicates the length of a DLT for a STA. It is given as a number of 1/2 OFDM symbols. If no ULT is scheduled for a STA, but a DLT is scheduled for that STA, then the ULT Duration is set to null (0).

The ULT Start Offset field indicates the start of the ULT. The first ULT is scheduled to begin after a SIFS interval from the end of the last DLT described in the PSAD. If no ULT is scheduled for a STA, but a DLT is scheduled for that STA, then the ULT Start Offset is set to null (0). The computation of ULT start offset shall ensure an IFS of ITS between two consecutive ULTs.

The ULT Duration field indicates the maximum length of a ULT for a STA. Even, if a STA has more data queued than the allocated time for its ULT, the STA shall release the medium at the end of the allocated duration. ULT duration is given as an integer number of 1/2 OFDM symbols. If no ULT is scheduled for a STA, but a DLT is scheduled for that STA, then the ULT duration is set to null (0). A STA cannot use the medium longer than the time allocated in PSAD frame.

## 7.2.2 Data Frames

***Change the text, figures and tables in 7.2.2 (.11e) as shown:***

The frame format for a Data frame is dependent on the QoS subfield of the subtype field and is as defined in Figure 22.

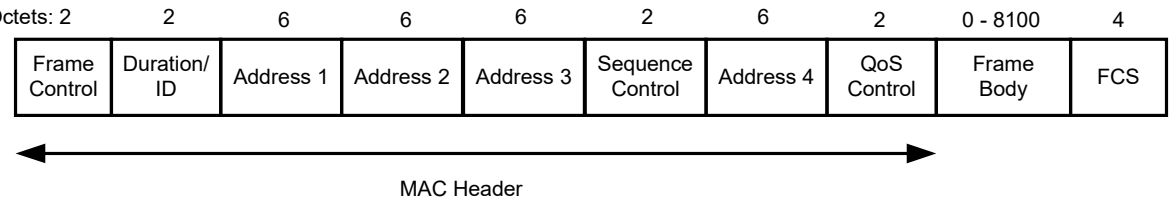



**Figure 22 – Data frame**

***Change the definitions as follows:***

The DA is the destination of the A-MSDU or MSDU (or fragment thereof) in the frame body field.

The SA is the address of the MAC entity which initiated the A-MSDU or MSDU (or fragment thereof) in the frame body field.

## 7.2.3 Management frames

### 7.2.3.1 Beacon frame format

***Insert the Channel Set and New Secondary Channel Number entries and change the notes in Table 5(.11g) to read as follows:***

| Order | Information | Notes |
|---|---|---|
| 7 | DS Parameter Set | The DS Parameter Set information element is present within Beacon frames generated by STAs using Clause 15, Clause 18 and Clause 19 PHYs and by STAs using Clause 20 PHYs while operating in the 2.4GHz band. |
| 15 | Channel Set | The Channel Set information element is present within Beacon frames generated by APs using a Clause 20 PHY operating on a 40 MHz channel pair |
| 19 | ERP Information | The ERP Information element is |

| | | |
|---|---|---|
| | | present within Beacon frames generated by STAs using ERP PHYs and HTP PHYs and is optionally present in other cases. |
| TBD | New Secondary Channel Number | The New Secondary Channel number information element may be present within Beacon frames generated by APs using a clause 20 PHY having the capability of 40MHz channel operation. |

*Add a new clause 7.2.3.1.1 immediately after the existing clause 7.2.3.1 "Beacon Frame Format"*

### 7.2.3.1.1 Secondary Channel Beacon Format

An AP with a Clause 20 PHY operating on a 40 MHz channel pair may send a Beacon frame on the secondary channel as described in clause 9.13.2.1. In contrast to the normal sending of Beacon frames, the aim of sending a Beacon frame on the secondary channel is to discourage use of that channel (other than as the secondary channel of the 40 MHz channel pair) and as a result, the required frame body is substantially different.

The contents of the fields of the Beacon frame sent on the secondary channel shall be the same as those of the Beacon frame sent on the primary channel, with the exceptions noted below.

The Supported Rate Set Information Element shall consist of a single Clause 20 rate, marked as a basic rate.

**Table 7.2.3.1.1T1 – Beacon Frame Body when used as a Secondary Channel Beacon**

| Order | Information | Notes |
|---|---|---|
| 1 | Timestamp | |
| 2 | Beacon Interval | |
| 3 | Capability | |
| 4 | Service Set Identifier (SSID) | |
| 5 | Supported Rate Set | |
| 6 | CF Parameter Set | May optionally be included to further discourage use of this channel. |
| 5 | Channel Set | |

### 7.2.3.9 Probe Response frame format

*Insert the Channel Set and New Secondary Channel entries and change the notes in Table 12(.11g) to read as follows:*

| Order | Information | Notes |
|---|---|---|
| 7 | DS Parameter Set | The DS Parameter Set information element is present within Probe Response frames generated by STAs using Clause 15, Clause 18 and Clause 19 PHYs and by STAs using Clause 20 PHYs while operating in the |

| | | |
|---|---|---|
| | | 2.4GHz band. |
| 11 | Channel Set | The Channel Set information element is present within Probe Response frames generated by APs using a Clause 20 PHY operating on a 40 MHz Channel Pair |
| 18 | ERP Information | The ERP Information element is present within Probe Response frames generated by STAs using ERP PHYs and HTP PHYs and is optionally present in other cases. |
| TBD | New Secondary Channel Number | The New Secondary Channel Number information element may be present within Probe Response frames generated by APs using a clause 20 PHY having the capability of 40MHz channel operation. |

# 7.3 Management frame body components

## 7.3.1 Fixed fields

### 7.3.1.4 Capability Information field

***Change the second paragraph in 7.3.1.4(.11e) as shown:***

The length of the Capability Information field is 2 octets. The format of the Capability Information field is defined as illustrated in Figure 27. No subfield is supplied for ERP as a STA supports ERP operation if it includes all the clause 19 mandatory rates in its supported rate set. No subfield is supplied for HTP (STAs employing a Clause 20 PHY), as a STA supports HTP operation if it includes all of the Clause 20 mandatory rates in its supported rate set.

***Change the contents of Figure 27 as shown:***

| B0 | B1 | B2 | B3 | B4 | B5 | B6 | B7 |
|---|---|---|---|---|---|---|---|
| ESS | IBSS | CF Pollable | CF Poll Request | Privacy | Short Preamble | PBCC | Channel Agility |

| B8 | B9 | B10 | B11 | B12 | B13 | B14 | B15 |
|---|---|---|---|---|---|---|---|
| Spectrum Management | QoS | Short Slot Time | APSD | AMSDU | DSS-OFDM | Delayed Block Ack | Immediate Block Ack |

**Figure 27—Capability Information fixed field**

***Insert the following paragraph between the 25th and 26th paragraphs of the clause:***

STAs (and APs) set the AMSDU subfield to 1 within the capability information field when the MIB attribute dot11AMSDUOptionImplemented is true and set it to 0 otherwise.

## 7.3.1.11 Action Field

***Add the following rows to Table 19A:***

| Name | Value | See Subclause |
|---|---|---|
| High Throughput | 4 | 7.4.5 |

***Add the following section at the end of section 7.3.1***

## 7.3.1.18 HT Block ACK Parameter Set Field

The HT Block Ack Parameter Set field is used in HT ADDBA frames to signal the parameters for setting up a HT Block Ack mechanism. The length of the Block Ack Parameter Set field is 4 octets. The Block Ack Parameter Set field is illustrated in Figure 33.x

| B0 | B1 | B2-B5 | B6-B15 | B16-B17 | B18-B23 | B24-31 |
|---|---|---|---|---|---|---|
| MPDU/ MSDU ACK | Block ACK Policy | TID | Buffer Size | Block ACK Mode | Implicit “n” frames/ sequence number interval | Bitmap Size |

**Figure 33.x – HT Block ACK Parameter Set**

The MPDU/MSDU Ack bit indicates whether the bitmap bits are indicating acknowledgement for MPDUs (MPDU/MSDU bit value of 0) or MSDUs (MPDU/MSDU bit value of 1).

The Block Ack Policy subfield is set to 1 for immediate Block Ack and 0 for delayed Block Ack. The Block ACK Policy subfield value assigned by the originator of the QoS Data frames is advisory.

The TID subfield contains the value of the TC or TS for which the Block Ack is being requested.

The Buffer Size indicates the number of buffers of size 2304 octets available for this particular TID.

In an HT ADDBA request frame, the Buffer Size subfield is intended to provide guidance for the frame receiver to decide its re-ordering buffer size, and is advisory only. When the Buffer Size subfield is set to 0, the originator of the Block ACK has no information to specify its value.

In an HT ADDBA response frame, when the Status code is set to 0, the Buffer size is set to a value of at least 1.

The Bitmap size is added to negotiate the bitmap size in bytes between the transmitter and receiver STAs with HT Capability. The HT ADDBA Request carries the needed size. The HT ADDBA Response confirms the assigned size. The interpretation of Block ACK Mode and Implicit "n" (binary value described in B18-B23 where B18 is the LSB) frames/sequence number interval are shown below:

| Block ACK Mode B16-B17 | Implicit "n" frames/ sequence number interval (B18-B23) | Meaning |
|---|---|---|
| 00 | Invalid | Explicit BA |
| 01 | valid | Send implicit BA after "n" frames received in the receiver buffer, since the last BA or from start |
| 10 | Valid | Send Implict BA when received frame sequence number is higher or equal to the last sequence number plus the sequence number interval, "n", in which the last BA was sent at, or from start |
| 11 | Invalid | Reserved |

## 7.3.2 Information Elements

***Add two new rows to Table 20 "Element IDs" as follows, and adjust reserved ids appropriately***

| | |
|---|---|
| Channel Set | XXX-To be assigned by ANA before letter ballot |
| New Secondary Channel Number | XXX-To be assigned by ANA before letter ballot |

***Add the following text to the end of clause 7.3.2 after the table of Element IDs***

Individual information elements may be extended in length by future versions of this standard by adding new fields to the end of an existing information element. STAs shall ignore any additional information beyond the expected end of an Information Element, and shall treat any such information element as legal.

## 7.3.2.13 ERP Information element

***Change the text of clause 7.3.2.13(.11g) as follows:***

~~The ERP Information element contains information on the presence of Clause 15 or Clause 18 stations in the BSS that are not capable of Clause 19 (ERP-OFDM) data rates. It also contains the requirement of the ERP Information element sender (AP in a BSS or STA in an IBSS) as to the use of protection mechanisms to optimize BSS performance and as to the use of long or short Barker preambles. See Figure 42E for a definition of the frame element.~~

The ERP Information element contains information on:

a) the presence of Clause 15 or Clause 18 stations in the BSS that are not capable of Clause 19 (ERP-OFDM) data rates
b) the directive from the ERP Information element sender (the AP, or in an IBSS a STA) as to the use of protection mechanisms to optimize BSS performance in the presence of STA which have implemented a PHY from Clause 15 or Clause 18 and not including Clause 19 capability
c) the directive from the ERP Information element sender (AP in a BSS or STA in an IBSS) as to the use of long or short Barker preambles
d) the presence of Clause 19 stations in the BSS, when the ERP Information element sender is an HTP STA
e) the directive from the ERP Information element sender (AP in a BSS or STA in an IBSS) as to the use of OFDM-protection mechanisms to optimize BSS performance
f) the presence of Clause 17 stations in the BSS, when the ERP Information element sender is a HTP STA
g) the presence of Clause 17 stations in the secondary 20 MHz channel which potentially limits the ability of the HTP STA to utilize a 40 MHz wide channel, when the ERP Information element sender is a HTP STA
h) the presence of HTP STA in the BSS which are not capable of receiving 40 MHz channel transmissions (20MHz HTP STA), when the ERP Information element sender is an HTP STA
i) the directive from the ERP Information element sender (AP in a BSS or STA in an IBSS) as to the use of 20MHz-protection mechanisms to optimize BSS performance

See Figure 42E for a definition of the ERP Information element.

In an infrastructure BSS, if one or more NonERP STAs are associated in the BSS, the Use_Protection bit shall be set to 1 in transmitted ERP Information Elements.

In an infrastructure BSS, if one or more Clause 19 or Clause 17 STAs are associated in the BSS, then the Use_OFDM_Protection bit shall be set to 1 in ERP Information Elements transmitted by HTP STAs and may be set to 1 in ERP Information Elements transmitted by nHTP STAs.

In an infrastructure BSS, if one or more 20MHz HTP STAs are associated in the BSS, then the Use_20MHz_Protection bit shall be set to 1 in ERP Information Elements transmitted by HTP STAs and may be set to 1 in ERP Information Elements transmitted by nHTP STAs.

In an IBSS, the setting of the Use_Protection and Use_OFDM_Protection and Use_20MHz_Protection bits is left to the STA. In an IBSS, there is no uniform concept of association; therefore, a typical algorithm for setting the Use_Protection and Use_OFDM_Protection and Use_20MHz_Protection bits will take into account the traffic pattern and history on the network. If a member of an IBSS which is not an HTP STA detects one or more NonERP STAs that are members of the same IBSS, then the Use_Protection bit should be set to 1 in the ERP Information Element of transmitted Beacon and Probe Response frames. If a member of an IBSS which is a HTP STA detects one or more Clause 19 STAs or one or more Clause 17 STAs that are members of the same IBSS, then the Use_OFDM_Protection bit should be set to 1 in the ERP Information Element of transmitted Beacon and Probe Response frames. If a member of an IBSS which is an HTP STA detects one or more 20MHz HTP STAs that are members of the same IBSS, then the Use_20MHz_Protection bit should be set to 1 in the ERP Information Element of transmitted Beacon and Probe Response frames.

In an infrastructure BSS, the NonERP_Present bit shall be set to 1 when a NonERP STA is associated with the BSS. Examples of when the NonERP present bit may additionally be set to 1 include, but are not limited to, when:

a) A NonERP infrastructure or independent BSS is overlapping (a NonERP BSS may be detected by the reception of a Beacon where the supported rates contain only Clause 15 or Clause 18 rates).

b) In an IBSS, if a Beacon frame is received from one of the IBSS participants where the supported rate set contains only Clause 15 or Clause 18 rates.

c) A management frame (excluding a Probe Request) is received where the supported rate set includes only Clause 15 or Clause 18 rates.

In an infrastructure BSS, the OFDM_PRESENT bit shall be set to 1 in ERP Information Elements transmitted by HTP STA when a Clause 17 or Clause 19 STA is associated with the BSS. Examples of when the OFDM_PRESENT bit may additionally be set to 1 in an ERP Information Element transmitted by a HTP STA include, but are not limited to, when

a) A Clause 17 or Clause 19 infrastructure or independent BSS is overlapping. (A Clause 17 BSS may be detected by the reception of a Beacon where the supported rates element and extended supported rates element contain only Clause 17 rates. A Clause 19 BSS may be detected by the reception of a Beacon where the supported rates and extended supported rates elements contain at least one rate from the set of Clause 19 rates and no HTP rates.)

b) In an IBSS, if a Beacon frame is received from one of the IBSS participants where the supported rate set contains:

   1) only Clause 17 rates
   OR
   2) at least one rate from the set of Clause 19 rates and no HTP rates.

c) A management frame (excluding a Probe Request) is received where the supported rate set includes:

   1) only Clause 17 rates
   OR
   2) at least one rate from the set of Clause 19 rates and no HTP rates.

The OFDM_PRESENT bit may optionally be set to 1 in ERP Information Elements transmitted by nHTP STA.

In an infrastructure BSS, the 20MHz_HTP_PRESENT bit shall be set to 1 in ERP Information Elements transmitted by HTP STA when one or more 20MHz HTP STAs are associated in the BSS. Examples of when the 20MHz_HTP_PRESENT bit may additionally be set to 1 in an ERP Information Element transmitted by a HTP STA include, but are not limited to, when

a) An infrastructure or independent BSS which is overlapping and which has signalled the presence of 20MHz HTP STA as indicated by the 20MHz_HTP_PRESENT bit.

b) In an IBSS, if a Beacon frame is received from one of the IBSS participants where the supported rate set contains at least one rate from the set of Clause 20 rates, but no 40MHz HTP rates.

c) A management frame (excluding a Probe Request) is received where the supported rate set contains at least one rate from the set of Clause 20 rates, but no 40MHz HTP rates.

The 20MHz_HTP_PRESENT bit may optionally be set to 1 in ERP Information Elements transmitted by nHTP STA.

~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs shall invoke the use of a protection mechanism as described in clause 9.13 after transmission or reception of the Use_Protection bit with a value of 1 in an MMPDU to or from the BSS that the ~~ERP AP or ERP STA~~ ERP AP, ERP STA, HTP AP or HTP STA has joined or started. ~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs may additionally invoke clause 9.13 protection mechanism use at other times.

~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs may disable clause 9.13 protection mechanism use after transmission or reception of the Use_Protection bit with a value of 0 in an MMPDU to or from the BSS that the ~~ERP APs or ERP STAs~~ ERP AP, ERP STA, HTP AP or HTP STA has joined or started.

HTP APs and HTP STAs shall invoke the use of an OFDM protection mechanism after transmission or reception of the Use_OFDM_Protection bit with a value of 1 in an MMPDU to or from the BSS that the HTP AP or HTP STA has joined or started unless a protection mechanism as defined in clause 9.13 is being concurrently employed, in which case, the use of an OFDM protection mechanism is optional. HTP APs and HTP STAs may optionally invoke OFDM protection mechanism use at other times.

HTP APs and HTP STAs may disable OFDM protection mechanism use after transmission or reception of the Use_OFDM_Protection bit with a value of 0 in an MMPDU to or from the BSS that the HTP AP or HTP STA has joined or started.

40MHz HTP APs and 40MHz HTP STAs shall invoke the use of a 20MHz protection mechanism after transmission or reception of the Use_20MHz_Protection bit with a value of 1 in an MMPDU to or from the BSS that the 40MHz HTP AP or 40MHz HTP STA has joined or started unless a protection mechanism as defined in clause 9.13, or an OFDM protection mechanism is being concurrently employed, in which case, the use of a 20MHz protection mechanism is optional. 40MHz HTP APs and 40 MHz HTP STAs may optionally invoke 20MHz protection mechanism use at other times.

40MHz HTP APs and 40MHz HTP STAs may disable 20MHz protection mechanism use after transmission or reception of the Use_20MHz_Protection bit with a value of 0 in an MMPDU to or from the BSS that the 40MHz HTP AP or 40MHz HTP STA has joined or started.

When there are no NonERP STAs associated with the BSS and the ERP Information Element sender's dot11ShortPreambleOptionImplemented MIB variable is set to true, then the Barker_Preamble_Mode bit may be set to 0. The Barker_Preamble_Mode bit shall be set to 1 by the ERP Information Element sender if one or more associated NonERP STAs are not short preamble capable as indicated in their Capability Information field, or if the ERP Information Element senders dot11ShortPreambleOptionImplemented MIB variable is set to false.

If a member of an IBSS detects one or more non-short preamble-capable STAs that are members of the same IBSS, then the Barker_Preamble_Mode bit should be set to 1 in the transmitted ERP Information Element.

~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs shall use long preambles when transmitting Clause 15, Clause 18, and Clause 19 frames after transmission or reception of an ERP Information Element with a Barker_Preamble_Mode value of 1 in an MMPDU to or from the BSS that the ~~ERP APs or ERP STAs~~ ERP AP, ERP STA, HTP AP or HTP STA has joined or started, regardless of the value of the short preamble capability bit from the same received or transmitted MMPDU that contained the ERP Information Element. ~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs may additionally use long preambles when transmitting Clause 15, Clause 18, and Clause 19 frames at other times. ~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs may use short preambles when transmitting Clause 15, Clause 18, and Clause 19 frames after transmission or reception of an ERP Information Element with a Barker_Preamble_Mode value of 0 in an MMPDU to or from the BSS that the ~~ERP APs or ERP STAs~~ ERP AP,

ERP STA, HTP AP or HTP STA has joined or started, regardless of the value of the short preamble capability bit from the same received or transmitted MMPDU. ~~NonERP STAs and NonERP APs~~STAs which are neither ERP nor HTP and APs which are neither ERP nor HTP may also follow the rules given in this paragraph.

The Secondary_Channel_Used bit may be set to 0 in ERP Information Elements transmitted by HTP STAs or HTP APs if no frames with a Clause 17 BSSID have been received within the last two seconds on the secondary 20 MHz channel of the BSS that the HTP AP or HTP STA has joined or started, otherwise, the Secondary_Channel_Used bit shall be set to 1. nHTP STAs and nHTP APs shall always set the Secondary_Channel_Used bit to 0 if they transmit ERP Information elements.

Recommended behavior for setting the Use_Protection bit is contained in 9.10.

The ERP Information element shall have the form shown in Figure 42E.

| B0-B7 | B0-B7 | B0 | B1 | B2 | B3 | B4 | B5 | B6 | B7 |
|---|---|---|---|---|---|---|---|---|---|
| ElementID | Length(4) | NonERP Present | Use_protection | Barker preamble mode | OFDM_present | Use_OFDM_Protection | Secondary_Channel_Used | 20MHz_HTP_PRESENT | USE_20MHz_PROTECTION |

| B8 | B9 | B10-B15 | B16-B30 | B31 |
|---|---|---|---|---|
| PSA | Use_ER_Protection | Reserved | ER_Beacon_Offset | Reserved |

**Figure 42E**

The PSA (Power Save Aggregation) sub field is 1 bit in length and specifies the support of PSAD mode of operation. If set to 0, the HTP STA transmitting this element does not support the PSAD mode of power save operation.

~~Bits r3 through r7 are reserved, set to 0, and are ignored on reception. Note that the length of this element is flexible and may be expanded in the future.~~

Note that the length of this element is flexible and may be expanded in the future.

The "Use ER Protection" bit is 1 bit in length location B9. When this bit is set, ER protection mechanisms as specified in clause 9.13.3 shall be used.

The ER_Beacon Offset value is indicated as a number of 32us intervals in the 15-bit field from B16 to B30. The value of this field shall be zero if a single beacon is transmitted by the AP.

## 7.3.2.22.1 Basic Report

***Change one of the reserved bits in figure 46o "Map Field Format" to be "Secondary Channel"***

***Add the following after the definition of the "Unmeasured bit"***

— Secondary Channel bit, which shall be set to 1 when at least one valid Secondary Channel Beacon (as described in clause 9.13.2.1) was received during the measurement period from another BSS. Otherwise the Secondary Channel bit shall be set to zero.

***Add the following new clauses as the last sub-clauses of 7.3.2 "Information Elements"***

## 7.3.2.25 Channel Set

The Channel Set information element is used to convey information about the channels from which a 40 MHz Channel Pair are formed. The Primary Channel field shall contain the channel number of the primary channel. The Secondary Channel shall contain the channel number of the secondary channel.

This information element may be extended in later versions of this standard.

See Figure 000n:

| | Element ID | Length | Primary Channel | Secondary Channel |
|---|---|---|---|---|
| Octets: | 1 | 1 | 1 | 1 |

**Figure 000n- Channel Set element format**

***Add the following new clause as the last sub-clause of 7.3.2 "Information Elements"***

### 7.3.2.27 New Secondary Channel Number element

The New Secondary Channel Number element is used by an AP in a BSS to advertise when it is changing the secondary channel of a 40MHz channel pair. The format of the New Secondary Channel Number element is shown in Figure 46u.

| | Element ID | Length | New Secondary Channel Number |
|---|---|---|---|
| **Octets:** | **1** | **1** | **1** |

**Figure 46u—New Secondary Number element format**

The Length field indicates the number of bytes contained in the element, not including the Element ID octet and not including the Length octet. Note that the length of this element is flexible and may be expanded in the future.

The New Secondary Channel Number field is set to the number of the secondary channel to which the STA is moving (as defined in 17.3.8.3.3) as part of an N-DFS operation. If the secondary channel will no longer be used following the move of the primary channel (i.e. the move involves both a movement of the primary channel and a change from a 40MHz channel pair to a single 20 MHz channel), then the New Secondary Channel field value is set to 0.

The New Secondary Channel Number element may be included in either of the Channel Switch Announcement frames as described in 7.4.1.5., beacon frames as described in 7.2.3.1. and probe response frames as described in 7.2.3.9. The use of the New Secondary Channel Number element is described in 11.6.7.

### 7.4.1.4 Channel Switch Announcement frame format

***Add the following sentences and figure at the end of the original section:***

When a channel switching operation includes a change of the secondary channel, the Channel Switch Announcement frame includes the New Secondary Channel Number element as shown in Figure 46z.

| | Category | Action | Channel Switch Announcement element | New Secondary Channel Number element |
|---|---|---|---|---|
| **Octets:** | **1** | **1** | **5** | **3** |

**Figure 46z—Channel Switch Announcement frame body format (Including New Secondary Channel Number element)**

### 7.4.4 Block Ack action frame details

Add the following rows to Table 20.18

| Action Field Values | Meaning |
|---|---|
| 3 | HT ADDBA request |
| 4 | HT ADDBA response |
| 5-255 | Reserved |

*Add the following sections*

### 7.4.4.4 HT ADDBA request frame format

An HT ADDBA request is sent by an originator of HT Block Ack to another HTP STA. The frame body of an HT ADDBA request frame contains the information shown in Table x.yy1

Table x.yy1 – HT ADDBA request frame body

| Order | Information |
|---|---|
| 1 | Category |
| 2 | Action |
| 3 | Dialog Token |
| 4 | HT Block ACK Parameter Set |
| 5 | Block Ack Timeout Value |
| 6 | Block Ack Starting Sequence Control |

The Category field is set to 3 (representing Block ACK).
The Action field is set to 3 (representing HT ADDBA request)
The Dialog Token field is set to a non-zero value chosen by the STA.
The HT Block Ack Paramter Set field is defined in 7.3.1.18.
The Block Ack Timeout value is defined in 7.3.1.15.
The Block Ack Starting Sequence Control field is defined in 7.2.1.7.

### 7.4.4.5 HT ADDBA response frame format

The HT ADDBA response frame is sent in response to an HT ADDBA request frame. The frame body of an HT ADDBA response contains the information shown in Table x.yy2

Table x.yy2 – HT ADDBA response frame body

| Order | Information |
|---|---|
| 1 | Category |
| 2 | Action |
| 3 | Dialog Token |
| 4 | Status code |
| 5 | HT Block ACK Parameter Set |
| 6 | Block Ack Timeout Value |

The Category field is set to 3 (representing Block ACK).
The Action field is set to 4 (representing HT ADDBA response)
The Dialog Token field is copied from the corresponding received HT ADDBA request frame.
The status code field is defined in 7.3.1.9.
The HT Block Ack Paramter Set field is defined in 7.3.1.18.
The Block Ack Timeout value is defined in 7.3.1.15.

## 7.4.5 High Throughput action details

Four Action frame formats are defined for High Throughput. An action field, in the octet field immediately after the Category field, differentiates the four formats. The Action field values associated with each format are defined in Table 20.22.

**Table 20.22 – High Throughput Action field values**

| Action field value | Description |
|---|---|
| 0 | Mode Request |
| 1 | Mode Report |
| 2 | MIMO Channel Request |
| 3 | MIMO Channel Report |
| 4-255 | Reserved |

### 7.4.5.1 Mode Request frame format

The Mode Request frame uses the Action frame body format and is transmitted by a STA requesting the receiving STA to indicate the best transmission mode to employ for high throughput communication. The format of the Mode Request frame is shown in Figure 000n1.

The Category field shall be set to 4 (representing High Throughput).

The Actions field shall be set to 0 (representing a Mode Request Frame).

The Dialog Token field shall be set to a nonzero value chosen by the STA sending the Mode Request to identify the request/report transaction.

The Mode Request field shall be set to 1. All other values for this field are reserved.

| | Category | Action | Dialog Token | Mode Request |
|---|---|---|---|---|
| Octets: | 1 | 1 | 1 | 1 |

**Figure 000n1- Mode Request frame format**

Upon reception of a Mode Request frame, an STA must respond with a Mode Response, as described in 7.4.5.2. A null response may be used.

### 7.4.5.2 Mode Response frame format

The Mode Response frame uses the Action frame body format and is transmitted by a STA in response to a Mode Request frame. It may also be used as an unsolicited request to use a certain PHY mode. The format of the Mode Response frame is shown in Figure 000n2.

The Category field shall be set to 4 (representing High Throughput).

The Actions field shall be set to 1 (representing a Mode Response Frame).

The Dialog Token field shall be set to the value in any corresponding Mode Request Frame. If the Mode Response is not being transmitted in response to a Measurement Request frame, the Dialog token shall be set to zero.

The Mode Response field shall contain the mode that the STA would prefer the requesting station to employ. The specific mechanism for determining this mode is implementation dependent. A null response of all ones (i.e. 0xFFFF) is used if the station is unable to determine a mode. Otherwise, the mode is indicating using bits b6:b21 as shown in Figure 017 (SIG-N field). All other bits are reserved and set to zero.

| | Category | Action | Dialog Token | Mode Response |
|---|---|---|---|---|
| Octets: | 1 | 1 | 1 | 4 |

**Figure 000n2- Mode Response frame format**

### 7.4.5.3 MIMO Channel Request frame format

The MIMO Channel Request frame uses the Action frame body format and is transmitted by a STA requesting the receiving STA to provide its estimate of the MIMO channel matrix seen on receiving this frame. The format of the MIMO Channel Request frame is shown in Figure 000n3.

The Category field shall be set to 4 (representing High Throughput).

The Actions field shall be set to 2 (representing a MIMO Channel Request Frame).

The Dialog Token field shall be set to a nonzero value chosen by the STA sending the MIMO Channel Request to identify the request/report transaction.

The MIMO Channel Request field shall be set to 1. All other values for this field are reserved.

| | Category | Action | Dialog Token | MIMO Channel Request |
|---|---|---|---|---|
| Octets: | 1 | 1 | 1 | 1 |

**Figure 000n3- MIMO Channel Request frame format**

### 7.4.5.4 MIMO Channel Response frame format

The MIMO Channel Response frame uses the Action frame body format and is transmitted by a STA in response to a MIMO Channel Request frame. It may also be used as an unsolicited indication of the observed MIMO channel matrix. The format of the MIMO Channel Response frame is shown in Figure 000n4.

The Category field shall be set to 4 (representing High Throughput).

The Actions field shall be set to 3 (representing a MIMO Channel Response Frame).

The Dialog Token field shall be set to the value in any corresponding MIMO Channel Request Frame. If the MIMO Channel Response is not being transmitted in response to a MIMO Channel Request frame, the Dialog token shall be set to zero.

| | Category | Action | Dialog Token | Mode Response |
|---|---|---|---|---|
| Octets: | 1 | 1 | 1 | N |

**Figure 000n4- MIMO Channel Response frame format**

The Mode Response field is of varying length depending on the actual channel matrix being encoded. The octets of the Mode Response field are set according to the table below.

**Table XYZ – Mode Response Encoding**

| Octet | Contents |
|---|---|
| 1-2 | Length of Mode Response field in octets (16 bit unsigned integer) |
| 3 | Response type<br>0 for Null<br>1 for MIMO channel estimate<br>2-255 Reserved |
| 4 | Number of Rows in Channel Matrix (i.e. NRX antennas) |
| 5 | Number of Columns in Channel Matrix (i.e. NTX antennas) |
| 6 to (5+Nst*Nrows*Ncols*4) | Channel matrix elements row by row starting with element (1,1) from lowest to highest subcarrier. Each element is encoded as two 16 bit signed integers (I and Q). |

For the MIMO channel estimate, the station sends the actual channel estimate it computes during preamble processing of a MIMO Channel Request Frame.

# 9. MAC sublayer functional description

## 9.1 MAC architecture

***Insert the following subclause after clause 9.1.3(.11e) and renumber existing subclauses 9.1.4(.11e) through 9.1.5(.11e) to be subclauses 9.1.5 through 9.1.6***

### 9.1.4 MSDU aggregation

One or more MSDUs being sent to the same receiver can be aggregated into a single A-MSDU. Aggregation of more than one frame can improve system efficiency as seen at the MAC sub-layer due to the fact that the overheads associated with channel access (e.g. PLCP preamble, MAC header, IFS spacing, etc.) can be amortized over two or more MSDUs. Frames with address types of Broadcast ,Multicast, or Unicast frames can be aggregated with other frames of the same address type, but not with frames of different address type due to the requirement to share the receiver address. Aggregation is optional and the process is considered a "sub-process" between MSDU queuing and sequence number assignment in Figure 11g of Clause 6.1.4.

A STA shall only use MSDU aggregation where it knows that the receiver supports MSDU aggregation. A STA shall not aggregate MSDUs that have different values of priority as indicated by the MA-UNITDATA.request primitive. A STA may aggregate MSDUs with different values of destination address as long as they would have the same value in the Address 1 field had they been sent as individual MPDUs.

To form an A-MSDU, two or more MSDUs are aggregated together, separated by a sub-frame header. This is shown in Figure 001n. The resulting A-MSDU is therefore the combination of all MSDUs in the A-MSDU along with a sub-frame header for each constituent MSDU.

The destination address of the A-MSDU is the address of the STA that is the next immediate intended receiver of the aggregated frame. The source address of the A-MSDU is the MAC address of the STA that created the A-MSDU.

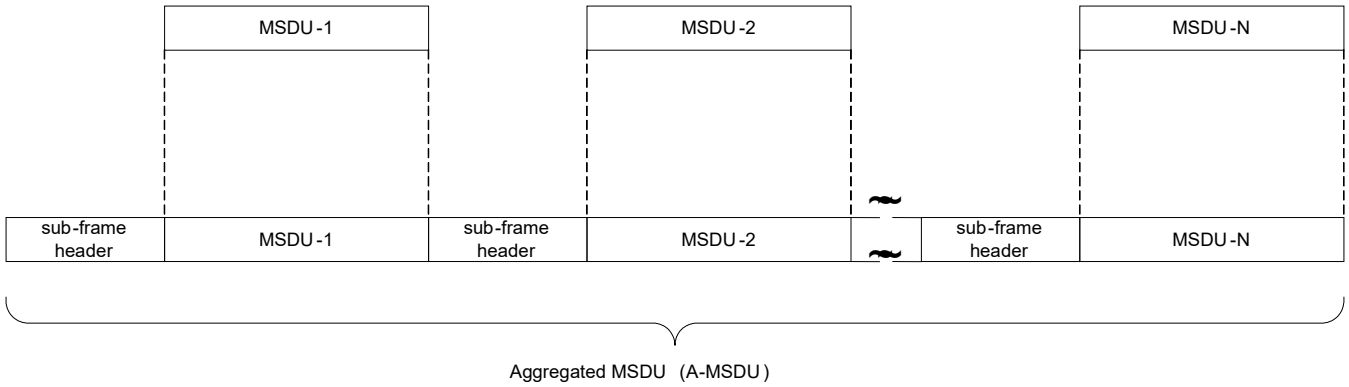



**Figure 001n – Formation of an A-MSDU**

The format for the sub-frame header is given in Figure 002n. The sub-frame header is 14 octets in length and consists of a 16-bit MSDU length field, a 6-octet source address of the constituent MSDU, and a 6-octet destination address of the constituent MSDU. The MSDU length field indicates the length, in octets, of the constituent MSDU.

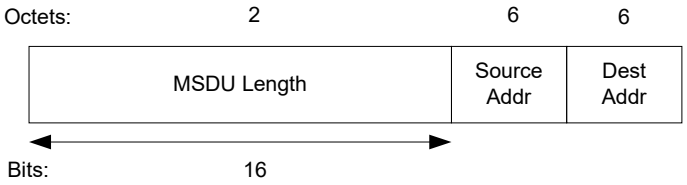



**Figure 002n – Sub-Frame Header**

A data frame bearing an A-MSDU within its frame body is identified by a '1' in the Aggregated MSDU bit of the QoS Control Field (Clause 7.1.3.5). For data frames containing a non-aggregated MSDU, this bit will be zero.

After aggregation, the procedures for handling an A-MSDU are no different from an MSDU including sequence number assignment, optional MSDU integrity protection, and fragmentation, with the single exception of the Aggregated MSDU bit described above. Once formed, A-MSDUs shall not be un-aggregated by the transmitter, as there are no facilities for individual sequencing or retransmission of the constituent MSDUs.

A method for determining when to engage optional MSDU aggregation is out of scope for this standard.

***Insert the following subclause after clause 9.1.3(.11e) and renumber existing subclauses 9.1.6(.11e) to be subclauses 9.1.7***

## 9.1.6 HTP Burst Transmission overview

The high-throughput PHY defines burst transmission formats that permit more efficient usage of the medium. A HTP burst transmission is performed in a single medium access, and permits frames to be sent to different destination addresses. These formats shall only be used to transmit frames to other HTP STAs, and may be used as part of any kind of TXOP. The medium spacing before and after a HTP burst transmission shall be governed by the rules covering the spacing before and after a non-burst transmission in the TXOP.

A HTP burst transmission consists of a sequence of frames transmitted by a single HTP STA without intervening frames by any other STA. The frames of the HTP burst transmission shall be transmitted using a single HTP rate group as defined in 20.3.2.2. During a HTP burst transmission, the MAC may utilise RIFS and/or instruct the PHY to aggregate multiple frames into a single A-PPDU. These formats are illustrated in Figure 003n.

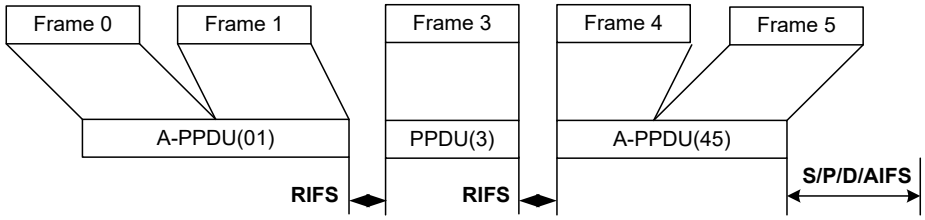



**Figure 003n – HTP Burst transmission**

Frames may be aggregated into a single A-PPDU if they are being transmitted at the same TXPWR_LEVEL. A frame that uses a different TXPWR_LEVEL as the previous frame in the HTP burst transmission may use RIFS.

### 9.1.6.1 HTP Burst Transmission with Power Efficiency and Uplink Scheduling

A HTP burst transmission by a HTP STA may include PPDUs for multiple receiving STAs. Each receiving STA needs to examine each PPDU in sequence in order to determine whether it is the intended recipient of any particular frame. The requirement on the part of receiving STA results in power drain for all STAs. The Power Save Aggregation Descriptor (PSAD) is used in conjunction with HTP Burst transmission to drastically reduce the power consumption necessary to receive the frames intended for reception by a given STA.

The PSAD frame, with its list of receiving STA IDs, ULT and DLT offsets, provides information to each STA regarding the time-location of PPDUs in a PAP. This allows a STA to recognize the position of its frames by reading only the PSAD, and subsequently waking up only at the time-positions necessary to receive its frames. Additionally, PSAD can provide ULT scheduling for any expected response or reverse data flow from the receiving STAs. The ULT schedule is conveyed with the help of ULT offset values in the PSAD.

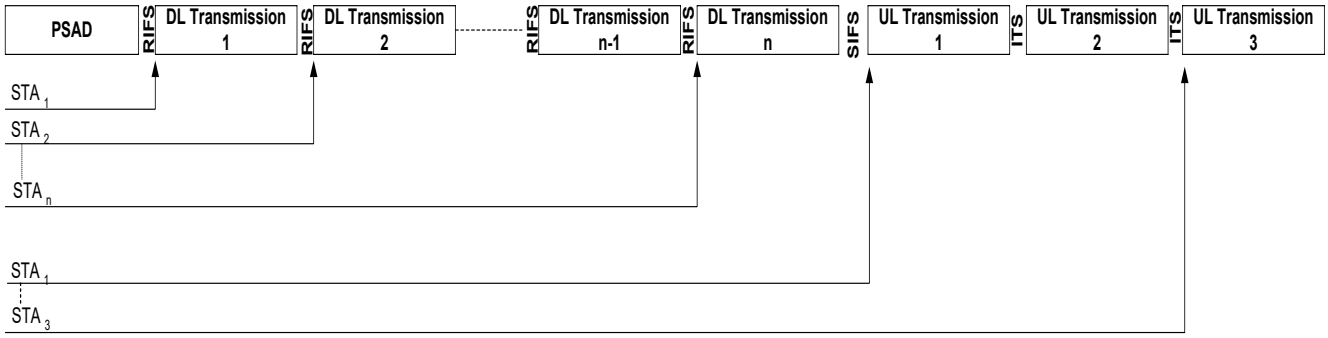



Figure 003n – HTP Burst transmission with Power Efficiency and ULT scheduling

If a PSAD is not received correctly by a receiving STA, then the behaviour of the STA is same as in section 9.6.1, i.e. it will examine each PPDU to discover frames for which it is the intended recipient. Also, the STA will not attempt to send any ULT frames as in section 9.6.1. Thus, the PSAD provides additional features of power efficiency and ULT scheduling with complete robustness.

The PSAD initiation and decoding is mandatory for the HTP QAP STA. Its initation is optional, but decoding of the PSAD frame is mandatory on the HTP non-QAP STA side. However, inclusion of a STA ID within the PSAD

STA INFO field may only occur when PSA capability is conveyed to the HTP QAP through the PSA bit of the ERP Information Element within (re)association frames.

# 9.2 DCF

## 9.2.3 Interframe Space (IFS)

***Change the text in clause 9.2.3(.11e) as follows***

The time interval between frames is called the IFS. A STA shall determine that the medium is idle through the use of the carrier sense function for the interval specified. An interframe space, RIFS, is defined for use between frames in a HTP burst transmission, and another five IFSs are defined to provide priority levels for access to the wireless media. To obtain access to the medium, a STA shall determine that the medium is idle through the use of the carrier sense function for the interval specified. ~~Five different IFSs are defined to provide priority levels for access to the wireless media; they~~ The interframe spaces are listed in order, from the shortest to the longest except for AIFS. Figure 49 shows some of these relationships.

a) RIFS Reduced Interframe Space
b) Short Interframe Space
c) PIFS Point Coordination Function (PCF) Interframe Space
d) DIFS Distributed Coordination Function (DCF) Interframe Space
e) AIFS Arbitration Interframe Space (used by the QoS facility)
f) EIFS Extended Interframe Space

***Insert the following subclause after clause 9.2.3(.11e) and renumber existing subclauses 9.2.3.1(.11e) through 9.2.3.5(.11e) to be subclauses 9.2.3.2 through 9.2.3.6.***

### 9.2.3.1 RIFS

The RIFS may be used for the second or subsequent frame of a HTP burst transmission if the frame will be transmitted at a different power than the immediately previous frame.

## 9.2.12 Determination of PLME aCWmin characteristics

***Modify the first paragraph of clause 9.2.12 as follows:***

In the case of the Clause 19 Extended Rate PHY and Clause 20 High Throughput PHY, the aCWmin value is dependent on the requestor's characteristic rate set. The characteristic rate set is equal to the IBSS's supported rate set when the STA is operating as a member of an IBSS. It is equal to the AP's supported rate set when the STA is associated with an AP. At all other times, it is equal to the STA's mandatory rate set. The MAC variable aCWmin is set to aCWmin(0) if the characteristic rate set includes only rates in the set 1, 2, 5.5, 11 otherwise, aCWmin is set to aCWmin(1). If the returned value for aCWmin is a scalar, then the MAC always sets the variable aCWmin to the returned scalar value of aCWmin.

# 9.6 Multirate support

***Make the following changes to paragraph 7 of clause 9.6(.11g) "Multirate Support":***

To allow the transmitting STA to calculate the contents of the Duration/ID field, a STA responding to a received frame shall transmit its Control Response (either CTS or ACK) frames at the highest rate in the BSSBasicRateSet that is less than or equal to the rate of the immediately previous frame in the frame exchange sequence (as defined in 9.7) and that is of the same modulation ~~type~~ class (see Clause 9.6.1) as the received frame. If no rate in the basic rate set meets these conditions, then the control frame sent in response to a received frame shall be transmitted at the highest mandatory rate of the PHY that is less than or equal to the rate of the received frame, and that is of the same modulation ~~type~~ class as the received frame. In addition, the Control Response frame shall be sent using the same PHY options as the received frame, unless they conflict with the requirement to use the BSSBasicRateSet.

***Add new clause 9.6.1 immediately following the existing clause 9.6***

### 9.6.1 Modulation Classes

In order to determine the rules for response frames given in clause 9.6, the following modulation classes are defined. Each row defines a modulation class. Modulation types within the same row have the same modulation class, while modulation types in different rows have different modulation classes.

**Table 9.6.1T Modulation Classes**

| Modulation Class | Description |
|---|---|
| 1 | Clause 16 Infrared PHY |
| 2 | Clause 14 Frequency Hopping Spread Spectrum PHY |
| 3 | Clause 15 DSSS PHY, and Clause 18 High Rate DSSS PHY |
| 4 | Clause 19.6 ERP-PBCC PHY |
| 5 | Clause 19.7 DSSS-OFDM |
| 6 | Clause 19.5 ERP-OFDM PHY |
| 7 | Clause 17 Orthogonal Frequency Division Multiplexing PHY in the 5GHz band |
| 8 | Clause 20 High Throughput PHY (20 MHz transmissions) |
| 9 | Clause 20 High Throughput PHY (40 MHz transmissions) |

## 9.9 HCF

### 9.9.1 HCF contention-based channel access (EDCA)

#### 9.9.1.4 Multiple frame transmission in an EDCA TXOP

***Change the first paragraph of subclause 9.9.1.4(.11e) as follows:***

Multiple frames may be transmitted in an acquired EDCA TXOP following the rules in 9.9.1.3. if there are more than one frame pending in the AC for which the channel has been acquired. However, those frames that are pending in other ACs shall not be transmitted in this EDCA TXOP. If a QSTA has in its transmit queue an additional frame of the same AC as the one just transmitted, and the duration of transmission of that frame plus any expected acknowledgement for that frame is less than the remaining medium occupancy timer value, then the QSTA may commence transmission of that frame ~~at SIFS after the completion of the immediately preceding frame exchange sequence~~ after the completion of the appropriate interframe space from the end of the immediately preceding frame exchange sequence. The intention of using the multiple frame transmission shall be indicated by the QSTA through the setting of the duration/ID values in one of the following two ways (see 7.1.4):

### 9.9.2 HCF controlled channel access

### 9.9.2.1 HCF controlled channel access procedure

### 9.9.2.1.2 CAP generation

***Change the second paragraph of subclause 9.9.2.1.2(.11e) as follows***

~~During a CFP or a TXOP in CP, after each data, QoS data or management type frame with a group address in the Address1 field, the HC shall wait for at least one PIFS period, and shall only continue to transmit if the WM is idle.~~ After the last frame of all ~~other non-final~~ frame exchange sequences ~~(e.g., sequences that convey unicast QoS data or management type frames)~~ during a TXOP, the holder of the current TXOP shall wait for one SIFS period before transmitting the first frame of the next frame exchange sequence, unless the frame exchange is part of a HTP burst transmission when the rules identified in clause 9.1.6 apply. The HC may sense the channel and reclaim the channel after a duration of PIFS after the TXOP, if the channel remains idle. A CAP ends when the HC does not reclaim the channel after a duration of PIFS after the end of a TXOP.

### 9.9.2.2 TXOP structure and timing

***Change the first paragraph of subclause 9.9.2.2(.11e) as follows***

Any QoS data type frame of a subclass that includes CF-Poll contains a TXOP limit in its QoS control field. The ensuing polled TXOP is protected by the NAV set by the Duration field of the frame that contained the QoS (+) CF-Poll function, as shown in Figure 62.4. Within a polled TXOP a QSTA may initiate the transmission of one or more frame exchange sequences, with all such sequences being part of a HTP burst transmission, or being nominally separated by a SIFS interval. The QSTA shall not initiate transmission of a frame unless the transmission, and any acknowledgement or other immediate response expected from the peer MAC entity, are able to complete prior to the end of the remaining TXOP duration. All transmissions, including the response frames, within the polled TXOP are considered to be the part of the TXOP and the HC shall account for these when setting the TXOP limit. If the TXOP Limit subfield in the QoS Control field of the QoS data type frame that includes CF-Poll is set to 0, then the QSTA to which the frame is directed to shall respond with either one MPDU or one QoS Null frame.

## 9.10 Block acknowledgment

### 9.10.1 Introduction (Informative)

***Change the first paragraph of subclause 9.9.10.1(.11e) as follows***

The Block Acknowledgement (Block Ack) mechanism allows a block of QoS Data MPDUs to be transmitted between two QSTAs without intervening ACK frames ~~each separated by a SIFS period, between two QSTAs~~. The mechanism is for improving the channel efficiency by aggregating several acknowledgements into one frame. There are two types of Block Ack mechanisms: immediate and delayed. Immediate Block Ack is suitable for high-bandwidth, low latency traffic while the delayed Block Ack is suitable for applications that tolerate moderate latency. In this clause, the QSTA with data to send using the Block Ack mechanism is referred to as the originator and the receiver of that data as the recipient.

### 9.10.3 Data and acknowledgement transfer

***Change the first paragraph of subclause 9.9.10.1(.11e) as follows***

After setting up for the Block exchange following the procedure in 9.10.2, the originator may transmit a Block of QoS data type frames ~~separated by SIFS period,~~ with the total number of frames not exceeding the Buffer Size subfield in the associated ADDBA response frame. Each of the frames shall have the Ack policy subfield in the QoS Control set to "Block Acknowledgement". The RA field of the frames shall be the recipient's *unicast* address. The originator requests acknowledgement of outstanding QoS Data type frames by sending a BlockAckReq frame. The recipient shall maintain a Block Ack record for the block.

***Insert the following subclause 9.10.6(.11e) as follows at the end of section 9.10***

### 9.10.6 HT Block ACK

The HT Block Ack (BA) mechanism improves channel efficiency by aggregating several Block ACK frames from a HTP STA into one frame. It provides this in the most comprehensive way by allowing different options. The HT BA is very useful for simultaneous applications from the same WLAN device. For example, simultaneous TCP and Voice applications in enterprise devices, simultaneous VoIP and SWIS (See What I See) in consumer devices, etc. The delay and reliability requirements for the simultaneous applications are different, thus, are carried over with different TIDs. The HT BA also reduces the size of the frame, compared to regular BA, even when it is used for single TID.

The HT BA mechanism is negotiated by an exchange of HT ADDBA request/ ADDBA response frames. The HT ADDBA procedure with HT Capability set to 1 allows a HTP STA to include the corresponding TID in the HT BA mechanism. When DELBA procedure is executed, the corresponding TID is removed from the HT BA mechanism. The HT BA allows compression of HT BA to carry only MSDU bitmap. It allows for the implicit HT BA, where HT BA is sent without any HT BAR. In implict HT BA mode, two options are supported. In the first option, receiver sends BA after a threshold number of received frames. In the second option, receiver sends BA after a threshold Sequence Number.

The interpretation of HT ADDBA Request/Response and HT BA Request/ HT BA messages are mandatory on HT STAs.

## 9.12 Frame exchange sequences

***Edit Table 22.1(.11e) <HCF sequence> and replace all "=" with"-".***

***Remove definition 36 from end of Table 22.4(.11e) (no PIFS spacing defined anymore).***

***Replace the last sentence of the text in subclause 9.12 as follows(.11e) with:***

Individual frames within each of these sequences ~~are separated by a SIFS~~ may be send as part of a HTP burst transmission if the frames meet the rules identified in clause 9.16., otherwise a SIFS separation is used unless an "=" sign appears between frames in the table, in which case, PIFS is used.

***Edit Table 22 <CF frame sequences> and change field "frames in sequence" for row "Beacon(CF)" from "1" to "1 or 2" and modify legend 14 (for Beacon) as follows:***

14—"Beacon(CF)" represents a management frame of subtype Beacon with a nonzero value in the CFPDurRemaining field of its CF Parameter Set element. The optional second Beacon shall be sent after the first Beacon using a lower rate. For example, this enables STAs which are out of normal communication range to receive a Beacon.

# 9.13 Protection mechanism

***Delete two paragraphs from the text of clause 9.13 as follows:***

If a protection mechanism is being used, a fragment sequence may only employ ERP-OFDM modulation for the final fragment and control response.

The rules for calculating RTS/CTS NAV fields are unchanged when using RTS/CTS as a protection mechanism.

***Insert the following three new subclauses after clause 9.13:***

## 9.13.1 OFDM Protection

The intent of an OFDM protection mechanism is to ensure that an HTP STA does not transmit an MPDU of type Data or an MMPDU, using a Clause 20 rate which is not also a Clause 17 or Clause 19 rate unless it has attempted to update the NAV or cause a PHY-CCA.indicate(status=BUSY) to be elicited by receiving Clause 17 or Clause 19 STAs.

The updated NAV period shall be longer than or equal to the total time required to send the data and any required response frames.

The PHY-CCA.indicate(status=BUSY) shall be longer than or equal to the total time required to send the data and any required response frames.

HTP STAs shall use OFDM protection mechanisms (such as RTS/CTS or CTS-to-self employing a Clause 19 or Clause 17 rate) for Clause 20-only rate MPDUs of type Data or MMPDUs when the Use_OFDM_Protection field of transmitted or received ERP Information elements is set to 1 and the BSSID of the frame which contained the ERP Information element is the same as the BSS which the HTP STA has joined or started. Clause 19 rates shall be employed when the BSS is operating in a Clause 19 channel. Clause 17 rates shall be employed when the BSS is operating in a Clause 17 channel.

OFDM Protection mechanism frames shall conform to at least one of the following conditions:
a) The frame shall be sent using one of the mandatory Clause 19 or Clause 17 rates and using one of the mandatory Clause 17 or Clause 19 waveforms, so that all known ERP or Clause 17 STAs in the BSA will know the duration of the exchange even if they cannot detect the Clause 20 frames using their CCA function
b) The frame shall be sent using a Clause 17 preamble and signal field (additional, non-clause 17 preamble and signal field may be present following the Clause 17 preamble and signal field)
c) The frame shall be sent using a Clause 19 preamble and signal field (additional, non-clause 19 preamble and signal field may be present following the Clause 19 preamble and signal field)

In the case of a BSS composed of only HTP STAs, but with knowledge of a neighboring co-channel BSS having nHTP traffic, the AP may require either or both of protection mechanisms and OFDM protection mechanisms to protect the BSSs traffic from interference. This will provide propagation of NAV of PHY-

CCA.indicate(status=BUSY) to all associated STAs and all STAs in a neighboring co-channel BSS within range through BSS basic rate set modulated messages. Frames that propagate the NAV throughout the BSS include RTS/CTS/ACK frames, all data frames with the "more fragments" field set to 1, all data frames sent in response to PS-Poll that are not preceded in the frame sequence by a data frame with the "more fragments" field set to 1, Beacon frames with nonzero CF time, +CF-POLL frames, various QOS frames, and CF-End frames. Frames that propagate PHY-CCA.indicate(status=BUSY) throughout the BSS include any frames which commence with an appropriately chosen preamble and signal field.

If any of the rates in the BSSBasicRateSet of the OFDM protection mechanism frame transmitting STAs BSS are Clause 17 or Clause 19 rates, then the OFDM protection mechanism frames shall be sent at one of those Clause 17 or Clause 19 basic rates, unless either condition b) or condition c) from above has been met, in which case, no rate restrictions apply.

OFDM Protection Mechanisms shall not be used where the frame transmission will be protected by the Protection Mechanism defined in clause 9.13

### 9.13.2 20MHz Protection

The intent of a 20MHz protection mechanism is to ensure that a 40MHz HTP STA does not transmit an MPDU of type Data or an MMPDU as a 40MHz transmission unless it has attempted to update the NAV or cause a PHY-CCA.indicate(status=BUSY) to be elicited by receiving 20MHz HTP STAs which may be present.

The updated NAV period shall be longer than or equal to the total time required to send the data and any required response frames.

The PHY-CCA.indicate(status=BUSY) shall be longer than or equal to the total time required to send the data and any required response frames.

40MHz HTP STAs shall use 20MHz protection mechanisms (such as RTS/CTS or CTS-to-self employing a 20MHz HTP rate) for 40MHz transmissions of MPDUs of type Data or MMPDUs when the Use_20MHz_Protection field of transmitted or received ERP Information elements is set to 1 and the BSSID of the frame which contained the ERP Information element is the same as the BSS which the 40MHz HTP STA has joined or started.

20MHz Protection mechanism frames shall conform to at least one of the following conditions:
a) The frame shall be sent using one of the mandatory 20MHz HTP rates, so that all known 20MHz HTP STAs in the BSA will know the duration of the exchange even if they cannot detect 40MHz transmissions using their CCA function.
b) The frame shall be sent using a 20MHz preamble and signal field (additional, non-20MHz preamble and signal field may be present following the 20MHz preamble and signal field)

In the case of a BSS composed of only 40MHz HTP STAs, but with knowledge of a neighboring co-channel BSS having nHTP traffic, the AP may require any of clause 9.13 protection mechanisms, OFDM protection mechanisms and 20MHz protection mechanisms to protect the BSSs traffic from interference. This will provide propagation of NAV of PHY-CCA.indicate(status=BUSY) to all associated STAs and all STAs in a neighboring co-channel BSS within range through BSS basic rate set modulated messages. Frames that propagate the NAV throughout the BSS include RTS/CTS/ACK frames, all data frames with the "more fragments" field set to 1, all data frames sent in response to PS-Poll that are not preceded in the frame sequence by a data frame with the "more fragments" field set to 1, Beacon frames with nonzero CF time, +CF-POLL frames, various QOS frames, and CF-End frames. Frames that propagate PHY-CCA.indicate(status=BUSY) throughout the BSS include any frames which commence with an appropriately chosen preamble and signal field.

If any of the rates in the BSSBasicRateSet of the 20MHz protection mechanism frame transmitting STAs BSS are 20MHz rates, then the 20MHz protection mechanism frames shall be sent at one of those 20MHz basic rates, unless condition b) from above has been met, in which case, no rate restrictions apply.

OFDM Protection Mechanisms shall not be used where the frame transmission will be protected by the Protection Mechanism defined in clause 9.13

### 9.13.3 ER Protection

The support of the protection mechanisms defined in this section is mandatory for NR and ER-capable STAs. These mechanisms support both the EDCA and HCCA access as defined in IEEE802.11e.

#### 9.13.3.1 ER Protection for EDCA TXOPs

An AP transmitting to an NR STA shall first transmit an ER CTS_to_Self to set the NAV of ER STAs. To mitigate the hidden node problem, it may then send an NR RTS and wait for NR CTS from the NR STA before proceeding with its downlink NR TxOP. This frame exchange is illustrated in Figure xxyz1.




**Figure xxyz1: Protection of an EDCA NR TxOP initiated by the AP (NR RTS and NR CTS are optional)**

Likewise, an ER-capable AP transmitting to an ER STA shall first transmit an NR CTS_to_Self to set the NAV of NR STAs. To mitigate the hidden node problem, it may send an ER RTS and wait for ER CTS from the ER STA or directly proceed with the ER TxOP. This frame exchange is illustrated in Figure xxyz2.




**Figure xxyz2: Protection of an EDCA ER TxOP initiated by the AP (ER RTS and ER CTS are optional)**

This section describes the protection mechanism for EDCA TXOPs, which is based on a dual CTS response. When the Use_ER_Protection bit is set, this protection mechanism shall be activated and the CTSTimeout value shall be set according to 9.13.3.2 of this document.

A non-AP ER STA transmitting to the AP shall first send an ER RTS. The ER-capable AP shall respond to ER RTS with an NR CTS_to_Self to set the NAV of NR STAs, followed by an ER CTS to set NAV of ER STAs. The ER STA can then proceed with the ER TxOP. The NR CTS_to_Self shall protect the duration of an ER CTS, followed by the ER TxOP duration. The ER CTS shall be set to cover the whole TxOP duration. This frame exchange is illustrated in Figure xxyz3.

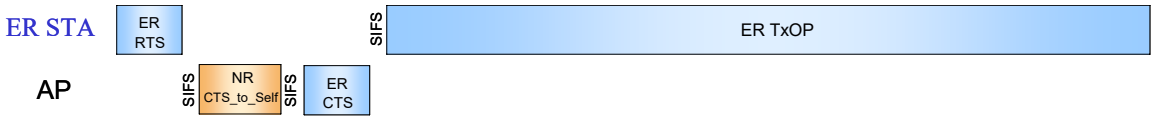



**Figure xxyz3: Protection of an EDCA ER TxOP initiated by a non-AP 802.11n STA**

Likewise, a non-AP NR STA transmitting to the AP shall first send an NR RTS. The ER-capable AP shall respond to NR RTS with an ER CTS_to_Self to set the NAV of ER STAs, followed by an NR CTS to set NAV of NR STAs. The NR STA can then proceed with the NR TxOP. The ER CTS_to_Self shall protect the duration of an NR CTS, followed by the NR TxOP duration. The NR CTS shall be set to cover the whole TxOP duration. This frame exchange is illustrated in Figure xxyz4.




**Figure xxyz4: Protection of an EDCA NR TxOP initiated by a non-AP 802.11n STA**

Legacy STAs cannot change the value of their CTS timeout. Therefore, the ER-capable AP may respond to an RTS initiated by a non-AP STA by an ER CTS_to_Self to set the NAV of ER STAs. The CTS_to_Self should protect the duration of an NR CTS, followed by a back-off and an NR RTS/CTS exchange and the whole TxOP duration. Following the ER CTS_to_Self, the AP should send a CTS addressed to the legacy STA, which prevents other NR STAs from accessing the medium. However, the CTS Timeout of the legacy STA expires and, after a back-off, the legacy STA retransmits an RTS responded by a CTS. The legacy STA can then proceed with its TxOP. The NR CTS should be set to cover a back-off and an NR RTS/CTS exchange and the whole TxOP duration. This frame exchange is illustrated in Figure xxyz5. The duration field of the subsequent NR CTS transmitted by the AP shall follow the normal rules for determining NR CTS duration values.

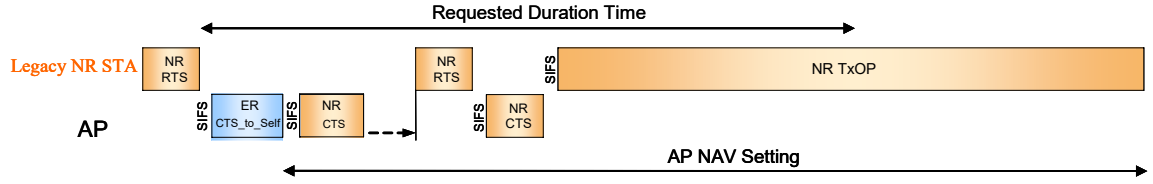



**Figure xxyz5: Protection of an EDCA NR TxOP initiated by a non-AP legacy STA**

### 9.13.3.2 Modification of the CTSTimeout for ER Protection

When the Use_ER_Protection bit is set, the CTSTimeout of all AP and STA shall be set to protect the successive transmission of an NR CTS at the lowest bit rate of the NR basic rate set plus an ER CTS at the lowest supported bit rate.

### 9.13.3.3 ER Protection for polled TXOPs

The AP shall precede NR CF-Poll by an ER CTS_to_Self, which sets the NAV of ER STAs for the whole duration of the following NR TxOP. The polled NR TxOP starts after the CF-Poll. This frame exchange is illustrated on Figure xxyz6.




**Figure xxyz6: Protection of a polled ER TxOP**

Likewise ER CF-Poll and the following ER TxOP must be protected by an NR CTS_to_Self with the duration set to protect the whole ER TxOP, as illustrated on Figure xxyz7.




**Figure xxyz7: Protection of a polled NR TxOP**

### 9.13.3.3 Alternate ER Protection mechanism (INFORMATIVE)

An alternate ER protection mechanism may be provided by the AP establishing ER transmission periods during which only ER-capable STAs are authorized to transmit, and NR transmission periods, during which ER transmissions are prohibited.

To initiate an ER transmission period, the AP sends an NR CTS_to_Self to set the NAV for all NR STAs to stop transmission for the duration of the ER transmission period. The AP continues by sending an ER CF-End which resets NAV for all ER STAs so that they can begin transmission. Within the ER transmission period, both EDCA and HCCA access are allowed. ER-capable NR STAs can decide to participate in the ER transmission time. In this case, they shall transmit only in ER modes

In order to end an ER transmission period, the AP sends an ER CTS_to_Self to set the NAV for all ER STAs to stop transmission. The AP then sends an NR CF-End to reset the NAV for all NR STAs to begin transmission. HCCA and EDCA access are allowed during the NR transmission period.

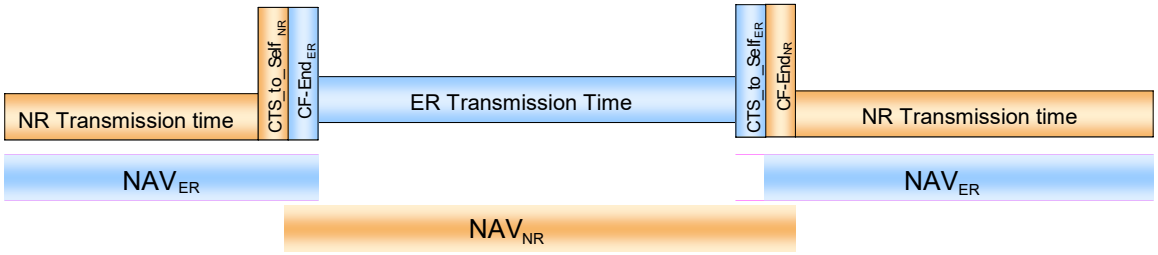



**Figure xyyz: Alternate ER/NR protection mechanism managed by AP**

***Insert new clause 9.14 and sub-clauses as follows:***

## 9.14 40 MHz Channel Pairs

Clause 20 defines a mode in which High Throughput PHYs can transmit a frame utilising a 40 MHz channel pair in order to achieve lower frame durations than if a single 20 MHz channel was used. This clause describes the MAC support for this feature in an infrastructure BSS. 40 MHz transmissions shall only be used when the STA has joined or started an Infrastructure BSS.

A 40 MHz channel pair consists of two 20 MHz channels, and a BSS operating on a 40 MHz Channel Pair will make use of one of these channels (called the primary channel) for 20 MHz transmissions. The other channel (called the secondary channel) will not be used by the BSS for 20 MHz transmissions.

### 9.14.1 40 MHz Fundamentals of Operation

A 40 MHz channel pair consists of two 20 MHz channels, on each of which there could be 20 MHz transmissions (from an overlapping BSS on either channel, or from 20 MHz transmissions on the primary channel), and on each of which the Carrier Sense mechanism described in clause 9.2.1 could be run. However, it is not possible to combine two Carrier Sense mechanisms without degrading the effective priority of 40 MHz transmissions to such an extent that they would provide no benefit.

For this reason the MAC models a 40 MHz channel pair as a single 20 MHz channel (the primary channel) in which some transmissions happen to "overflow" into the Secondary Channel.

A STA that wishes to transmit on both channels of a 40MHz channel shall conduct CCA on the primary channel, with the following extension. For any frame transmission that requires the CCA function to indicate a clear channel before transmission, the secondary channel CCA state shall also be checked. If the secondary channel CCA indicates a busy channel, the STA shall not transmit on the secondary channel. It shall either fall back to 20MHz operation (for only the current transmission), or shall consider the frame transmission to have failed (including all incrementing of retry counters and contention windows etc where required).

An AP shall indicate that it is operating on a 40 MHz channel pair by including the Channel Set information element in its Beacon frames. An AP shall not change the information contained in the Channel Set information element without invoking the channel move procedure described in clause 11.6.7. A STA that has joined a BSS and that wishes to use 40 MHz transmissions shall check the setting of the Secondary_Channel_Used bit in the ERP Information Element in the last valid Beacon frame received from the BSS, and shall not use 40 MHz transmissions where the Secondary_Channel_Used bit is set to 1.

A STA shall not send a 20 MHz transmission to a member STA of a BSS on the secondary channel of that BSS. A STA that has joined or started a BSS operating on a 40 MHz channel pair shall discard all 20 MHz transmissions received on the secondary channel. A STA shall not join a BSS on its secondary channel.

An AP that detects significant evidence of collisions on the secondary channel may invoke the channel move procedure described in clause 11.6.7.

#### 9.14.2.1 Secondary Channel Beacon

In order to reduce the chance of the secondary channel being used by an overlapping BSS, an AP may send a Beacon frame using the secondary channel with contents chosen to discourage use of the secondary channel by other BSSes.

The frame body of such a beacon is shown in Clause 7.2.3.1.1. These beacons contain a rate set consisting of a single clause 20 basic rate, and so should not cause non-clause 20 STAs to attempt to associate with the AP on the secondary channel.

When transmitting a beacon on the secondary channel, the AP may observe the channel access mechanisms described elsewhere in clause 9 for the transmission of Beacon frames, or it may transmit the Beacon frame without consideration of the state of the secondary channel.

### 9.14.3 Beacon Transmission

An AP operating on a 40 MHz channel pair shall send Beacon frames (with the exception of Secondary Channel Beacon frames) on the primary channel using a 20 MHz transmission.

### 9.14.4 Limits on Channel Numbering

Both the primary and secondary Channels shall be legal 20 MHz channels in the 5GHz band. For a primary channel number "n", the secondary channel number shall be either "n+4" or "n-4".

***Add the following new clause as clause 9.15:***

## 9.15 ER/NR Operation

Extended Range (ER) capable devices are devices which support the optional Extended Range MCS, in addition to the Normal Range (NR) MCS, and the long SIG-N field format, as defined in section 20.3.4. The Space-Time Block Code MCS with the lowest bit rate is by definition an ER MCS. Whether other MCS are considered as ER is implementation dependent. ER frames shall be transmitted with the long SIG-N field format and the REXT bit set to value 1, as described in section 20.3.4. NR devices are devices which only support the NR MCS.

A characteristic of ER MCS is that they have a longer range than NR MCS. Due to the optional nature of the ER MCS, and considering the problem of backwards compatibility with pre-802.11n devices, the AP may decide to transmit a beacon using an NR MCS. This beacon will be referred to as an NR beacon. However, for ER stations to benefit from the larger BSA, the ER capable AP may also transmit a second beacon, using an ER MCS, which is referred to as an ER beacon. ER beacons allow ER devices to find the AP and associate with it even when they are outside of the NR range. The rules for transmitting ER and NR beacons are specified in clause 11.1.2.1.

A second measure to allow for mixed mode operation of ER and NR stations is a new set of protection rules, as specified in clause 9.13.3. These rules shall be followed only when the AP sets the Use_ER_Protection bit to value 1 (similar to the legacy protection bit in 802.11g). If the Use_ER_Protection bit value is 0, the ER protection rules of clause 9.13.3 shall not be used.

# 10. Layer management

## 10.4 PLME SAP interface

### 10.4.3 PLME_CHARACTERISTICS.confirm

#### 10.4.3.2 Semantics of the service primitive

***Change the primitive description as follows:***

The primitive provides the following parameters:

```
PLME-CHARACTERISTICS.confirm(
                                aSlotTime,
                                aSIFSTime,
                                aRIFSTime,
                                aCCATime,
                                aRxTxTurnaroundTime,
                                aTxPLCPDelay,
                                aRxPLCPDelay,
```

aRxTxSwitchTime,
aTxRampOnTime,
aTxRampOffTime,
aTxRFDelay,
aRxRFDelay,
aAirPropagationTime,
aMACProcessingDelay,
aPreambleLength,
aPLCPHeaderLength,
aMPDUDurationFactor,
aMPDUMaxLength,
aCWmin,
aCWmax
)

***Add the following entry to the table:***

| | | |
|---|---|---|
| aRIFSTime | integer | The minimum time (in microseconds) that the PHY requires between PSDUs that are transmitted with differing TXPWR_LEVELs within a HTP burst transmission. |

## 10.4.4 PLME-DSSSTESTMODE.request

## 10.4.4.2 Semantics of the service primitive

***Change the sixth row in the table in 10.4.4.2 as shown:***

| | | | |
|---|---|---|---|
| DATA_RATE | Integer | 2, 4, 11, 12,<br>18, 22, 24,<br>36, 44, 48,<br>66, 72, 73-92, 96,<br>97-106, 108, 109-121 | Selects among rates and transmission modes<br>02 = 1 Mbit/s<br>04 = 2 Mbit/s<br>11 = 5.5 Mbit/s<br>12 = 6 Mbit/s<br>18 = 9 Mbit/s<br>22 = 11 Mbit/s<br>24 = 12 Mbit/s<br>36 = 18 Mbit/s<br>44 = 22 Mbit/s<br>48 = 24 Mbit/s<br>66 = 33 Mbit/s<br>72 = 36 Mbit/s<br>96 = 48 Mbit/s<br>108 = 54 Mbit/s<br>73-95, 97-107, 109-122 = See Tables 003-009 and Table 019 in subclause 20.3.2.2 and 20.3.5.10 respectively |

***Modify clause 11.1.2.1 as follows:***

## 11.1.2.1 Beacon generation in infrastructure networks

***Add the following text to the end of subclause 11.1.2.1 as a new sublcause 11.1.2.1.1:***

### 11.1.2.1.1 Beacon generation in infrastructure networks

This subclause defines the rules for the optional sending of a second beacon previously described in section 9.15. The support of these rules is mandatory for ER-capable AP.

An ER-capable AP can be configured (AP policy) to broadcast two beacons in order to enable the association of NR STAs and ER STAs. These two beacons are called NR beacon and ER beacon.

The contents of both NR and ER beacons shall be the same, except for the Timestamp and Basic Rate Set (BRS.) The Timestamp shall reflect the actual TSF timer value at the time of transmission.

The BRS signaled in the ER beacon is called the ER BRS. Management and Control frames such as beacon probe, authentication, association, RTS, CTS shall be transmitted in an MCS of the ER BRS. An ER-capable STA can associate if it supports the BRS, but it can participate in ER transmissions only if it supports the ER BRS.

The ER beacon need not be transmitted immediately after the NR beacon. The interval between NR and ER beacon is implementation dependent, and its value is signaled in the ER_Beacon_Offset field of the ERP Information element of each beacon, as described in clause 7.3.2.13. NR STAs shall ignore the value of ER_Beacon_Offset as it is primarily used by the PS ER STAs to synchronize to the TBTT time. However, the NR and ER beacon periods shall be the same. NR STAs (including PS devices) expect to receive NR beacons based on TBTT intervals as per normal TSF timing. ER STAs (including PS devices) expect to receive ER beacons at time at shifted TBTT intervals, as illustrated in Figure xyz. An ER-capable STA which is able to receive both NR and ER beacons may decide to drop all ER beacons or to drop all NR beacons.

Broadcast and multicast frames sent by the AP as part of the power savings mechanism and which follow the NR beacon shall be duplicated, such that they also follow the transmission of the ER beacon, as illustrated in Figure xyz.

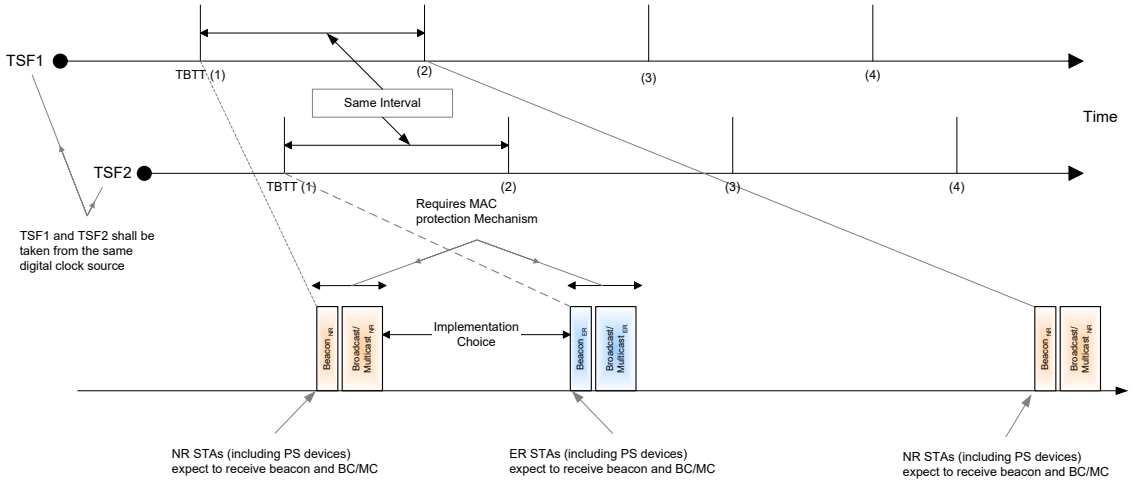



**Figure xyz: Illustration of the transmission of NR and ER beacons**

ER protection mechanisms are described in clause 9.13.3 of this document. In order to protect the NR beacon from ER transmissions, the AP sends an ER CTS_to_Self prior to the NR beacon, with the duration set to protect the transmission of the NR beacon, the NR broadcast and NR multicast frames. The ER CTS_to_Self shall be transmitted at the lowest rate of the ER BRS. Likewise, the ER beacon shall be protected from NR transmissions by an NR CTS_to_Self with the duration set to protect the ER beacon, the ER broadcast and ER multicast frames. NR STAs which are ER-capable may decide to drop duplicated broadcast/multicast frames.

With the exception of the value contained in the Timestamp fixed field, the content of the ER and NR beacons is the same.

ER STAs may use a dual probe request for active scanning, by transmitting both an ER and an NR probe request frame on the same channel.

# 11.5.1 Set up and modification of the Block Ack parameters

***Update the text to as follows:***

Block Ack may be set up at the MAC (see 9.10.2) or by the initiation of SME. The mechanism to set up HT Block ACK (see 9.10.6) at the initiation of the SME is similar to the mechanism used to set up Block Ack and, it is as described in this subclause.

11.5.1.3 Set up and modification of HT Block Ack parameters

The procedure for setting up and modifying HT Block Ack parameters is similar to the procedure shown in 11.5.1.1. However, the procedure is initiated by HT STA. If the originator is aware that the receiver is a HT STA it would initiate HT Block Ack instead of Block Ack procedure. However, if the HT Block Ack procedure fails, then the sender falls back to Block Ack procedure as described in section 11.5.1.1

Upon receipt of MLME-HTADDBA.request,m an initiating HT STA that intends to QoS type Data frames under the HT Block Ack mechanism shall set up the HT Block Ack using the following procedure.

a) Check if the intended peer HT STA is capable in the HT Block Ack mechanism by discovering and examining its “Block Ack” capability bit. Note that, if a HT STA sets it’s Block Ack capability it is assumed that HT STA can support HT Block Ack and Block Ack. If the recipient is capable of participating, the originator sends an HT ADDBA frame as described in section 7.4.4.4

b) If an HT ADDBA response frame is received with the matching Dialog Token and the TID, and with a Status Code set to a value of 0, the HT STA has established HT Block Ack mechanism with the recipient HT STA and the MLME shall issue an MLME-HTADDBA.confirm indicating the successful completion of the HT Block Ack set up.

c) If an HT ADDBA response frame is received with the matching Dialog Token and the TID, and with a Status Code to a value other than 0, the HT STA has not established Block Ack mechanism with recipient HT STA and the MLME shall issue and MLME-HTADDBA.confirm indicating the failure of the HT Block Ack set up.

d) If there is no response from the recipient with dot11HTADDBAFailureTimeout, the HT STA has not established HT Block Ack mechanism with the recipient HT STA and the MLME shall issue an MLME-HTADDBA.confirm with ResultCode “TIMEOUT”

11.5.1.4 Procedure at the HT Block Ack request recipient

A recipient shall operate as follows in order to support HT Block Ack initialisation and modification.

a) Whenever an HT ADDBA request frame is received from another HT STA, the MLME shall issue an MLME-ADDBA.indication.

b) Upon receipt of the MLME-HTADDBA.response, the HT STA s shall respond by an HT ADDBA response frame with a Result code as defined in 7.4.4.5

a. If the ResultCode is "SUCCESS" the HT Block Ack is considered to be established with the originator. Contained in the frame are the type of HT Block Ack and the, number of buffers, Maximum Bit map length

b. If the ResultCode is "REFUSED" the Block Ack is not considered to have been established.

The encoding of the ResultCode values to Status Code field values are defined in Table 26.4

***Update section 11.5.2 to include the following:***

Mechanism proposed for Block Ack Teardown procedures are the same for HT Block Ack teardown.

## 11.6.7 Selecting and advertising a new channel

### 11.6.7.1 Selecting and advertising a new channel in an infrastructure BSS

***Add the following text to the end of the section:***

When an HTP AP supports 40MHz operation, it is allowed to use the N-DFS procedure to determine if a channel change will be made. There are three possible transitions that can be made as a result of an N-DFS decision to change channels:

1. Transition from a 20MHz channel to a 40MHz channel
2. Transition from a 40MHz channel pair to a different 40MHz channel pair
3. Transition from a 40MHz channel pair to a 20 MHz channel

The required behavior regarding the propagation of the new channel information for each of the three transitions is described in the next sections.

All 40MHz HTP STAs shall support the reception of the New Secondary Channel Number information element.

#### 11.6.7.1.1 N-DFS Transition from a 20MHz to a 40MHz channel pair or from a 40MHz channel pair to a different 40MHz channel pair

When an AP decides to switch from a 20MHz channel to a 40MHz channel pair or from a 40MHz channel pair to a different 40MHz channel pair, the AP shall announce this decision by indicating the new channel information in Beacon, Probe Response and Channel Swtich Announcement frames. The new primary channel number shall be indicated in the New Channel Number field in the Channel Switch Announcement information element and the new secondary channel number shall be indicated in the New Secondary Channel Number information element.

#### 11.6.7.1.2 N-DFS Transition from a 40MHz channel pair to a 20MHz channel

When an AP decides to switch from a 40MHz channel pair to a 20MHz channel, the AP shall announce this decision by indicating the new channel information in Beacon, Probe Response and Channel Swtich Announcement frames. The new channel number shall be indicated in the New Channel Number field in the Channel Switch Announcement information element. The original secondary channel will no longer be used, so there will be no new secondary channel number, and as such, the Secondary Channel Number field of the New Secondary Channel Number element shall be set to 0, when the New Secondary Channel Number element is included in transmitted Beacon, Probe Response or Channel Switch Announcement frames. Inclusion of the New Secondary Channel Number element is optional in this case.

# 20. High throughput PHY specification for the 2.4 and 5 GHz bands

## 20.1 Overview

This clause specifies the PHY entity for a multiple input multiple output orthogonal frequency division multiplexing (MIMO-OFDM) system and the additions that have to be made to the base standard to accommodate the MIMO-OFDM PHY. The radio frequency LAN system is aimed for both the 2.4 GHz band and the 5 GHz bands, as specified in subclause 20.3.8.3

### 20.1.1 Introduction

The MIMO-OFDM system provides a wireless LAN with mandatory data payload communication capabilities of up to 135 Mbit/s and with optional modes capable of supporting data rates up to 540 Mbit/s. The MIMO-OFDM PHY draws from the basic OFDM PHY defined in Clause 17, and builds its extensions to two, three, and four transmit antenna modes (hereafter known as 2TX, 3TX, and 4TX, respectively), operating in 20 MHz bandwidth. Additionally, 1TX, 2TX, 3TX, and 4TX modes are also defined for operation in 40 MHz bandwidth.

### 20.1.2 Operational Modes

The radio portion of all Clause 20 compliant MIMO-OFDM PHY systems shall implement all mandatory and optional data rates defined in Clause 17, all mandatory data rates defined in Clause 19, and all optional data rates of the OFDM-based ERP defined in Clause 19, in their respective bands of operation. In addition, support for transmitting and receiving data using the MIMO-OFDM PHY defined in this Clause is mandatory for all rates specified for the 2TX, 20 MHz mode in subclause 20.3.2.2. Support for 3TX and 4TX modes in 20 MHz; 1TX, 2TX, 3TX, and 4TX modes in 40 MHz; and all modes defined in subclause 20.3.5.10 shall be optional.

Furthermore, the amendment extends the optional ‘half-clocked’ operation with 10 MHz channel spacings described in Section 17 and Annex J to high throughput modes. For each mode offered at 20 MHz channel spacing, a corresponding mode with half the data rate is offered with 10 MHz channel spacing. Support of the 27, 40.5, 54, 60.75, and 67.5 Mbps modes corresponding to the modes in Table 003 is mandatory when using 10 MHz channel spacing.

### 20.1.3 Scope

This subclause describes the PHY services provided to the IEEE 802.11 wireless LAN MAC by the MIMO-OFDM system. The MIMO-OFDM PHY layer consists of two protocol functions, defined as follows:

a) A PHY convergence function, which adapts the capabilities of the physical medium dependent (PMD) system to the PHY service. This function is supported by the physical layer convergence procedure (PLCP), which defines a method of mapping the IEEE 802.11 PHY sublayer service data units (PSDU) into a framing format suitable for sending and receiving user data and management information between two or more stations using the associated PMD system.

b) A PMD system whose function defines the characteristics and method of transmitting and receiving data through a wireless medium between two or more stations, each using the MIMO-OFDM PHY.

### 20.1.4 MIMO-OFDM PHY functions

The architecture of the MIMO-OFDM PHY is depicted in the ISO/IEC basic reference model shown in Figure 141 of 18.4.1. The MIMO-OFDM PHY contains three functional entities: the PMD function, the PHY convergence function (PLCP), and the layer management function.

The MIMO-OFDM PHY service is provided to the MAC through the PHY service primitives defined in Clause 12. Interoperability is addressed by use of the carrier sense mechanism specified in 9.2.1 and the protection mechanism in 9.10. This mechanism allows non-MIMO-OFDM stations to know of MIMO-OFDM traffic that they cannot demodulate so they may defer the medium to that traffic.

## 20.2 PHY-specific service parameter list

The architecture of the IEEE 802.11 MAC is intended to be PHY independent. Some PHY implementations require PHY-dependent MAC state machines running in the MAC sublayer in order to meet certain PMD requirements. The PHY-dependent MAC state machine resides in a sublayer defined as the MAC sublayer management entity (MLME). In certain PMD implementations, the MLME may need to interact with the PLME as part of the normal PHY SAP primitives. These interactions are defined by the PLME parameter list currently defined in the PHY service primitives as TXVECTOR and RXVECTOR. The list of these parameters, and the values they may represent, are defined in the specific PHY specifications for each PMD. This subclause addresses the TXVECTOR and RXVECTOR for the MIMO-OFDM PHY.

The parameters in Table 001 are defined as part of the TXVECTOR parameter list in the PHY-TXSTART.request service and PLME-TXTIME.request primitives.

**Table 001—TXVECTOR parameters**

| Parameter | Value |
|---|---|
| DATARATE | The rate used to transmit the PSDU in Mbit/s. Allowed value depends on the values of TRANSMISSION_MODE and NUM_STREAMS parameters<br><br>Values: 6.75, 10.125, 13.5, 20.25, 27, 40.5, 54, 60.75, 67.5, 81, 108, 121.5, 135, 162, 182.25, 202.5, 216, 243, 270, 324, 364.5, 405, 432, 486, 540 |
| LENGTH | The length of the PSDU in octets<br><br>Range: 1-8191 |
| TRANSMISSION_MODE | The mode used for transmission of the PPDU. Determines the preamble type used.<br><br>Enumerated type: 2TX20GF, 3TX20GF, 4TX20GF, 2TX20MM, 3TX20MM, 4TX20MM, 1TX40GF, 2TX40GF, 3TX40GF, 4TX40GF, 1TX40MM, 2TX40MM, 3TX40MM, 4TX40MM. |
| NUM_STREAMS | The number of independent spatial streams transmitted.<br><br>Values: 1, 2, 3, 4. |
| CODE_TYPE | Convolutional or LDPC<br><br>Values: 0 (convolutional), 1 (LDPC) |
| SERVICE | The scrambler initialization vector.<br><br>16 null bits |

| | |
|---|---|
| TXPWR_LEVEL | The transmit power level. The definition of these levels is up to the implementer.<br><br>Range: 1-8 |
| LPI | Indicates that this is the last PSDU to be aggregated into the current PPDU<br><br>Values: true, false |
| BURST_ DURATION | The length in microseconds of the BURST_DURATION field in the mixed-mode preamble. Only used when a mixed-mode TRANSMISSION_MODE is selected.<br><br>Range: 0-4095 |

The parameters in Table 002 are defined as part of the RXVECTOR parameter list in the PHY-RXSTART.indicate service primitive. When implementations require the use of these vectors, some or all of these parameters may be used in the vectors.

**Table 002—RXVECTOR parameters**

| Parameter | Value |
|---|---|
| DATARATE | The rate at which the PSDU was received in Mbit/s. Allowed value depends on the values of TRANSMISSION_MODE and NUM_STREAMS parameters<br><br>Values: 6.75, 10.125, 13.5, 20.25, 27, 40.5, 54, 60.75, 67.5, 81, 108, 121.5, 135, 162, 182.25, 202.5, 216, 243, 270, 324, 364.5, 405, 432, 486, 540 |
| LENGTH | The length of the PSDU in octets.<br><br>Range: 1-8191 |
| TRANSMISSIO N_MODE | The transmission type detected during reception of the PPDU<br><br>Enumerated type: 2TX20GF, 3TX20GF, 4TX20GF, 2TX20MM, 3TX20MM, 4TX20MM, 1TX40GF, 2TX40GF, 3TX40GF, 4TX40GF, 1TX40MM, 2TX40MM, 3TX40MM, 4TX40MM. |
| NUM_STREAM S | The number of independent spatial streams transmitted.<br><br>Values: 1,2,3,4. |
| CODE_TYPE | Convolutional or LDPC<br><br>Values: 0 (convolutional), 1 (LDPC) |
| SERVICE | Null |
| RSSI | The RSSI is a measure of the RF energy received by the MIMO-OFDM PHY, averaged across all RX antennas. The 8-bit value is in the range of 0 to RSSI maximum as described in 17.2.3.2. |
| LPI | Indicates that this is the last PSDU to be aggregated into the current PPDU<br><br>Values: true, false |
| BURST_ DURATION | The length in microseconds of the BURST_DURATION field in the mixed-mode preamble. Only valid when a mixed-mode TRANSMISSION_MODE is used.<br><br>Range: 0-4095 |

# 20.3 MIMO-OFDM PLCP sublayer

## 20.3.1 Introduction

This subclause provides a convergence procedure by which PSDUs are converted to and from PPDUs at the transmitter and receiver. During transmission, the PSDU shall be appended with a PLCP preamble and header to create the PPDU. At the receiver, the PLCP preamble and header are processed to aid in the demodulation and delivery of the PSDU.

Stations implementing the MIMO-OFDM PHY shall use one of two methods of access to the medium. The medium may be reserved solely via a MAC mechanism, as defined in subclause 9.13. Alternatively, a special PLCP frame format may be used to cause non-MIMO-OFDM stations to defer the medium to MIMO-OFDM traffic. Hereafter, these two methods of access shall be known as greenfield and mixed-mode, respectively.

## 20.3.2 PLCP frame format

Figure 001 shows the format of the PPDU used with greenfield access in the 1TX mode of operation in 40 MHz and the 2TX modes of operation in both 20 and 40 MHz. The PPDU consists of a MIMO-OFDM PLCP preamble, MIMO-OFDM PLCP header, PSDU, and may consist of appended tail bits and pad bits.

The MIMO-OFDM PLCP preamble is composed of a sequence of short and long training symbols. The format of the PLCP preamble is defined in subclause 20.3.3 for each mode of operation in the MIMO-OFDM PHY.

The MIMO-OFDM PLCP header is composed of the SIGNAL-N field and the SERVICE field. The SIGNAL-N field is defined in 20.3.4 and consists of 54 bits that specify all configuration and length-related parameters associated with PPDU transmission. The SERVICE field is composed of 16 bits and is defined in subclause 20.3.5.1.

The SERVICE field of the PLCP header and the PSDU (with tail and pad bits appended, if necessary) are denoted as DATA and may constitute multiple MIMO-OFDM symbols. These symbols are transmitted according to the configuration parameters specified in the SIGNAL-N field.

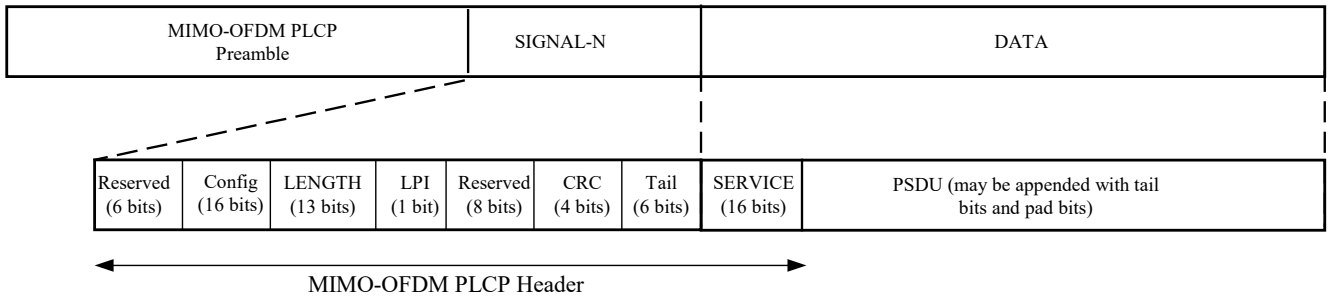



**Figure 001 – PPDU frame format: Greenfield access in the 1TX (40 MHz) and 2TX (20 and 40 MHz) modes**

Figure 002 shows the format of the PPDU used with greenfield access in the 3TX and 4TX modes of operation in both 20 and 40 MHz. In these modes the MIMO-OFDM PLCP preamble field is extended according to subclause 20.3.3 in order to provide training from the additional transmit antennas.

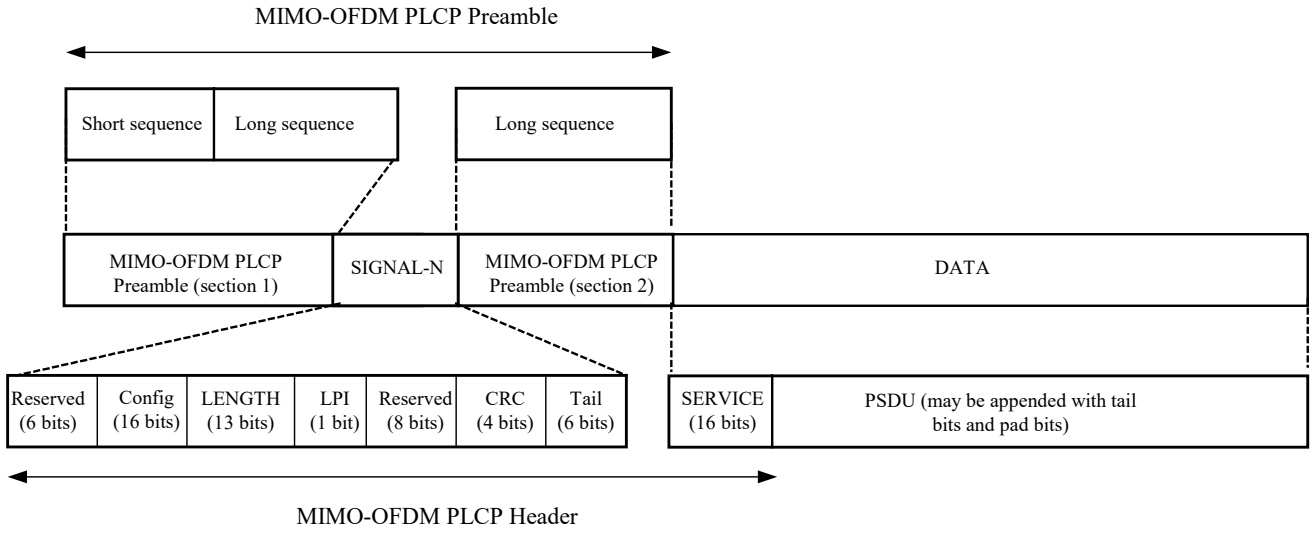



**Figure 002 – PPDU frame format: Greenfield access in the 3TX and 4TX modes (20 and 40 MHz)**

Figure 003 shows the format of the PPDU used with mixed-mode access in the 1TX mode of operation in 40 MHz and the 2TX modes of operation in both 20 and 40 MHz. The PLCP header in these modes consists of an additional SIGNAL-MM field that conveys information about the MIMO-OFDM PPDU transmission to non-MIMO-OFDM stations, causing them to defer the medium for the duration of the MIMO-OFDM transmission. The SIGNAL-MM field is defined in subclause 20.3.4.

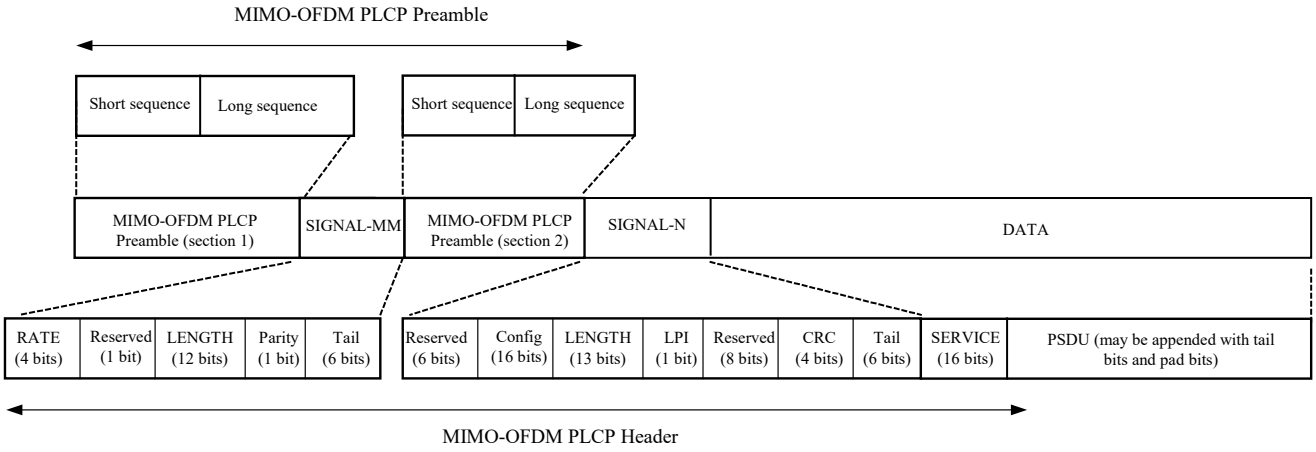



**Figure 003 – PPDU frame format: Mixed-mode access in the 1TX (40 MHz) and 2TX (20 and 40 MHz) modes**

Figures 004 and 005 shows the format of the PPDU used with mixed-mode access in the 3TX and 4TX modes, operating in 20 MHz and 40 MHz, respectively.

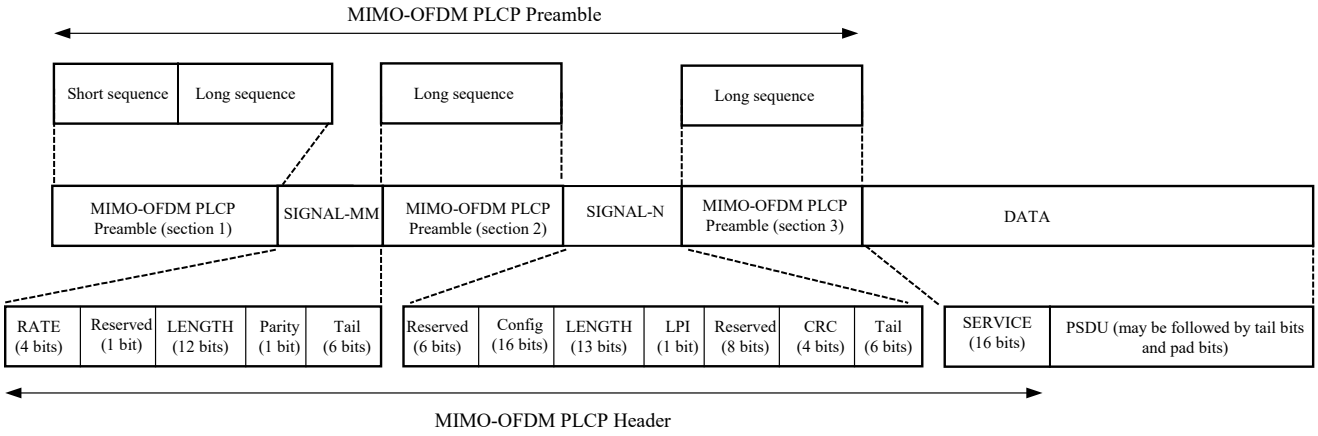



**Figure 004– PPDU frame format: Mixed-mode access in the 3TX and 4TX modes (20 MHz)**

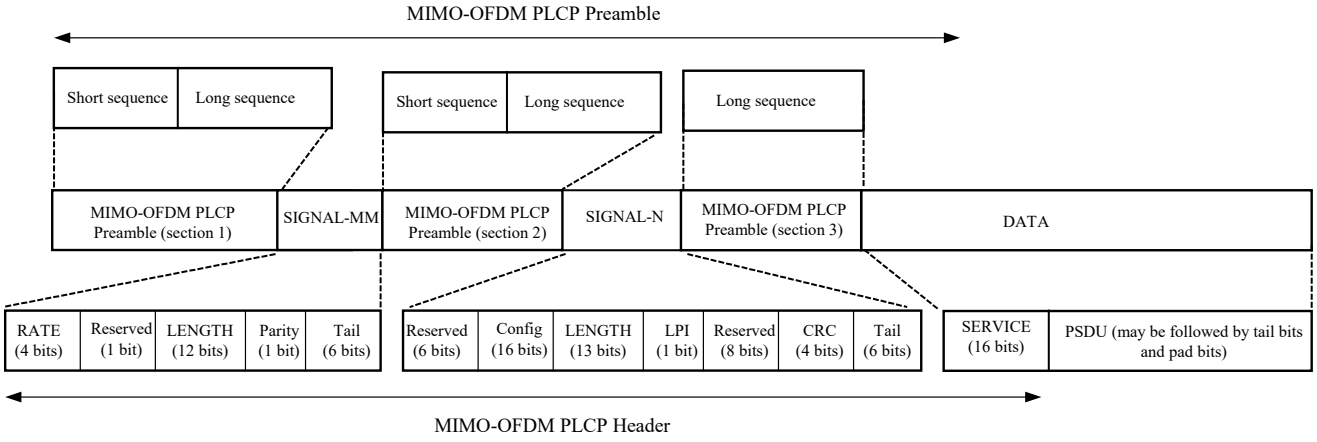



**Figure 005– PPDU frame format: Mixed-mode access in the 3TX and 4TX modes (40 MHz)**

### 20.3.2.1 Overview of the PPDU encoding process

The encoding process is composed of many detailed steps, which are described fully in later subclauses, as noted below. The following overview intends to facilitate understanding the details described in these subclauses:

a) Produce the PLCP preamble fields for each transmit antenna based on the TRANSMISSION_MODE field of the TXVECTOR. Refer to 20.3.3 for details.

b) Produce the PLCP header field from the LENGTH, DATARATE, TRANSMISSION_MODE, NUM_STREAMS, CODE_TYPE, and SERVICE fields of the TXVECTOR by filling the appropriate bit fields, as described in subclause 20.3.4 and subclause 20.3.5.1.

c) Calculate from the DATARATE, TRANSMISSION_MODE, and NUM_STREAMS fields of the TXVECTOR, the number of data bits per MIMO-OFDM symbol ($N_{DBPS}$), the code rate (R), the number of bits in each OFDM subcarrier per antenna ($N_{BPSC}$), the number of coded bits per MIMO-OFDM symbol ($N_{CBPS}$), the number of spatial streams ($N_{SS}$), and the number of encoding streams ($N_{ES}$).

d) Extend the data bit string with “zero” bits (at least 6 bits for each encoding stream) so that the resulting length will be a multiple of the number of data bits per OFDM symbol ($N_{DBPS}$).

e) Initiate the scrambler with a pseudorandom non-zero state; generate a sequence of scrambled data bits as defined in subclause 20.3.5.4.

f) Demultiplex every other bit of the "data" to the $N_{ES}$ encoding streams, with bit 0 directed to the first encoder.

g) Replace the six scrambled "zero" bits following the "data" of each parallel encoding stream with six nonscrambled "zero" bits (These bits return the convolutional encoder to the "zero state" and are denoted as "tail bits.").

h) Encode each extended, scrambled parallel encoding stream data string with a convolutional encoder (R = 1/2). Omit (puncture) some of the encoder output string (chosen according to "puncturing pattern") to reach the desired "code rate", as defined in subclause 20.3.5.5.

i) Divide the parallel encoded bit strings into groups of $N_{CBPS} / N_{ES}$ bits and multiplex them alternately between the $N_{ES}$ encoders' outputs to obtain a single aggregated bit string.

j) Divide the aggregated bit string into groups of $N_{CBPS}$ bits. Within each group, perform an "interleaving" (reordering) of the bits according to the rule specified in subclause 20.3.5.6. The interleaving parameters are independent of $N_{ES}$.

k) Divide the resulting coded and interleaved data string into groups of $N_{BPSC}$ bits. For each of the bit groups, convert the bit group into a complex number according to the modulation encoding tables.

l) Divide the complex number string into groups of $N_{SD} \times N_{SS}$ complex numbers, where $N_{SD}$ is the number of data subcarriers per OFDM symbol, and $N_{SS}$ is the number of spatial streams to be transmitted. Map the complex numbers to antennas and subcarriers, as specified in subclause 20.3.5.8. The first $N_{SD}$ complex numbers are modulated on the subcarriers of the first transmit antenna.

m) Insert $N_{SP}$ subcarriers as pilots on each transmit antenna, according to subclause 20.3.5.9.

n) For each group of subcarriers, and on each TX antenna, convert the subcarriers to time domain using inverse Fourier transform. Prepend to the Fourier-transformed waveform a circular extension of itself thus forming a guard interval (GI), and truncate the resulting periodic waveform to a single OFDM symbol length by applying time domain windowing. Refer to 20.3.2.4 for details.

o) Append the OFDM symbols for each antenna one after another, starting with the SIGNAL symbols defined in subclause 20.3.4, and with fields of the PLCP preamble inserted in between if necessary. Refer to 20.3.3 for details.

p) Up-convert the resulting "complex baseband" waveform on each antenna to an RF frequency according to the center frequency of the desired channel and transmit. Refer to 20.3.2.4 and 20.3.8.1 for details.

#### 20.3.2.2 RATE-dependent parameters

When the number of transmitted spatial streams $N_{SS}$ is equal to the number of transmit antennas $N_{TX}$, the RATE-dependent modulation parameters shall be set according to the values defined in Tables 003, 004, and 005 respectively for the 2TX, 3TX, and 4TX modes in 20 MHz. The RATE-dependent parameters for the 1TX, 2TX, 3TX, and 4TX modes in 40 MHz shall be set according to the values defined in Tables 006, 007, 008, and 009, respectively.

The number of parallel encoding streams $N_{ES}$ shall be 2 for all modes in 40 MHz in which the number of spatial streams $N_{SS}$ is greater than two. $N_{ES}$ shall be 1 for all other modes.

**Table 003—Rate-dependent parameters for 20 MHz, $N_{SS}$ = 2 ($N_{ES}$ = 1)**

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data sub-carriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 54 | 16-QAM | 1/2 | 4 | 54 | 2 | 432 | 216 | 73 |
| 81 | 16-QAM | 3/4 | 4 | 54 | 2 | 432 | 324 | 74 |
| 108 | 64-QAM | 2/3 | 6 | 54 | 2 | 648 | 432 | 75 |
| 121.5 | 64-QAM | 3/4 | 6 | 54 | 2 | 648 | 486 | 76 |
| 135 | 64-QAM | 5/6 | 6 | 54 | 2 | 648 | 540 | 77 |

**Table 004—Rate-dependent parameters for 20 MHz, $N_{SS}$ = 3 ($N_{ES}$ = 1)**

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data sub-carriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 81 | 16-QAM | 1/2 | 4 | 54 | 2 | 648 | 324 | 78 |
| 121.5 | 16-QAM | 3/4 | 4 | 54 | 2 | 648 | 486 | 79 |
| 162 | 64-QAM | 2/3 | 6 | 54 | 2 | 972 | 648 | 80 |
| 182.25 | 64-QAM | 3/4 | 6 | 54 | 2 | 972 | 729 | 81 |
| 202.5 | 64-QAM | 5/6 | 6 | 54 | 2 | 972 | 810 | 82 |

**Table 005—Rate-dependent parameters for 20 MHz, $N_{SS}$ = 4 ($N_{ES}$ = 1)**

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data sub-carriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 108 | 16-QAM | 1/2 | 4 | 54 | 2 | 864 | 432 | 83 |
| 162 | 16-QAM | 3/4 | 4 | 54 | 2 | 864 | 648 | 84 |
| 216 | 64-QAM | 2/3 | 6 | 54 | 2 | 1296 | 864 | 85 |
| 243 | 64-QAM | 3/4 | 6 | 54 | 2 | 1296 | 972 | 86 |
| 270 | 64-QAM | 5/6 | 6 | 54 | 2 | 1296 | 1080 | 87 |

**Table 006—Rate-dependent parameters for 40 MHz, $N_{SS}$ = 1 ($N_{ES}$ = 1)**

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data sub-carriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 13.5 | BPSK | 1/2 | 1 | 108 | 4 | 108 | 54 | 88 |
| 20.25 | BPSK | 3/4 | 1 | 108 | 4 | 108 | 81 | 89 |
| 27 | QPSK | 1/2 | 2 | 108 | 4 | 216 | 108 | 90 |
| 40.5 | QPSK | 3/4 | 2 | 108 | 4 | 216 | 162 | 91 |
| 54 | 16-QAM | 1/2 | 4 | 108 | 4 | 432 | 216 | 92 |
| 81 | 16-QAM | 3/4 | 4 | 108 | 4 | 432 | 324 | 93 |
| 108 | 64-QAM | 2/3 | 6 | 108 | 4 | 648 | 432 | 94 |
| 121.5 | 64-QAM | 3/4 | 6 | 108 | 4 | 648 | 486 | 95 |
| 135 | 64-QAM | 5/6 | 6 | 108 | 4 | 648 | 540 | 97 |

**Table 007—Rate-dependent parameters for 40 MHz, $N_{SS}$ = 2 ($N_{ES}$ = 1)**

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data sub-carriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 108 | 16-QAM | 1/2 | 4 | 108 | 4 | 864 | 432 | 98 |
| 162 | 16-QAM | 3/4 | 4 | 108 | 4 | 864 | 648 | 99 |
| 216 | 64-QAM | 2/3 | 6 | 108 | 4 | 1296 | 864 | 100 |
| 243 | 64-QAM | 3/4 | 6 | 108 | 4 | 1296 | 972 | 101 |
| 270 | 64-QAM | 5/6 | 6 | 108 | 4 | 1296 | 1080 | 102 |

**Table 008—Rate-dependent parameters for 40 MHz, $N_{SS}$ = 3 ($N_{ES}$ = 2)**

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data sub-carriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 162 | 16-QAM | 1/2 | 4 | 108 | 4 | 1296 | 648 | 103 |
| 243 | 16-QAM | 3/4 | 4 | 108 | 4 | 1296 | 972 | 104 |
| 324 | 64-QAM | 2/3 | 6 | 108 | 4 | 1944 | 1296 | 105 |
| 364.5 | 64-QAM | 3/4 | 6 | 108 | 4 | 1944 | 1458 | 106 |
| 405 | 64-QAM | 5/6 | 6 | 108 | 4 | 1944 | 1620 | 107 |

**Table 009—Rate-dependent parameters for 40 MHz, $N_{SS}$ = 4 ($N_{ES}$ = 2)**

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data sub-carriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 216 | 16-QAM | 1/2 | 4 | 108 | 4 | 1728 | 864 | 109 |
| 324 | 16-QAM | 3/4 | 4 | 108 | 4 | 1728 | 1296 | 110 |
| 432 | 64-QAM | 2/3 | 6 | 108 | 4 | 2592 | 1728 | 111 |
| 486 | 64-QAM | 3/4 | 6 | 108 | 4 | 2592 | 1944 | 112 |
| 540 | 64-QAM | 5/6 | 6 | 108 | 4 | 2592 | 2160 | 113 |

#### 20.3.2.3 Timing related parameters

Table 010 is a list of timing parameters associated with the MIMO-OFDM PLCP.

**Table 010—Timing-related parameters**

| Parameter | Value (20 MHz modes) | Value (40 MHz modes) | Remarks |
|---|---|---|---|
| $N_{SD}$ : Number of data subcarriers | 54 | 108 | |
| $N_{SP}$ : Number of pilot subcarriers | 2 | 4 | |
| $N_{ST}$ : Number of subcarriers, total | 56 | 112 | $N_{ST} = N_{SD} + N_{SP}$ |
| $N_{OT}$: Index of outermost populated subcarrier | 28 | 58 | |
| $N_{TX}$: Number of transmit antennas | 2,3,4 | 1,2,3,4 | |
| $\Delta_F$: Subcarrier frequency spacing | 0.3125 MHz | 0.3125 MHz | $\Delta_F = 20/64 = 40/128$ MHz |
| $T_{FFT}$ : IFFT/FFT period | 3.2 μs | 3.2 μs | $T_{FFT} = 1/\Delta_F$ |
| $T_{GI}$ : GI duration | 0.8 μs | 0.8 μs | ($T_{FFT}$ /4) |
| $T_{GI2}$ : Training symbol guard duration | 1.6 μs | 1.6 μs | |
| $T_{SYM}$ : Symbol interval | 4 μs | 4 μs | ($T_{GI} + T_{FFT}$ ) |

#### 20.3.2.4 Mathematical conventions in the signal descriptions

The transmitted signal will be described in a complex baseband signal notation. The RF (radio frequency) signal issued from the antenna is related to the complex baseband signal by the following relation:

$$r_{RF}(t) = \mathrm{Re}\{r(t)\exp(j2\pi f_c t)\} \quad (1)$$

where Re(.) represents the real part of the complex argument, and $f_c$ denotes the carrier frequency. The actual RF signal over the air is the sum of RF signals emanated from each transmit antenna.

The transmitted baseband signal from any antenna is composed of contributions from several OFDM symbols, including preamble, signal, and data. Each symbol is constructed as an inverse Fourier transform of a set of coefficients $C_k$, with $C_k$ defined later as data, pilots, or training symbols in subclause 20.3.3 through 20.3.5:

$$r_{SYMBOL}(t) = w_{SYMBOL}(t)\sum_{k=-N_{OT}}^{N_{OT}} C_k \exp(j2\pi k\Delta_F(t - T_{GUARD})). \quad (2)$$

The parameters $\Delta_F$ and $N_{OT}$ are defined in Table 010. The resulting waveform is periodic with a period of $T_{FFT} = 1/\Delta_F$. Shifting the time by $T_{GUARD}$ creates the "cyclic prefix" used in OFDM to avoid ISI from the previous symbol. Three kinds of $T_{GUARD}$ are defined: for the short training sequence (= 0μs), for the long training sequence (=$T_{GI2}$), and for data OFDM symbols (=$T_{GI}$). Informative considerations related to the windowing function $w_{SYMBOL}(t)$ and other implementation aspects, as specified in subclause 17.3.2.4, may also apply on a per-antenna basis in the MIMO-OFDM PHY.

The common way to implement the inverse Fourier transform, as shown in Equation (2), is by an inverse Fast Fourier Transform (IFFT) algorithm. If, for example, a 128-point IFFT is used to implement the 40 MHz transmission modes, the coefficients 3 to 58 are mapped to the same numbered IFFT inputs, while the coefficients

-58 to -3 are copied into IFFT inputs 70 to 125. The rest of the inputs, 59 to 69, 1, 2, 126, 127, as well as the 0 (dc) input, shall be set to zero. This mapping is illustrated in Figure 006. After performing an IFFT, the output is cyclically extended to the desired length.

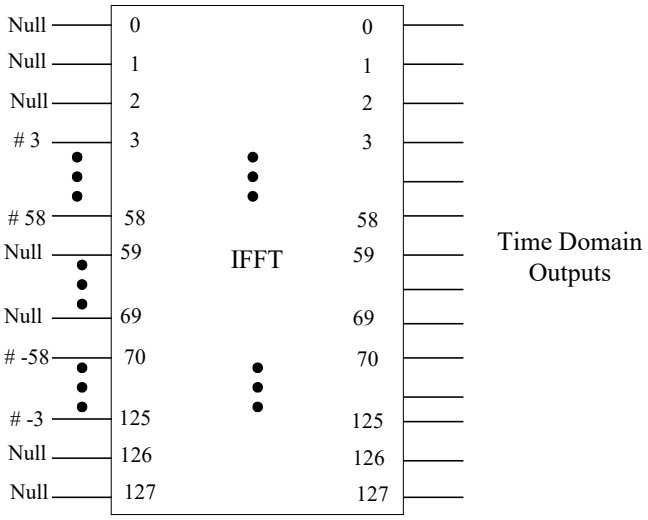



**Figure 006– Inputs and outputs of 128-point IDFT for 40 MHz data transmission**

### 20.3.3 PLCP preamble (SYNC)

The PLCP preamble field is used for synchronization. It consists of a sequence of short symbols and long symbols that are transmitted simultaneously from all transmit antennas, as described in this subclause.

Figure 007 shows the PLCP preamble format for greenfield 2TX mode in 20 MHz. The PLCP preamble is followed in this mode by the SIGNAL-N field and DATA. The total duration of the training symbols is 16 μsec. The short MIMO-OFDM training sequence transmitted from the first antenna consists of 12 subcarriers, which are modulated by elements of the sequence $SS_{20}$, given by

$SS_{20}[-28,28] = \sqrt{7/3} \times$ {0, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, –1–j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 0}. (3)

The second antenna transmits a cyclically shifted version of the sequence transmitted from the first antenna, such that the first sample of the short sequence transmitted from the first antenna is the sample that is transmitted 400 nsec after the start of the short sequence on the second antenna. This is denoted by "(400 ns cs)" in Figure 007. More generally, an indicator "S ($t_0$ ns cs)" in Figures 007 through 016 denotes that the transmitted sequence $r'(t)$ is obtained by cyclically shifting by $t_0$ nsec, the time-domain sequence $r(t)$ corresponding to frequency domain sequence S:

$$r'(t) = r(t - t_0 \text{ ns}). \quad (4)$$

The indicator "GI" or "GI2" in these figures denotes respectively the last $T_{GI}$ or $T_{GI2}$ duration of waveform of the immediately ensuing OFDM symbol, prepended to the OFDM symbol as a guard interval.

The short sequence is followed by a long OFDM training sequence which is generated by modulating the elements of the sequence

$LS_{20}$[-28..28] = {1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 0, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, -1, -1} (5)

according to the equation

$$r_{LONG}(t) = w_{TLONG}(t) \sum_{k=-N_{ST}/2}^{N_{ST}/2} LS_{20}[k] \exp\left(j2\pi k\Delta_F\left(t - T_{GI2}\right)\right), \quad (6)$$

where $T_{GI2}$ = 1.6 μsec. Two periods of the long symbol are transmitted for improved channel estimation accuracy. The long training sequence is also transmitted simultaneously from both antennas. The second antenna transmits a 1600 nsec cyclically shifted version of the long training symbols transmitted from the first antenna.

The PLCP preamble format for 2TX mixed-mode operation in 20 MHz is shown in Figure 008. The definition of the long and short sequences, as well as relative cyclic shifts between transmit antennas in this mode shall follow the description provided in Figure 008. The first and second TX antennas simultaneously transmit the first and second rows respectively of the MIMO-OFDM training structure shown in the figure.

Figure 009 and 010 define the PLCP preamble format for the 3TX and 4TX modes in 20 MHz, with greenfield access and mixed-mode access respectively. In the 3TX modes, only the first three rows shown in the corresponding MIMO-OFDM training structure are transmitted.

Figures 011, 013, and 015 show the PLCP preamble format for the 1TX, 2 TX, and 3TX/4TX greenfield modes in 40 MHz. The short sequence in these modes are obtained by modulating the elements of the sequence

$SS_{40GF}$[-58,58] = $\sqrt{2}$ ×{0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0} (7)

on the subcarriers of the OFDM signal. The ensuing long sequence for 40 MHz greenfield operation is defined by the sequence

$LS_{40GF}$[-58..58] = {1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, -1, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, -1, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 1} (8)

The mixed-mode training structures for 1TX, 2TX, and 3TX/4TX modes in 40 MHz are defined in Figure 012, 014, and 016 respectively. The additional short and long sequences used in these modes are defined by the following frequency domain sequences:

$SS_{40MM}$[-58..58] = $\sqrt{7/3}$ ×{0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0} (9)

$LS_{40MM}$[-58..58] = {1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 0, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, -1, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 1}. (10)

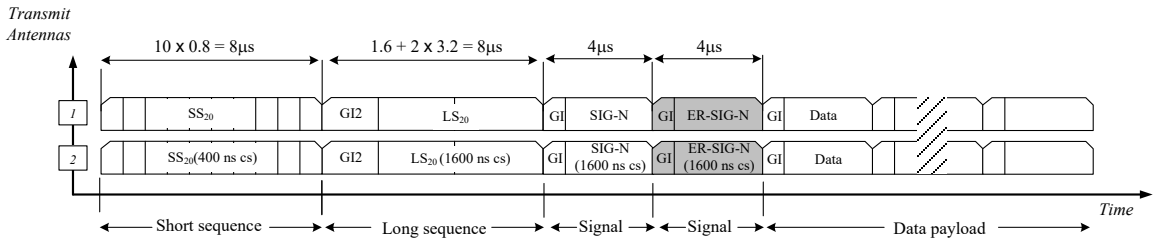



**Figure 007 – MIMO-OFDM Training structure for $N_{TX}$ = 2, 20 MHz, greenfield operation. The shaded field indicates the optional duplicate SIG-N for extended range communication.**

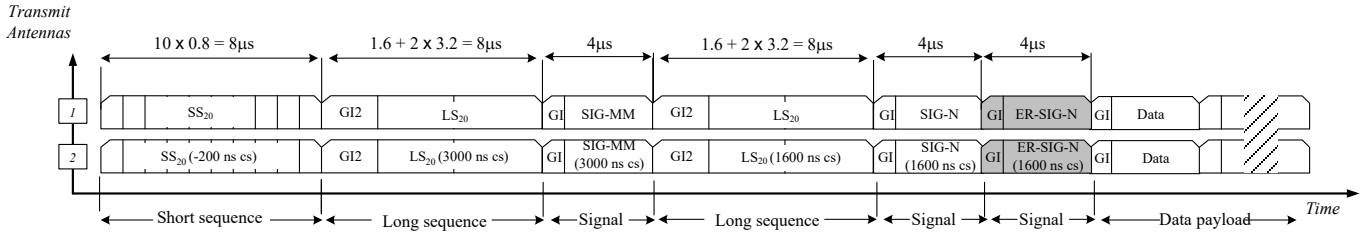



**Figure 008 – MIMO-OFDM Training structure for $N_{TX}$ = 2, 20 MHz, mixed-mode operation. The shaded field indicates the optional duplicate SIG-N for extended range communication.**

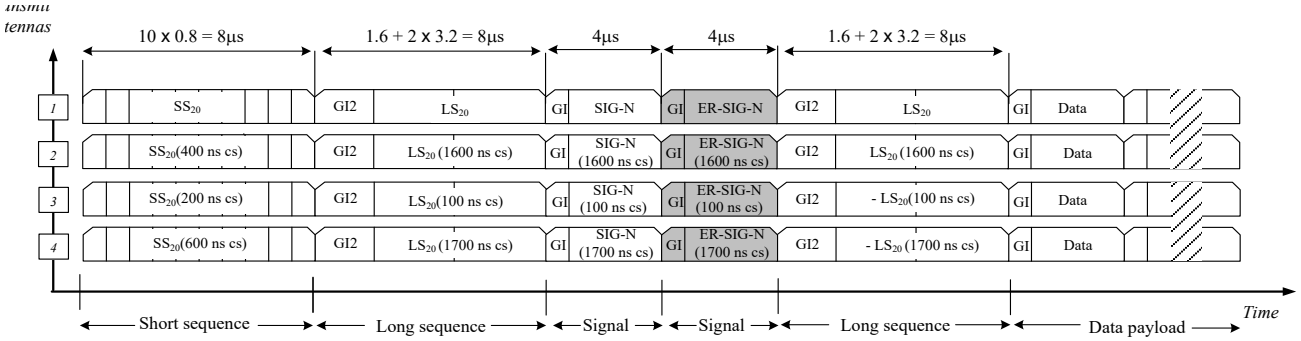



**Figure 009 – MIMO-OFDM Training structure for $N_{TX}$ = 3 and 4, 20 MHz, greenfield operation. The shaded field indicates the optional duplicate SIG-N for extended range communication.**

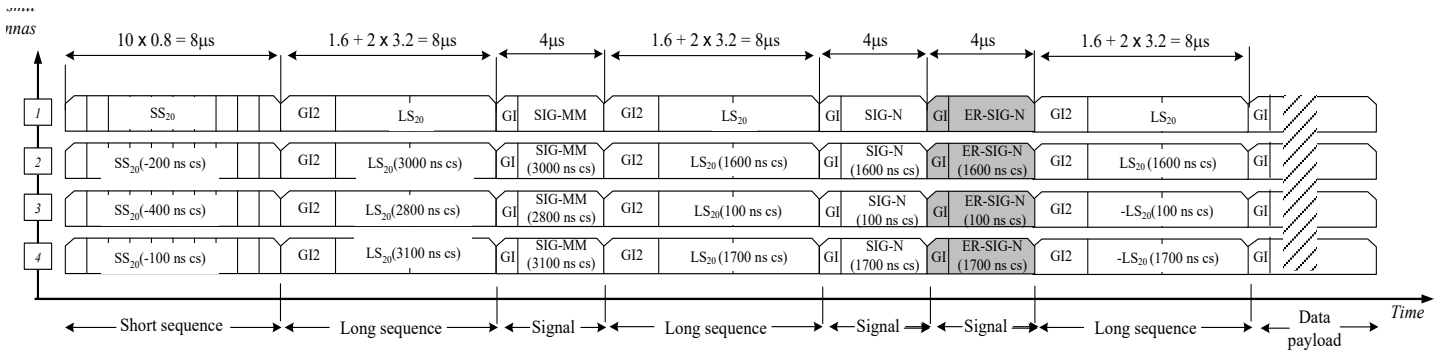



**Figure 010 – MIMO-OFDM Training structure for $N_{TX}$ = 3, 4, 20 MHz, mixed-mode operation. The shaded field indicates the optional duplicate SIG-N for extended range communication.**

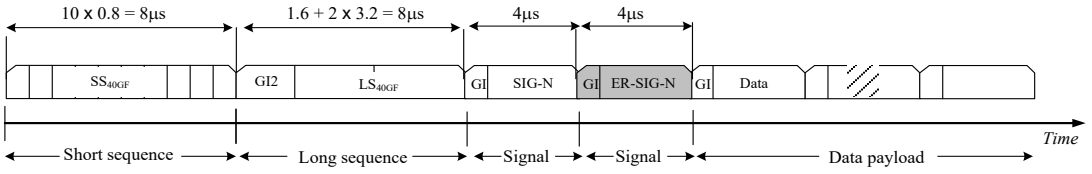



**Figure 011 – MIMO-OFDM Training structure for $N_{TX}$=1, 40 MHz, greenfield operation. The shaded field indicates the optional duplicate SIG-N for extended range communication.**

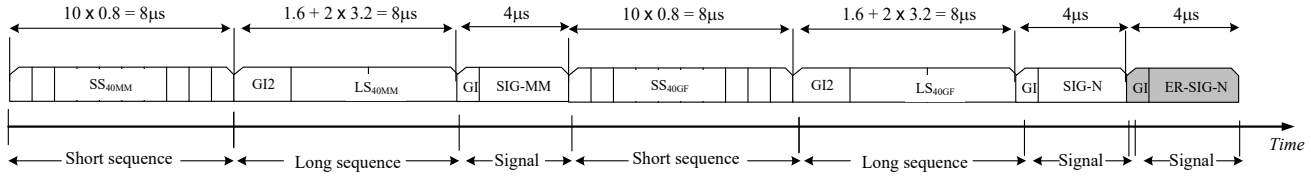



**Figure 012 – MIMO-OFDM Training structure for $N_{TX}$=1, 40 MHz, mixed-mode operation. The shaded field indicates the optional duplicate SIG-N for extended range communication.**

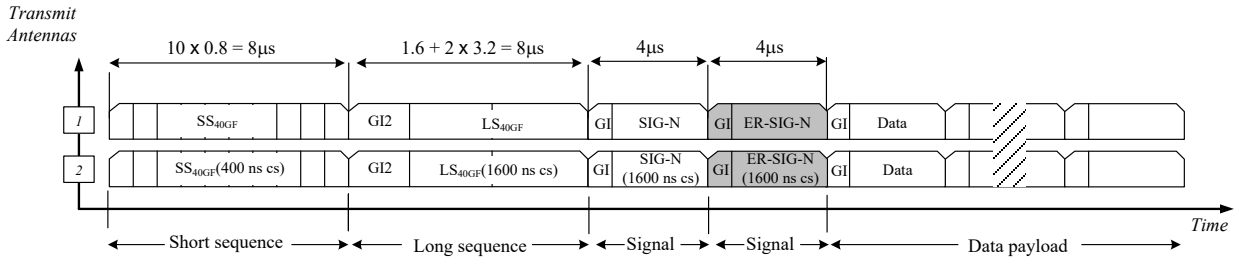



**Figure 013 – MIMO-OFDM Training structure for $N_{TX}$ = 2, 40 MHz, greenfield operation. The shaded field indicates the optional duplicate SIG-N for extended range communication.**

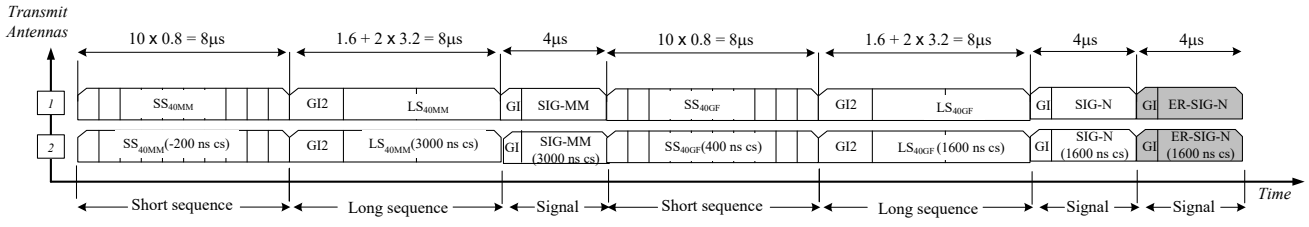



**Figure 014 – MIMO-OFDM Training structure for $N_{TX}$ = 2, 40 MHz, mixed-mode operation. The shaded field indicates the optional duplicate SIG-N for extended range communication.**

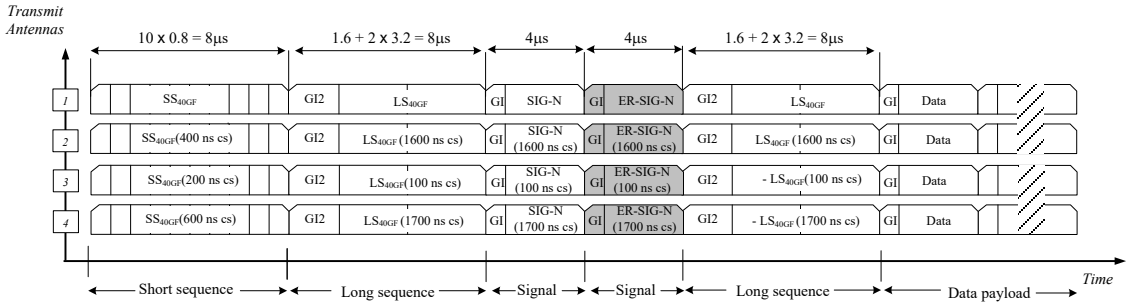



**Figure 015 – MIMO-OFDM Training structure for $N_{TX}$ = 3 and 4, 40 MHz, greenfield operation. The shaded field indicates the optional duplicate SIG-N for extended range communication.**

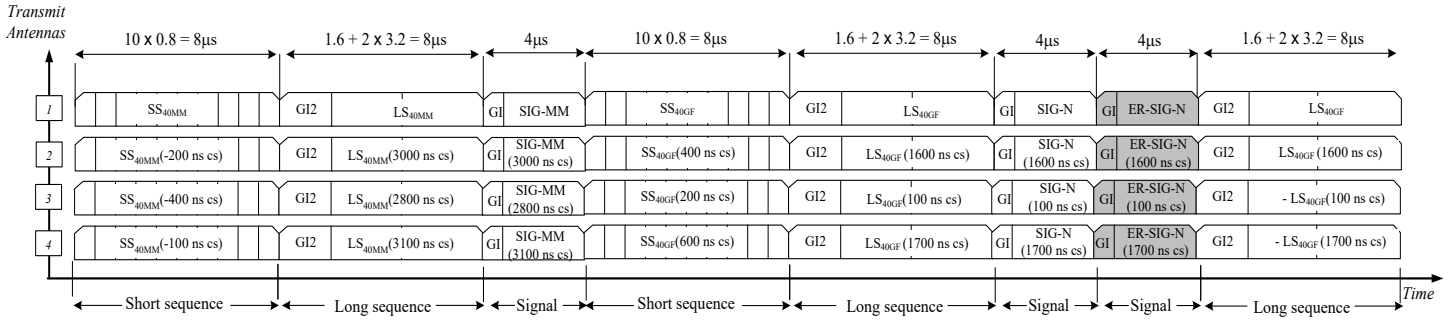



**Figure 016 – MIMO-OFDM Training structure for $N_{TX}$ = 3, 4, 40 MHz, mixed-mode operation. The shaded field indicates the optional duplicate SIG-N for extended range communication.**

### 20.3.4 Signal fields (SIG-N and SIG-MM)

The SIGNAL-N field (SIG-N) is separately defined for a mandatory standard configuration and an optional "extended communication range" configuration (ER) described below.

In the mandatory standard configuration, SIG-N is composed of a single MIMO-OFDM symbol that provides all length and configuration parameters associated with a MIMO-OFDM PPDU.

In the extended communication range configuration (ER), SIG-N is composed of two consecutive MIMO-OFDM symbols: The SIG-N MIMO-OFDM symbol is followed by a second MIMO-OFDM symbol,denoted as ER-SIG-N. The frequency domain MIMO-OFDM symbol ER-SIG-N is derived from MIMO-OFDM symbol SIG-N by applying the following permutation on the subcarrier indices (as described in subclause 20.3.2.4) of the OFDM data symbols composing SIG-N:

- For 20MHz data transmissions: With SIG-N=(0, s(1), s(2)…, s(28), 0, …, 0, s(-28), s(-27), …, s(-1)), ER-SIG-N is specified as ER-SIG-N =(0, s(-28), s(-27), …, s(-1), 0, …, 0, s(1), s(2)…, s(28));
- For 40MHz data transmissions: With SIG-N=(0, 0, 0, s(3), s(4)…, s(58), 0, …, 0, s(-58), s(-57), …, s(-3), 0, 0), ER-SIG-N is specified as ER-SIG-N=(0, 0, 0, s(-58), s(-57), …, s(-3), 0, …, 0, s(3), s(2)…, s(58), 0, 0).

The extended communication range configuration is only used with the optional NTX-STBC modes (described in subclause 20.3.5.10) and only with rate-1/2 encoding using BPSK modulation.

The SIGNAL-N field is composed of 54 bits, which shall be interpreted according to the bit assignment specified in Figure 017 and Table 011. The REXT bit, indicating extended range communication, can only be set in the optional NTX-STBC modes with rate-1/2 encoding and BPSK modulation.

**Table 011—SIG-N field bit assignment**

| Bits | Field | Subfield | Parameter | Values |
|---|---|---|---|---|
| B0 : b5 | RSVD | | Reserved bits | 111111, Bits shall be ignored at the receiver |
| B6 : b21 | CONFIG | | Configuration | |
| B6 : b8 | | NSS | Number of spatial streams | 000: 1, 001: 2, 010: 3, 011: 4 |
| B9 : b11 | | NTX | Number of transmit antennas | 000: 1, 001: 2, 010: 3, 011: 4 |
| B12 : b13 | | BW | Bandwidth | 00: 20 MHz, 01: 40 MHz |
| B14: b16 | | R | Code rate | 000: 1/2, 001: 2/3, 010: 3/4, 011: 5/6 |
| B17 : b18 | | CT | ECC type | 00 : convolutional, 01 : LDPC |
| B19 : b21 | | CON | Constellation type | 000: BPSK, 001: QPSK, 010: 16-QAM, 011: 64-QAM |
| B22 : b34 | LEN | | Length | Number of bytes in the payload. The value of 0 is allowed. |
| b35 | LPI | | Last PSDU indicator | 1 indicates that this is the last PSDU to be aggregated into the current PPDU. LPI shall have the value of 1 when the value of the LEN field is 0. |
| b36 | REXT | | Standard or extended communication range configuration | 0 indicates the standard configuration, 1 indicates the extended communication range configuration |
| b37 : b43 | RSVD | | Reserved | 0000000, bits shall be ignored at the receiver |
| b44 : b47 | CRC | | Cyclic Redundancy Check | CRC calculated on bits 0-43 using generator polynomial $x^4+x+1$ |
| b48 : b53 | TAIL | | | 000000 |

In all 20 MHz modes, the encoding of the single SIG-N MIMO-OFDM symbol shall be performed with QPSK modulation of the subcarriers of the first antenna and shall use convolutional coding at R = 1/2. In all 40 MHz modes, the encoding of the single SIG-N MIMO-OFDM symbol shall be performed with BPSK modulation of the subcarriers of the first antenna and shall use using convolutional coding at R = 1/2. The contents of the SIG-N field are not scrambled.

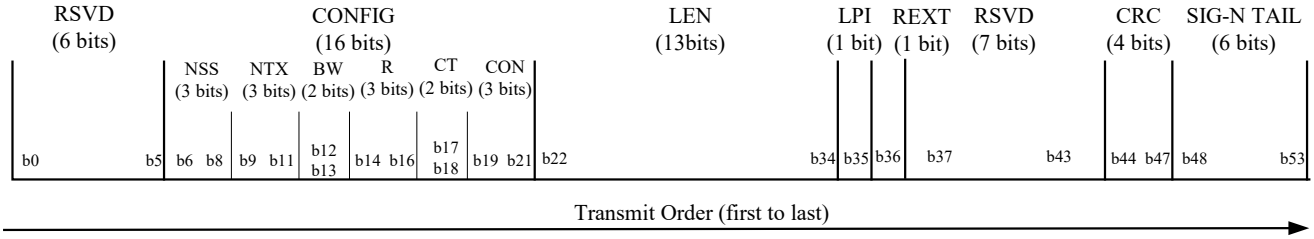



**Figure 017 – SIG-N field bit assignment**

The SIG-N MIMO-OFDM symbol is transmitted simultaneously from all TX antennas in all modes, with the same values of relative cyclic shift between antennas as are used to transmit the long training symbol preceding the SIG-N symbol. The value of the cyclic shift in each operating mode is specified in Figures 007 through 016 in subclause 20.3.3.

With mixed-mode access, another symbol, denoted as SIGNAL-MM (SIG-MM) is sent in the PLCP header. The SIG-MM field is encoded and transmitted from the first antenna as per IEEE 802.11a-1999 subclause 17.3.4. The remaining antennas simultaneously transmit the same OFDM symbol, with relative cyclic shifts defined in subclause 20.3.3. The reserved bit in the SIG-MM field shall be set to signal a MIMO-OFDM PPDU transmission. The duration for which the medium will be used by the MIMO-OFDM PPDU transmission is signaled to non MIMO-OFDM stations via the LENGTH and RATE fields of the SIG-MM symbol.

In 40 MHz mixed-mode operation, the SIG-MM field shall be transmitted such that it can be decoded by non-MIMO-OFDM stations operating in either the upper or the lower 20 MHz band.

When the LEN field is set to 0, no PSDU bits are present and the Last PSDU indicator (LPI) shall be set to 1 to end the current PPDU.

### 20.3.5 DATA field

The DATA field contains the SERVICE field, the PSDU, the TAIL bits, and the PAD bits, if needed, as described in 20.3.5.2 and 20.3.5.4. All bits in the DATA field except the TAIL bits are scrambled, as described in 20.3.5.4.

#### 20.3.5.1 Service field (SERVICE)

The IEEE 802.11 SERVICE field has 16 bits, which shall be denoted as bits 0-15. The bit 0 shall be transmitted first in time. The bits 0-6 of the SERVICE field, which are transmitted first, are set to zeros and are used to synchronize the descrambler in the receiver. The remaining 9 bits (7-15) of the SERVICE field shall be reserved for future use. All reserved bits shall be set to zero. Refer to Figure 112, IEEE 802.11a-1999 subclause 17.3.5.1.

#### 20.3.5.2 PPDU tail bits

The PPDU tail bits shall follow IEEE 802.11a-1999 subclause 17.3.5.2.

### 20.3.5.3 PAD bits

The number of bits in the DATA field shall be a multiple of $N_{CBPS}$, the number of coded bits in an OFDM symbol. To achieve that, the length of the message is extended so that it becomes a multiple of $N_{DBPS}$, the number of data bits per OFDM symbol. At least 6 bits per encoding stream ($N_{ES}$) are appended to the message, in order to accommodate the TAIL bits, as described in 20.3.5.2. The number of MIMO-OFDM symbols, $N_{SYM}$; the number of bits in the DATA field, $N_{DATA}$; and the number of pad bits, $N_{PAD}$, are computed from the length of the PSDU (LENGTH) as follows:

$$N_{SYM} = \text{Ceiling}\left((16 + 8 \times \text{LENGTH} + 6 \times N_{ES})/N_{DBPS}\right) \quad (11)$$

$$N_{DATA} = N_{SYM} \times N_{DBPS} \quad (12)$$

$$N_{PAD} = N_{DATA} - (16 + 8 \times \text{LENGTH} + 6 \times N_{ES}) \quad (13)$$

The appended bits ("pad bits") are set to "zeros" and are subsequently scrambled with the rest of the bits in the DATA field.

### 20.3.5.4 PLCP data scrambler and descrambler

The PPDU data scrambler and descrambler shall follow IEEE 802.11a-1999 subclause 17.3.5.4.

### 20.3.5.5 Convolutional encoder

The DATA field, composed of SERVICE, PSDU, tail, and pad parts, shall be coded with a convolutional encoder that conforms to IEEE 802.11a-1999 subclause 17.3.5.5 for code rates of R = 1/2, 2/3, and 3/4. Additionally, the code rate of R = 5/6 shall be implemented according to the puncturing pattern illustrated in Figure 018.

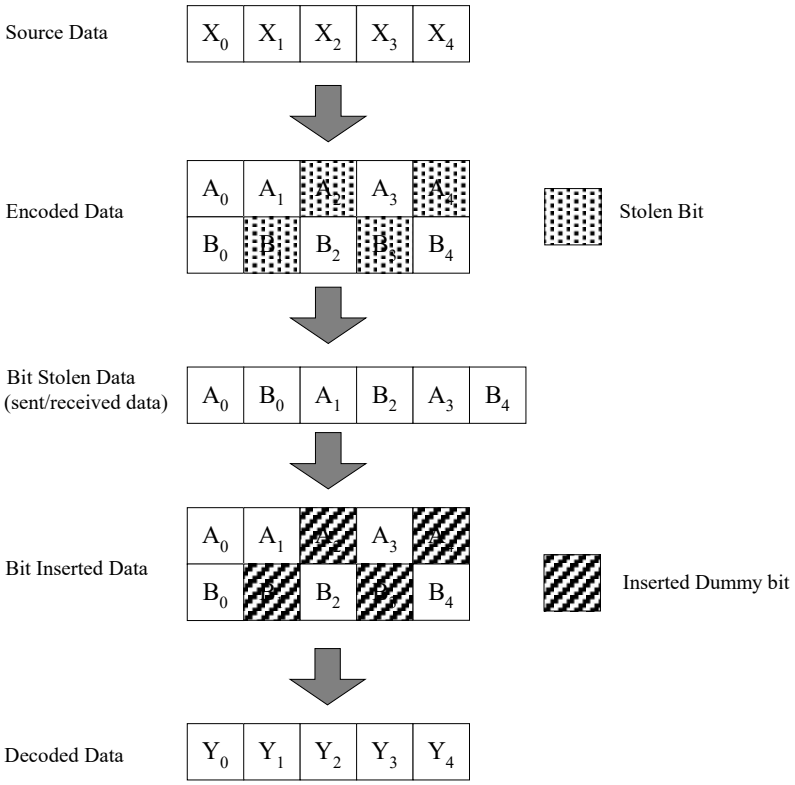



**Figure 018 – An illustration of the bit stealing and bit insertion procedure for R = 5/6**

### 20.3.5.6 Interleaver

All encoded bits shall be interleaved by a block interleaver with a block size equal to the number of bits in a single MIMO-OFDM symbol, $N_{CBPS}$. The interleaver is defined by the following series of permutations.

We shall denote by $k$ the index of the coded bits before interleaving, $k = 0, 1 \ldots N_{CBPS}-1$. $n = 0, 1 \ldots N_{SS}-1$ denotes the index of the spatial streams. The bits are first distributed across spatial streams by inputting the bit with index $k_n \times N_{SS} + n$ into the $n$th spatial stream. This is illustrated in Figure 019.

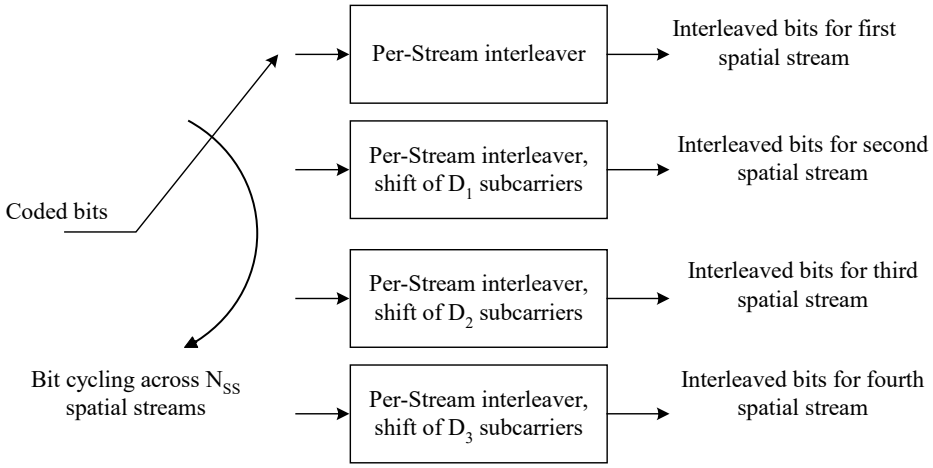



**Figure 019 – Illustration of the interleaver function**

The interleaver for spatial stream $n$ within its block of $N_{CBPS}/N_{SS}$ bits is defined by the following relations.

$$k = k_n \times N_{ss} + n$$

$$i = ((N_{CBPS}/N_{SS})/I_{DEPTH})\ (k_n \bmod I_{DEPTH}) + \text{floor}\ (k_n/I_{DEPTH}) \qquad k_n = 0, 1 \ldots (N_{CBPS}/N_{SS})-1$$

$$j = s \times \text{floor}(i/s) + (i + N_{CBPS}/N_{SS} - \text{floor}\ (I_{DEPTH} \times i / (N_{CBPS}/N_{SS}))) \bmod s \qquad s = \max(N_{BPSC}/2,1)$$

$$j_n = (j + N_{CBPS}/N_{SS} - N_{BPSC}\ D_n) \bmod (N_{CBPS}/N_{SS}). \qquad (14)$$

The parameter $D_n$ which denotes the shift in subcarriers for spatial stream $n$ is given by

$$D_n = 5n. \qquad (15)$$

The interleaving depth $I_{DEPTH}$ shall conform to the values given in Table 012.

**Table 012—Interleaving parameters**

| $N_{SS}$ | $N_{SD}$ | $I_{DEPTH}$ |
|---|---|---|
| 1, 2, 3, 4 | 54 | 6 |
| 2,3,4 | 108 | 6 |
| 1 | 108 | 12 |

The deinterleaver, which performs the inverse relation, is defined by the following series of permutations.

$$k_d = \bmod (k_n + N_{CBPS}/N_{SS} + 2sD_n) \bmod (N_{CBPS}/N_{SS})$$

$$i_d = s\ \text{floor}(k_d / s) + (k_d + \text{floor}\ (I_{DEPTH} \times k_d / (N_{CBPS}/N_{SS}))) \bmod s$$

$$j_{dn} = I_{DEPTH} \times i_d - ((N_{CBPS}/N_{SS}) - 1) \times \text{floor}\,(I_{DEPTH} \times i_d / (N_{CBPS}/N_{SS})). \quad (16)$$

where s and $D_n$ are as defined for the interleaver.

#### 20.3.5.7 Low density parity check codes (optional ECC)

This subclause describes the LDPCCs to be optionally used in the MIMO-OFDM system as high-performance ECC technique, instead of the convolutional code (20.3.5.5). The rate-dependent parameters in subclause 20.3.2.2 shall still apply.

When this subclause applies, the following clauses are to be considered no more applicable:

20.3.2.1: changes needed, as described in 20.3.5.7.3;
20.3.5.2: not used;
20.3.5.3: replaced by 20.3.5.7.3;
20.3.5.5: replaced by 20.3.5.7.4;
20.3.5.6: not used.

#### 20.3.5.7.1 LDPCC Code Rates and Block Sizes

The supported code rates, information block size, and coded block size are described in Table 013.

**Table 013— LDPCC parameters**

| Code rate (R) | LDPC information bits (bits) | LDPC codeword length (bits) |
|---|---|---|
| 1/2 | 972 | 1944 |
| 2/3 | 1296 | 1944 |
| 3/4 | 1458 | 1944 |
| 5/6 | 1620 | 1944 |

#### 20.3.5.7.3 LDPCC PPDU encoding process

a) Produce the PLCP preamble fields for each transmit antenna based on the TRANSMISSION_MODE field of the TXVECTOR. Refer to 20.3.3 for details.

b) Produce the PLCP header field from the LENGTH, DATARATE, and SERVICE fields of the TXVECTOR by filling the appropriate bit fields, as described in subclause 20.3.4 and subclause 20.3.5.1.

c) Compute the integer number of LDPCC codewords to be transmitted, $L_1$, and the possible remainder $K_1$.

$$L_1 = \text{ceil}(\,(\text{LENGTH} \times 8 + 16)/1944/R),$$

$$K_1 = \text{rem}(\,(\text{LENGTH} \times 8 + 16)\,,1944 \times R). \quad (17)$$

d) If $K_1 > 0$ compute the number of zeros for padding in order to encode the last codeword as

$$N_{P1} = 1944 \times R - K_1. \quad (18)$$

These bits will not be transmitted nor scrambled. If $K_1 > 0$, the last frame has an effective information frame (i.e. information frame excluding padded zeros) of size $K_1$, generally less than *k.* The last codeword includes a fixed number of parity bits equal to $p = (1944 - k)$. This implies the code rate for the last codeword is different from the overall target code rate and is given by:

$$\frac{K_1}{K_1 + (1944 - k)}. \tag{19}$$

e) Compute the number of coded bits to be transmitted (including the shortened codeword) as

$$L_2 = \begin{cases} 1944 \times L_1, & K_1 = 0 \\ 1944 \times (L_1 - 1) + 1944 \times (1 - R) + K_1, & K_1 \neq 0 \end{cases} \tag{20}$$

f) Compute the integer number of MIMO-OFDM symbols $N_{S1}$ and the possible reminder $R_{S1}$:

$$N_{S1} = \text{ceil}(L_2/N_{CBPS}),$$

$$R_{S1} = \text{rem}(L_2, N_{CBPS}). \tag{21}$$

g) If $R_{S1} > 0$ append $N_{P2}$ zeros to info bits in order to fill an integer number of MIMO-OFDM symbols

$$N_{P2} = N_{CBPS} - R_{S1}. \tag{22}$$

h) The service field at the beginning of the resulting sequence is used to initialize a scrambler, which is then used to scramble the rest of the sequence including the zeros appended in step g).

k) The resulting PSDU is then coded by the LDPCC at the proper code rate (R) and block size (i.e. 1944 bits for all frames). The last codeword is encoded extending the info bits with $N_{P1}$ zeros; these $N_{P1}$ bits are not transmitted. The last $N_{P2}$ bits are not encoded.

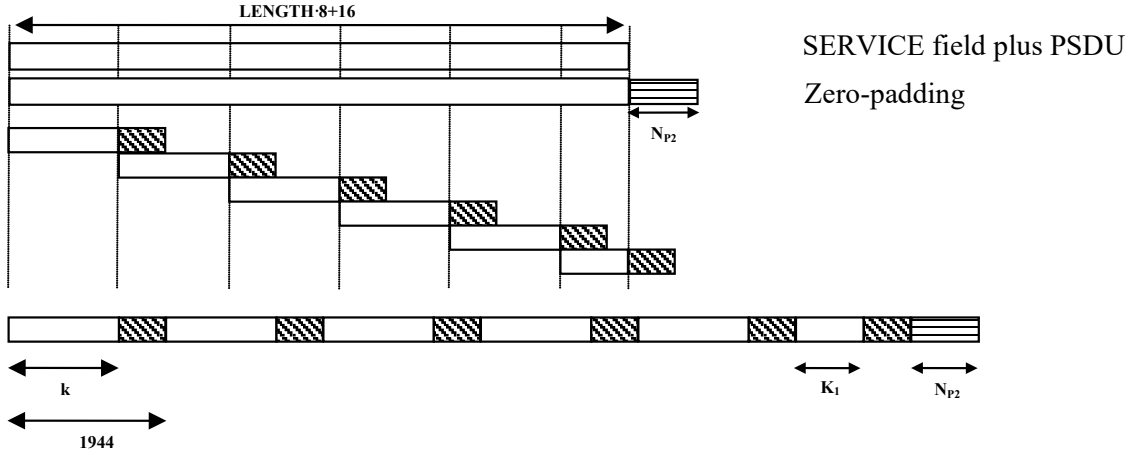



**Figure 020 – LDPC PPDU encoding.**

#### 20.3.5.7.4 LDPCC Encoder

The proposed LDPCC supports rate-1/2, rate-2/3, rate-3/4 and rate-5/6 encoding. The LDPCC encoder is systematic, i.e. it encodes an information block of size $k$, I=($i_0,i_1,\ldots\ i_{(k-1)}$) into a codeword **c** of size $n$, **c**=($i_0,i_1,\ldots\ i_{(k-1)}, p_0, p_1, \ldots, p_{(n-k-1)}$), by adding $n$-$k$ parity bits obtained so that $\mathbf{H}\cdot\mathbf{c}^T = \mathbf{0}$. The parameters $k$ and $n$ are defined in Table 013 according to the selected encoder rate.

The parity-check matrix for each encoder rate is "structured" (as opposed to "random") in the sense that it can be partitioned into square subblocks (submatrices) of size $Z$ x $Z$. These submatrices are either cyclic permutations of the diagonal identity matrix, null sub-matrices, or a subdiagonal matrix ("$D$"). The submatrix types (except for the null submatrix) are illustrated in Figure 021. At each encoding rate, the structure of parity-check matrix allows a linear-complexity encoder (based on back substitution).

#### 20.3.5.7.5 Parity check matrix

In each parity-check matrix, the upper right-hand subblock is the subdiagonal matrix, $D$, and the rest of the non-null subblocks are cyclic permutation matrices. The cyclic permutation matrix $P_i$ is obtained from the identity matrix by cyclically shifting the rows to the right by $i$ elements. The matrix $P_0$ is the identity matrix. Figure 021 illustrates examples (for a subblock size of 8 x 8) of cyclic-permutation matrices $P_i$, as well as the $D$-matrix which has the subdiagonal structure.

$$P_0 = \begin{bmatrix} 1&0&0&0&0&0&0&0\\ 0&1&0&0&0&0&0&0\\ 0&0&1&0&0&0&0&0\\ 0&0&0&1&0&0&0&0\\ 0&0&0&0&1&0&0&0\\ 0&0&0&0&0&1&0&0\\ 0&0&0&0&0&0&1&0\\ 0&0&0&0&0&0&0&1 \end{bmatrix}, P_1 = \begin{bmatrix} 0&1&0&0&0&0&0&0\\ 0&0&1&0&0&0&0&0\\ 0&0&0&1&0&0&0&0\\ 0&0&0&0&1&0&0&0\\ 0&0&0&0&0&1&0&0\\ 0&0&0&0&0&0&1&0\\ 0&0&0&0&0&0&0&1\\ 1&0&0&0&0&0&0&0 \end{bmatrix}, P_5 = \begin{bmatrix} 0&0&0&0&0&1&0&0\\ 0&0&0&0&0&0&1&0\\ 0&0&0&0&0&0&0&1\\ 1&0&0&0&0&0&0&0\\ 0&1&0&0&0&0&0&0\\ 0&0&1&0&0&0&0&0\\ 0&0&0&1&0&0&0&0\\ 0&0&0&0&1&0&0&0 \end{bmatrix}$$

$$D = \begin{bmatrix} 0&0&0&0&0&0&0&0\\ 1&0&0&0&0&0&0&0\\ 0&1&0&0&0&0&0&0\\ 0&0&1&0&0&0&0&0\\ 0&0&0&1&0&0&0&0\\ 0&0&0&0&1&0&0&0\\ 0&0&0&0&0&1&0&0\\ 0&0&0&0&0&0&1&0 \end{bmatrix}$$

**Figure 021 – Types of subblock matrices. The matrix $P_i$ is produced by cyclically shifting the rows of the identity matrix to the right by $i$ places.**

Table A.1 of Annex A displays the "matrix prototype" of the rate-1/2 parity-check matrix. The integer $i$ denotes the cyclic-permutation matrix $P_i$, and $D$ denotes the subdiagonal matrix, as illustrated in Figure 021. Vacant entries of the table denote null (zero) submatrices.

Table A.2 of Annex A displays the matrix prototype of the rate-2/3 parity-check matrix in the same fashion.
Table A.3 of Annex A displays the matrix prototype of the rate-3/4 parity-check matrix in the same fashion.
Table A.4 of Annex A displays the matrix prototype of the rate-5/6 parity-check matrix in the same fashion.

### 20.3.5.8 Subcarrier modulation mapping

The subcarrier modulation mapping shall follow IEEE 802.11a-1999 clause 17.3.5.7 for each spatial stream.

### 20.3.5.9 NTX-SDM (Spatial Data Multiplexing) Modes

The NTX-SDM modes are those modes in which $N_{TX,}$ the number of TX antennas, is equal to $N_{SS,}$ the number of transmitted spatial streams. Throughout the description of the MIMO signaling modes, we shall number the MIMO-OFDM symbols transmitted in a PSDU sequentially, with $n$ = 1 denoting the first symbol that follows the PLCP preamble.

#### 20.3.5.9.1 Pilot tones for the NTX-SDM modes

The subcarriers with index -21 and +21 are dedicated in all 20 MHz NTX-SDM modes to transmit pilot signals during each OFDM symbol, in order to increase robustness against frequency offsets and phase noise. In the 40 MHz modes, 4 subcarriers are dedicated to transmitting pilots. These subcarriers have indices -42, -14, +14, and +42.

The relative polarity of the pilots transmitted from various antennas shall be determined using the following relations. We shall use $p_n$ to denote the $n$th element of the sequence $p_{0\ldots126v}$ specified in equation (25) of IEEE 802.11a-1999 subclause 17.3.5.9. We define the following matrices:

$$A=\begin{bmatrix}+1 & +1 & +1 & -1\\ +1 & -1 & +1 & +1\end{bmatrix},\quad B=\begin{bmatrix}+1 & +1 & -1 & -1\\ +1 & -1 & +1 & -1\\ -1 & +1 & +1 & -1\end{bmatrix},\quad C=\begin{bmatrix}+1 & +1 & +1 & -1\\ +1 & +1 & -1 & +1\\ +1 & -1 & +1 & +1\\ -1 & +1 & +1 & +1\end{bmatrix}. \qquad (24)$$

Furthermore, we define $a_{i,j}$, $b_{i,j}$, and $c_{i,j}$ as the element on the $i$th row and $j$th column of the matrices A, B, and C, respectively. For example, $i$ =0, 1, 2; $j$ = 0, 1, 2, 3 for matrix B. Then the pilot values sent from the $m$th antenna ($m$ = 1, 2, …4) during the $n$th OFDM symbol in the 20 MHz modes shall be given by the corresponding value in Table 014, multiplied with $p_{n \bmod 127}$. The function f( · ) in Table 014 is defined as f(0) = 0, f(1)=2, f(2)=1, f(3)=3.

The pilot value in the 40 MHz modes shall be given by the corresponding value in Table 015, multiplied with $p_{n \bmod 127}$.The value of the pilot signals sent from the first antenna during the SIG-N symbol shall be obtained by setting $n$ = 0 in this subclause. The pilot signals sent during the SIG-MM symbol in the mixed-mode preambles shall follow IEEE 802.11a-1999 subclause 17.3.5.9, and the polarity of the sequence $p_{0\ldots126v}$ shall be reset after the SIG-MM symbol is transmitted.

**Table 014—Pilot value sent from *m*th antenna during *n*th OFDM symbol in 20 MHz $N_{TX}$-SDM modes.**

| Subcarrier index, *k* | 2TX-SDM mode | 3TX-SDM mode | 4TX-SDM mode |
|---|---|---|---|
| -21 | $a_{\text{m-1, } n \bmod 2}$ | $b_{\text{m-1, f}(n \bmod 4)}$ | $c_{\text{m-1, f}(n \bmod 4)}$ |
| +21 | $a_{\text{m-1, } (n+1) \bmod 2}$ | $b_{\text{m-1, f}((n+2) \bmod 4)}$ | $c_{\text{m-1, f}((n+2) \bmod 4)}$ |

**Table 015—Pilot value sent from *m*th antenna during *n*th OFDM symbol in 40 MHz $N_{TX}$-SDM modes.**

| Subcarrier index, *k* | 1TX-mode | 2TX-SDM mode | 3TX-SDM mode | 4TX-SDM mode |
|---|---|---|---|---|
| -42 | +1 | $a_{\text{m-1, } n \bmod 4}$ | $b_{\text{m-1, } n \bmod 4}$ | $c_{\text{m-1, } n \bmod 4}$ |
| -14 | +1 | $a_{\text{m-1, } (n+1) \bmod 4}$ | $b_{\text{m-1, } (n+1) \bmod 4}$ | $c_{\text{m-1, } (n+1) \bmod 4}$ |
| +14 | +1 | $a_{\text{m-1, } (n+2) \bmod 4}$ | $b_{\text{m-1, } (n+2) \bmod 4}$ | $c_{\text{m-1, } (n+2) \bmod 4}$ |
| +42 | -1 | $a_{\text{m-1, } (n+3) \bmod 4}$ | $b_{\text{m-1, } (n+3) \bmod 4}$ | $c_{\text{m-1, } (n+3) \bmod 4}$ |

Figure 022 provides an illustration of the relative polarity of pilot signals transmitted in the 20 MHz 2TX-SDM mode of operation.

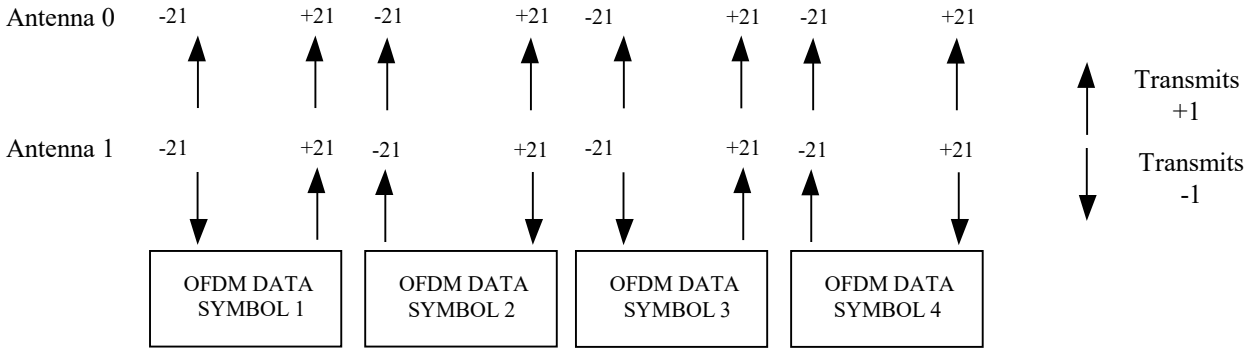



**Figure 022 – An illustration of the relative polarity of pilot signals in the 20 MHz 2TX-SDM mode. "-21" and "+21" indicate the subcarrier indices on which pilot signals are sent**

#### 20.3.5.9.2 Data tones in NTX-SDM modes

The signaling on the data tones of the NTX-SDM modes is described in subclause 20.3.2.1., item (l).

### 20.3.5.10 NTX-STBC (Space-Time Block Coding) Modes

This subclause defines a set of robust transmission rates which are applicable when $N_{TX,}$ the number of TX antennas, is greater than $N_{SS,}$ the number of transmitted spatial streams. These rates are based on space time block coding. Implementation of all modes defined in this subclause is optional.

#### 20.3.5.10.1 $N_{TX}$-STBC modes with single spatial stream $N_{SS}$=1

#### 20.3.5.10.1.1 Pilot tones in the NTX-STBC modes with $N_{SS}$=1

The pilot structure of the optional NTX-STBC modes closely follows that of the 2TX-SDM modes. For 20 MHz operation, the subcarriers with indices *k*=-21,+21 are reserved for piloting. For 40 MHz operation, the subcarriers with indices *k*=-42,-14,+14,+42 are reserved for piloting.

In the NTX-STBC modes, only two antennas per pilot subcarrier transmit pilots on a given OFDM symbol. For $N_{TX}$=3 and $N_{TX}$=4, the active antennas on a given OFDM symbol are determined using the antenna selection functions *g* and *h* defined in the following. We define g(*m*,*n*,*p*) via Table 016, and *h*(*m*,*n*,*p*) via Table 017 below. The notation [*x*] is used to denote *floor*(*x*).

**Table 016—The *g* function used in antenna selection for 3TX-STBC modes.**

| *([n/2]+p) mod 3* / *M* | *0* | *1* | *2* |
|---|---|---|---|
| *1* | *1* | *0* | *1* |
| *2* | *0* | *1* | *2* |
| *3* | *2* | *2* | *0* |

**Table 017—The *h* function used in antenna selection for 4TX-STBC modes.**

| *([n/2]+p) mod 4* / *m* | *0* | *1* | *2* | *3* |
|---|---|---|---|---|
| *1* | *1* | *0* | *1* | *0* |
| *2* | *0* | *1* | *0* | *1* |
| *3* | *2* | *0* | *0* | *2* |
| *4* | *0* | *2* | *2* | *0* |

The pilot values sent from the $m$th antenna ($m$ = 1, …,$N_{TX}$) during the $n$th OFDM symbol in the 20 MHz-STBC modes shall be given by the corresponding value in Table 018, multiplied with $p_{n \bmod 127}$. The values $a_{i,j}$ with $i$ =-1 in Table 018 are interpreted as zero.

**Table 018—Pilot value sent from *m*th antenna during *n*th OFDM symbol in 20 MHz $N_{TX}$-STBC modes.**

| Subcarrier index, *k* | 2TX-STBC-mode with $N_{SS}$=1 | 3TX-STBC-mode with $N_{SS}$=1 | 4TX-STBC-mode with $N_{SS}$=1 |
|---|---|---|---|
| -21 | $a_{m\text{-}1,\ n \bmod 2}$ | $(3/2)^{1/2}\, a_{g(m,n,0)\text{-}1,\ n \bmod 2}$ | $2^{1/2}\, a_{h(m,n,0)\text{-}1,\ n \bmod 2}$ |
| +21 | $a_{m\text{-}1,\ (n+1) \bmod 2}$ | $(3/2)^{1/2}\, a_{g(m,n,1)\text{-}1,\ (n+1) \bmod 2}$ | $2^{1/2}\, a_{h(m,n,1)\text{-}1,\ (n+1) \bmod 2}$ |

The pilot values sent from the $m$th antenna ($m$ = 1, …,$N_{TX}$) during the $n$th OFDM symbol in the 40 MHz-STBC modes shall be given by the corresponding value in Table 019, multiplied with $p_{n \bmod 127}$. The values $a_{i,j}$ with $i$ =-1 in Table 019 are interpreted as zero.

**Table 019—Pilot value sent from *m*th antenna during *n*th OFDM symbol in 40 MHz $N_{TX}$-STBC modes.**

| Subcarrier index, *k* | 2TX-STBC-mode with $N_{SS}$=1 | 3TX-STBC-mode with $N_{SS}$=1 | 4TX-STBC-mode With $N_{SS}$=1 |
|---|---|---|---|
| -42 | $a_{m\text{-}1,\ n \bmod 4}$ | $(3/2)^{1/2}\, a_{g(m,n,0)\text{-}1,\ n \bmod 4}$ | $2^{1/2}\, a_{h(m,n,0)\text{-}1,\ n \bmod 4}$ |
| -14 | $a_{m\text{-}1,\ (n+1) \bmod 4}$ | $(3/2)^{1/2}\, a_{g(m,n,1)\text{-}1,\ n \bmod 4}$ | $2^{1/2}\, a_{h(m,n,1)\text{-}1,\ (n+1) \bmod 4}$ |
| +14 | $a_{m\text{-}1,\ (n+2) \bmod 4}$ | $(3/2)^{1/2}\, a_{g(m,n,2)\text{-}1,\ n \bmod 4}$ | $2^{1/2}\, a_{h(m,n,2)\text{-}1,\ (n+2) \bmod 4}$ |
| +42 | $a_{m\text{-}1,\ (n+3) \bmod 4}$ | $(3/2)^{1/2}\, a_{g(m,n,3)\text{-}1,\ n \bmod 4}$ | $2^{1/2}\, a_{h(m,n,3)\text{-}1,\ (n+3) \bmod 4}$ |

#### 20.3.5.10.1.2 Data tones in the NTX-STBC modes with $N_{SS}$=1

The 2TX-STBC schemes for $N_{SS}$ =1 in 20 MHz and 40 MHz are defined as follows. The bits output from the interleaver of the (single) spatial stream are mapped to the subcarriers of the first antenna, according to subclause 20.3.5.8. Let $x_t(k)$ denote the complex symbol associated to the subcarrier $k$ of the input spatial stream during OFDM symbol $t$ defined accordingly to subclause 20.3.5.8.

The matrix $M_{0,}$ defined in (27), describes the signals transmitted from the two antennas during the pair of OFDM symbols with indices $2j$-1 and $2j$, as a function of the complex symbols $x_{2j-1}(k)$ and $x_{2j}(k)$.

$$M_0\left(x_{2j-1}(k), x_{2j}(k)\right) = \begin{bmatrix} x_{2j-1}(k) & x_{2j}(k) \\ -x_{2j}^{*}(k) & x_{2j-1}^{*}(k) \end{bmatrix} \tag{27}$$

During the two OFDM symbols, $2j$-1 and $2j$, the signals associated with the first antenna (first row of $M_1$) are exactly $x_{2j-1}(k)$ and $x_{2j}(k)$, whereas the signals associated with the second antenna are $-x^{*}_{2j}(k)$ and $x^{*}_{2j-1}(k)$, respectively.

The RATE-dependent parameters for 20 MHz, $N_{TX}$ = 2, $N_{SS}$ = 1 are defined in Table 020.

The RATE-dependent parameters for 40 MHz, $N_{TX}$ = 2, $N_{SS}$ = 1 are defined in Table 006.

**Table 020—Rate-dependent parameters for 20 MHz, NTX-STBC modes with $N_{SS}$ = 1**

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$ ) | Number of data sub-carriers ($N_{SD}$ ) | Number of pilots ($N_{SP}$ ) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$ ) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$ ) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 6 .75 | BPSK | 1/2 | 1 | 54 | 2 | 54 | 27 | 114 |
| 10.125 | BPSK | 3/4 | 1 | 54 | 2 | 54 | 40.5 | 115 |
| 13.5 | QPSK | 1/2 | 2 | 54 | 2 | 108 | 54 | 116 |
| 20.25 | QPSK | 3/4 | 2 | 54 | 2 | 108 | 81 | 117 |
| 27 | 16-QAM | 1/2 | 4 | 54 | 2 | 216 | 108 | 118 |
| 40.5 | 16-QAM | 3/4 | 4 | 54 | 2 | 216 | 162 | 119 |
| 54 | 64-QAM | 2/3 | 6 | 54 | 2 | 324 | 216 | 120 |
| 60.75 | 64-QAM | 3/4 | 6 | 54 | 2 | 324 | 243 | 121 |
| 67.5 | 64-QAM | 5/6 | 6 | 54 | 2 | 324 | 270 | 122 |

Since encoding takes place across pairs of MIMO-OFDM symbols in this subclause, the number of pad bits inserted in subclause 20.3.5.3 shall be sufficient to ensure that an even number of MIMO-OFDM symbols are transmitted in the PPDU.

For $N_{TX} = 3$, $N_{SS} = 1$ modes, and for $N_{TX} = 4$, $N_{SS} = 1$ modes, each data subcarrier transmits on two consecutive OFDM symbol pairs using the basic STBC encoding rule on two of the transmit antennas. The selection of the two active antennas on each data subcarrier is achieved through a circulation pattern given by

$$cir(k_d) = ((k_d \bmod 9) + \text{floor}(k_d/9)) \bmod N_{TX}, \quad (28)$$

where $k_d$ is the "data tone index". For subcarrier indices $k$, Table 021 lists the corresponding data tone indices for 20 MHz modes. For subcarrier indices $k$, Table 022 lists the corresponding data tone indices for 40 MHz modes.

**Table 021- Data tone indices as a function of subcarrier indices in 20 MHz modes.**

| Subcarrier index, $k$ | Data tone index, $k_d$ |
|---|---|
| $-28 \le k \le -22$ | $k+28$ |
| $-20 \le k \le -1$ | $k+27$ |
| $1 \le k \le 20$ | $k+26$ |
| $22 \le k \le 28$ | $k+25$ |

**Table 022— Data tone indices as a function of subcarrier indices in 40 MHz modes.**

| Subcarrier index, $k$ | Data tone index, $k_d$ |
|---|---|
| $-58 \le k \le -43$ | $k+58$ |
| $-41 \le k \le -15$ | $k+57$ |
| $-13 \le k \le -3$ | $k+56$ |
| $3 \le k \le 13$ | $k+51$ |
| $15 \le k \le 41$ | $k+50$ |
| $43 \le k \le 58$ | $k+49$ |

Table 023 displays the transmitted signals over two consecutive OFDM symbols in the NTX-STBC modes with $N_{SS}=1$, using the basic STBC encoding rule summarized in (27). For each data subcarrier $k$, the selection of the two antennas for the basic STBC encoding rule for 3TX and 4TX is achieved via the binary matrices $S_3(cir(k_d))$ and $S_4(cir(k_d))$, defined below, where $k_d$ is the data tone index corresponding to data subcarrier index $k$ (Table 021 and Table 022).

**Table 023— NTX-STBC-mode encoding rules for $N_{TX}$=2, 3, 4 and $N_{SS}$=1**

| $N_{TX}$ | Signal over OFDM symbol pair ($2j$-1, $2j$), $n$ odd |
|---|---|
| 2 | $M_0(x_{2j-1}(k), x_{2j}(k))$ |
| 3 | $(3/2)^{1/2}\, S_3(cir(k_d))\, M_0(x_{2j-1}(k), x_{2j}(k))$ |
| 4 | $2^{1/2}\, S_4(cir(k_d))\, M_0(x_{2j-1}(k), x_{2j}(k))$ |

Depending on the value of the data tone index $k_d$, the matrix $S_3(cir(k_d))$ assumes one of the three values shown in Figure 024. The values $S_3(0)$, $S_3(1)$, $S_3(2)$ indicate that the basic STBC encoding rule shall be applied to antenna pairs (1,3), (2,3) or (1,2), respectively. Similarly, depending on the values of $k_d$, the matrix $S_4(cir(k_d))$ takes on one of the four values shown in Figure 025. The values $S_4(0)$, $S_4(1)$, $S_4(2)$, $S4(2)$ indicate that the basic STBC encoding rule shall be applied to antenna pairs (1,3), (2,4) ,(1,4) or (2,3) respectively.

$$S_3(0)=\begin{bmatrix}1&0\\0&0\\0&1\end{bmatrix},\quad S_3(1)=\begin{bmatrix}0&0\\1&0\\0&1\end{bmatrix},\quad S_3(2)=\begin{bmatrix}1&0\\0&1\\0&0\end{bmatrix}$$

**Figure 024 – Antenna selection via $S_3$.**

$$S_4(0)=\begin{bmatrix}1&0\\0&0\\0&1\\0&0\end{bmatrix},\quad S_4(1)=\begin{bmatrix}0&0\\1&0\\0&0\\0&1\end{bmatrix},\quad S_4(2)=\begin{bmatrix}1&0\\0&0\\0&0\\0&1\end{bmatrix},\quad S_4(3)=\begin{bmatrix}0&0\\1&0\\0&1\\0&0\end{bmatrix}$$

**Figure 025 – Antenna selection via $S_4$.**

The RATE-dependent parameters for 20 MHz, $N_{TX}=3$, $N_{SS}=1$ are the same as those for the 20MHz, $N_{TX}=2$, $N_{SS}=1$, given by Table 022.
The RATE-dependent parameters for 20 MHz, $N_{TX}=4$, $N_{SS}=1$ are the same as those for the 20MHz, $N_{TX}=2$, $N_{SS}=1$, given by Table 022.
The RATE-dependent parameters for 40 MHz, $N_{TX}=2$, $N_{SS}=1$ are defined in Table 006.
The RATE-dependent parameters for 40 MHz, $N_{TX}=3$, $N_{SS}=1$ are the same as those for the 40MHz, $N_{TX}=2$, $N_{SS}=1$,given by Table 006.
The RATE-dependent parameters for 40 MHz, $N_{TX}=4$, $N_{SS}=1$ are the same as those for the 40MHz, $N_{TX}=2$, $N_{SS}=1$,given by Table 006.

### 20.3.5.10.2 NTX-STBC modes with more than one single spatial stream ($2 \le N_{SS} < N_{TX}$)

#### 20.3.5.10.2.1 Pilot tones in NTX-STBC modes with $N_{SS} \ge 2$

The pilot tones and their structure in NTX-STBC modes with $N_{SS} \ge 2$ follow those of the NTX-SDM modes described in subclause 20.3.5.9.1

#### 20.3.5.10.2.2 Data tones in NTX-STBC modes with $N_{SS} \ge 2$

For $n$=0,…,$N_{SS}$-1, let $x_{n,t}(k)$ represent the complex symbol from the spatial stream $n$, associated with subcarrier $k$ and OFDM symbol $t$.

The RATE-dependent parameters for 20 MHz, $N_{TX}=3$, $N_{SS}=2$ are defined in Table 003. In this configuration, the basic STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8. The following matrix, $M_1$, describes the signals transmitted from the three transmit antennas during the pair of OFDM symbols with indices $2j$-1 and $2j$, as a function of the complex symbols $x_{n,t}(k)$ $n$=0,1 and $t$=$2j$-1, $2j$.

$$M_1\left(x_{0,2j-1}(k),x_{0,2j}(k),x_{1,2j-1}(k),x_{1,2j}(k)\right)=\begin{bmatrix}x_{0,2j-1}(k)&x_{0,2j}(k)\\-x^*_{0,2j}(k)&x^*_{0,2j-1}(k)\\x_{1,2j-1}(k)&x_{1,2j}(k)\end{bmatrix}$$

The RATE-dependent parameters for 20 MHz, $N_{TX} = 4$, $N_{SS} = 2$ are defined in Table 003. In this configuration, the basic STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream, and on the third and fourth antennas using bits from the second spatial stream. The specific STBC encoding scheme detailed in this paragraph is represented by the following encoding matrix $M_2$:

$$M_2\left(x_{0,2j-1}(k), x_{0,2j}(k), x_{1,2j-1}(k), x_{1,2j}(k)\right) = \begin{bmatrix} x_{0,2j-1}(k) & x_{0,2j}(k) \\ -x^*_{0,2j}(k) & x^*_{0,2j-1}(k) \\ x_{1,2j-1}(k) & x_{1,2j}(k) \\ -x^*_{1,2j}(k) & x^*_{1,2j-1}(k) \end{bmatrix}$$

The RATE-dependent parameters for 20 MHz, $N_{TX} = 4$, $N_{SS} = 3$ are defined in Table 004. In this configuration, the basic STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8. Bits from the third spatial stream shall be mapped to subcarriers of the fourth transmit antenna, according to subclause 20.3.5.8. The specific STBC encoding scheme detailed in this paragraph is represented by the following encoding matrix $M_3$:

$$M_3\left(x_{0,2j-1}(k), x_{0,2j}(k), x_{1,2j-1}(k), x_{1,2j}(k), x_{2,2j-1}(k), x_{2,2j}(k)\right) = \begin{bmatrix} x_{0,2j-1}(k) & x_{0,2j}(k) \\ -x^*_{0,2j}(k) & x^*_{0,2j-1}(k) \\ x_{1,2j-1}(k) & x_{1,2j}(k) \\ x_{2,2j-1}(k) & x_{2,2j}(k) \end{bmatrix}$$

The RATE-dependent parameters for 40 MHz, $N_{TX} = 3$, $N_{SS} = 2$ are defined in Table 007. In this configuration, the basic STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8.

The RATE-dependent parameters for 40 MHz, $N_{TX} = 4$, $N_{SS} = 2$ are defined in Table 007. In this configuration, the basic STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream, and on the third and fourth antennas using bits from the second spatial stream.

The RATE-dependent parameters for 40 MHz, $N_{TX} = 4$, $N_{SS} = 3$ are defined in Table 008. In this configuration, the basic STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8. Bits from the third spatial stream shall be mapped to subcarriers of the fourth transmit antenna, according to subclause 20.3.5.8.

### 20.3.6 Clear channel assessment

PLCP shall provide the capability to perform CCA and report the result to the MAC. The CCA mechanism shall detect a “medium busy” condition with a performance specified in 20.3.10.5. This medium status report is indicated by the primitive PHY_CCA.indicate.

### 20.3.7 PLCP data modulation and modulation rate change

The PLCP preamble shall be transmitted using a set of OFDM-modulated fixed waveforms, specified in subclause 20.3.3 for each transmit antenna for each mode of operation defined in the MIMO-OFDM PHY. The SIG-N field, composed of 54 bits, shall indicate the bandwidth, modulation, code rate, code type, number of TX antennas, and number of spatial streams that shall be used to transmit the MPDU. The transmitter (receiver) shall initiate the modulation constellation, code rate, code type, and other configuration parameters according to the CONFIG indicated in the SIG-N field. The MPDU transmission rate shall be set by the DATARATE parameter in the TXVECTOR, issued with the PHY-TXSTART.request primitive described in 20.2.

### 20.3.8 PMD operating specifications

Subclauses 20.3.8.1 through 20.3.8.8 provide general specifications for the various modes and options defined in the MIMO-OFDM PMD sublayer. These specifications apply to both the receive and transmit functions and general operation of the MIMO-OFDM PHY.

#### 20.3.8.1 TX Block diagram

The general block diagram of the transmitter for the MIMO-OFDM PHY is shown in Figure 024. The blocks that are shaded in the figure may be replicated $N_{TX}$ times in a MIMO-OFDM system with $N_{TX}$ transmit antennas.

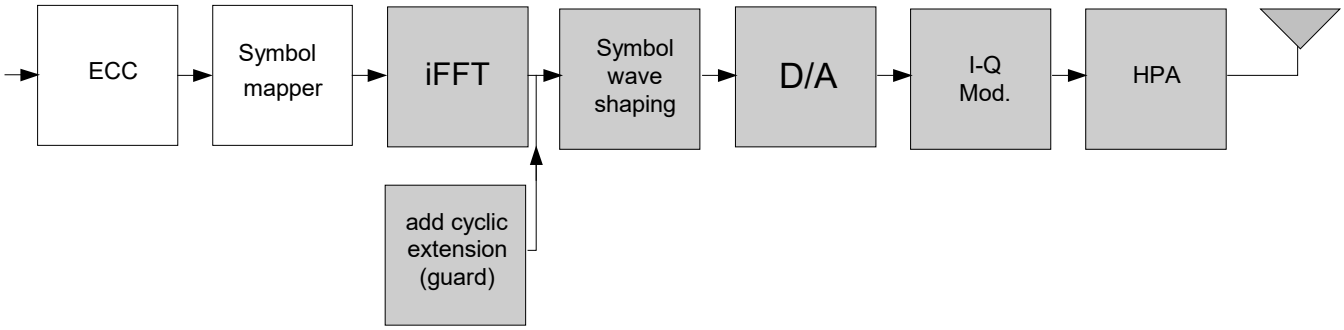



**Figure 024 – Transmitter block diagram for the MIMO-OFDM PHY**

#### 20.3.8.2 Regulatory requirements

All systems shall comply with the local regulatory requirements for operation in the band in which they are implemented. For 2.4 GHz operation, refer to FCC 15.247, 15.249, 15.205, and 15.209 for the USA; ETS 300-328 for Europe; and MPHPT article 49-20 for Japan. For 5 GHz operation in the USA, refer to FCC CFR47, Part 15, sections 15.205 and 15.209; and Subpart E, sections 15.401-15.407.

The documents listed here are provided for information only, and are subject to change or revision at any time.

#### 20.3.8.3 Operating channel frequencies

The range of operating frequencies for the MIMO-OFDM PHY shall be 2400-2497 MHz and 4920-5805 MHz. The channel numbering shall be as defined in IEEE 802.11b-1999 clause 18.4.6.2, and clause 17.3.8.3.2 of IEEE P802.11j/D1.5, May 2004. The relationship between center frequency and channel number is given by the following equations:

$$\text{Channel center frequency} = 5000 + (\text{channel number}) \times 5 \text{ (MHz) for center frequency} > 5000 \text{ MHz} \quad (25)$$

$$\text{Channel center frequency} = 4000 + (\text{channel number}) \times 5 \text{ (MHz) for } 4900 \leq \text{center frequency} \leq 5000 \text{ MHz} \quad (26)$$

40 MHz operation shall be restricted to the 5 GHz band only. Each 40 MHz channel shall occupy two 20 MHz channels, with the center frequency of the 40 MHz transmission selected to be midway between the center frequencies of the two occupied 20 MHz channels. For example, if the two occupied 20 MHz channels are centered at channel number 149 and 153, then the 40 MHz transmission shall be centered at channel number 151.

#### 20.3.8.4 Spurious emissions

The spurious emissions shall conform to IEEE 802.11a-1999 subclause 17.3.8.4

#### 20.3.8.5 TX RF delay

The TX RF delay shall follow IEEE 802.11a-1999 subclause 17.3.8.5.

#### 20.3.8.6 Slot time

The slot time shall follow IEEE 802.11a-1999 subclause 17.3.8.6 for 5 GHz bands and IEEE 802.11g-1999 subclause 19.4.4 for 2.4 GHz bands.

#### 20.3.8.7 Transmit and receive antenna port impedance

The transmit and receive antenna port impedance for each transmit and receive antenna shall follow IEEE 802.11a-1999 subclause 17.3.8.7.

#### 20.3.8.8 Transmit and receive operating temperature range

The transmit and receive temperature range shall follow IEEE 802.11a-1999 subclause 17.3.8.8.

### 20.3.9 PMD TX specifications

Subclauses 20.3.9.1 through 20.3.9.7 describe the transmit specifications associated with the PMD sublayer. In general, these are specified by primitives from the PLCP, and the transmit PMD entity provides the actual means by which the signals required by the PLCP primitives are imposed into the medium.

#### 20.3.9.1 TX power levels

The maximum allowable output power shall conform to national regulatory constraints on the maximum radiated power allowed in any frequency band.

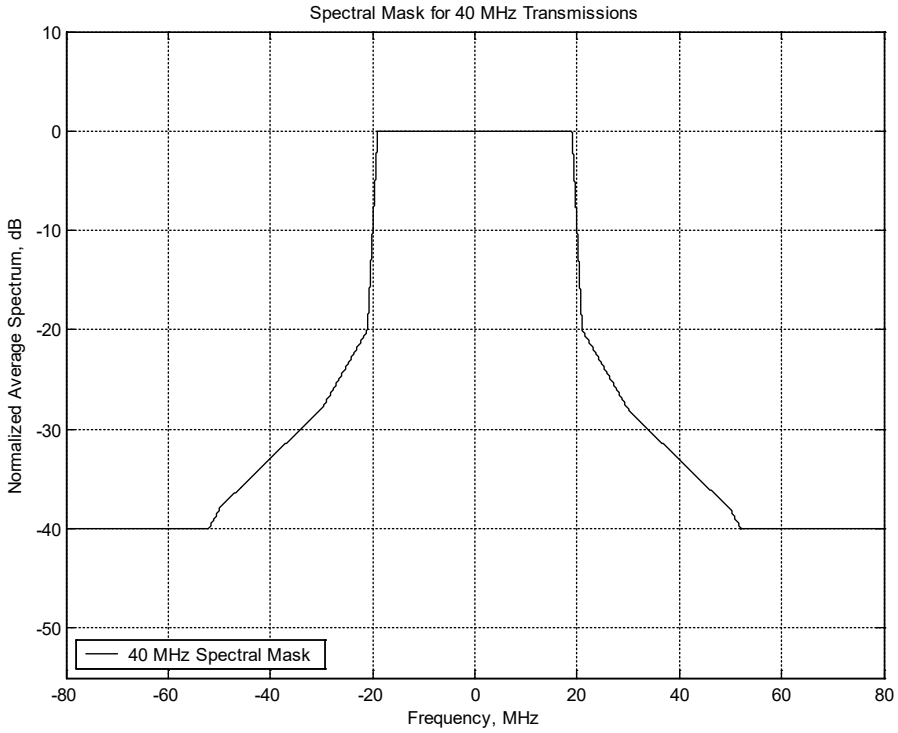



**Figure 025 –Transmit spectrum mask for 40 MHz transmissions**

### 20.3.9.2 TX spectrum mask

The transmitted spectral density of the transmitted signal shall conform to subclause IEEE 802.11a-1999 17.3.9.2 for all 20 MHz transmissions. The transmitted spectrum for 40 MHz transmissions shall have a 0 dBr bandwidth not exceeding 38 MHz, -20 dBr at 21 MHz frequency offset, -28 dBr at 30 MHz frequency offset, -38 dBr at 50 MHz frequency offset, and -40 dBr at 52 MHz frequency offset and above. The transmitted spectral density of the 40 MHz transmitted signal shall fall within the spectral mask shown in Figure 025. The measurements shall be made using a 100 kHz resolution bandwidth and a 30 kHz video bandwidth.

### 20.3.9.3 TX spurious

Spurious transmissions from Clause 20 compliant devices shall conform to national regulations.

### 20.3.9.4 TX center frequency tolerance

The transmitted center frequency tolerance shall be ±20 ppm maximum for 5 GHz bands and ±25 ppm for 2.4 GHz bands. The transmit center frequency and the symbol clock frequency for all transmit antennas shall be derived from the same reference oscillator.

.

### 20.3.9.5 TX symbol clock frequency tolerance

The symbol clock frequency tolerance shall be ±20 ppm maximum for 5 GHz bands and ±25 ppm for 2.4 GHz bands. The transmit center frequency and the symbol clock frequency for all transmit antennas shall be derived from the same reference oscillator.

### 20.3.9.6 Modulation accuracy

Transmit modulation accuracy specifications are described in this subclause. The test method is described in 20.3.9.7.

#### 20.3.9.6.1 TX center frequency leakage

TX center frequency leakage shall follow IEEE 802.11a-1999 subclause 17.3.9.6.1 for all 20 MHz modes of transmission. For 40 MHz modes, the center frequency leakage shall not exceed -18 dB relative to overall transmitted power, or,equivalently, +2 dB relative to the average energy of the rest of the subcarriers.

#### 20.3.9.6.2 TX spectral flatness

For 20 MHz transmissions, the average energy of the constellation in each of the spectral lines -16…-1 and +1…+16 will deviate no more than ±2 dB of their average energy. The average energy of the constellations in each of the spectral lines -28…-17 and +17…+28 will deviate no more than +2/-4 dB from the average energy of the spectral lines -16…-1 and +1…+16.

For 40 MHz transmissions, the average energy of the constellation in each of the spectral lines -32…-3 and +3…+32 will deviate no more than ±2 dB of their average energy. The average energy of the constellations in each of the spectral lines -58…-33 and +33…+58 will deviate no more than +2/-4 dB from the average energy of the spectral lines -32…-3 and +3…+32.

#### 20.3.9.6.3 TX constellation error

The relative constellation RMS error, averaged over subcarriers, transmit spatial streams, OFDM frames, and packets, shall not exceed a constellation and code rate dependent value according to Table 020 for the all modes in which the number of spatial streams is equal to the number of transmit antennas.

**Table 020—Allowed relative constellation error versus constellation type and code rate**

| Constellation size | Code Rate | Relative constellation error (dB) |
|---|---|---|
| 16-QAM | 1/2 | -17 |
| 16-QAM | 3/4 | -20 |
| 64-QAM | 2/3 | -24 |
| 64-QAM | 3/4 | -26 |
| 64-QAM | 5/6 | -27 |

#### 20.3.9.7 TX modulation accuracy (EVM) test

The transmit modulation accuracy test shall be performed by instrumentation capable of converting the transmitted signals into a stream of complex samples at 20 Msamples/s or more for 20 MHz modes, and 40 Msamples/s or more for 40 MHz modes, with sufficient accuracy in terms of I/Q arm amplitude and phase balance, DC offsets, phase noise, etc. A possible embodiment of such a setup is converting the signals to a low IF frequency with a microwave synthesizer, sampling the signals with a digital oscilloscope, and decomposing them digitally into quadrature components.

The test procedure for this requirement is as follows: Matrices $H_{1TX}$, $H_{2TX}$, $H_{3TX}$, and $H_{4TX}$ are defined to give the connections from the transmit antennas to the receive antennas for the 1TX, 2TX, 3TX, and 4TX cases respectively. They are specified as follows:

$$H_{1TX} = \alpha \cdot 1$$

$$H_{2TX} = \alpha \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

$$H_{3TX} = \alpha \begin{bmatrix} -1 & 2 & 2 \\ 2 & -1 & 2 \\ 2 & 2 & -1 \end{bmatrix}$$

$$H_{4TX} = \alpha \begin{bmatrix} -1 & 1 & 1 & 1 \\ 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \end{bmatrix} \quad (27)$$

The elements of the above matrices $h_{ij}$ specify the connection from the $j^{th}$ transmitter to the $i^{th}$ receiver, where $h_{ij}$ is the element of the $i^{th}$ row and $j^{th}$ column where $i = 1,\ldots, N_{RX}$ and $j = 1,\ldots, N_{TX}$. The attenuation $\alpha$ is chosen to ensure an appropriate received signal power at the test equipment. Figure 026 shows an example test setup for a 2TX mode.

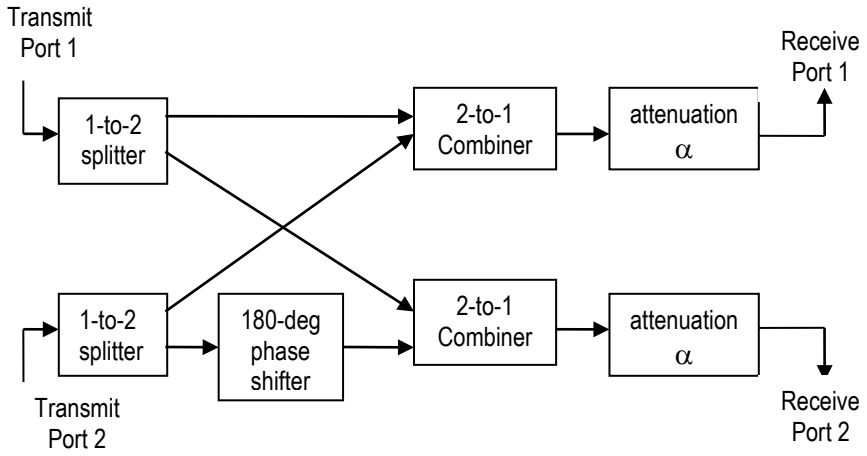



**Figure 026 –EVM test setup**

The 180 degree phase shifter shall be 180 +/- 10 degrees. The relative amplitudes of the connections $h_{ij}$ shall be within +/-1 dB of the relative values specified in the H matrices above.

The sampled signals shall be processed in a manner similar to an actual receiver, according to the following steps, or an equivalent procedure:

a) Start of frame shall be detected.
b) Transition from short sequences to channel estimation sequences shall be detected, and fine timing (with one sample resolution) shall be established.
c) Coarse and fine frequency offsets shall be estimated.
d) The packet shall be derotated according to estimated frequency offset.
e) The complex channel response coefficients shall be estimated for each of the subcarriers.
f) For each of the data OFDM symbols: transform the symbol into subcarrier received values, estimate the phase from the pilot subcarriers, derotate the subcarrier values according to estimated phase, and apply an

MMSE channel equalizer to each vector of received subcarrier values based on complex estimated channel response coefficients found in (e).

g) For each data-carrying subcarrier of each transmitted stream, find the closest constellation point and compute the Euclidean distance from it.

h) Compute the RMS average of all errors in a packet. It is given by:

$$Error_{RMS} = \frac{\sum_{i=1}^{N_f} \sqrt{\frac{\sum_{l=1}^{N_{SS}} \sum_{j=1}^{L_P} \sum_{k=1}^{N_{ST}} \{(I(i,j,k,l) - I_0(i,j,k,l))^2 + (Q(i,j,k,l) - Q_0(i,j,k,l))^2\}}{N_{ST} L_P P_0 N_{SS}}}}{N_f} \quad (28)$$

where

$L_P$ is the length of the packet;

$N_{SS}$ is the number of spatial streams;

$N_f$ is the number of frames for the measurement;

$N_{ST}$ is the total number of subcarriers (data and pilots) per OFDM symbol;

$(I_0(i,j,k,l), Q_0(i,j,k,l))$ denotes the ideal symbol point of the $i^{th}$ frame, $j^{th}$ OFDM symbol of the frame, $k^{th}$ subcarrier, and $l^{th}$ spatial stream of the OFDM symbol in the complex plane;

$(I(i,j,k,l), Q(i,j,k,l))$ denotes the observed point of the $i^{th}$ frame, $j^{th}$ OFDM symbol of the frame, $k^{th}$ subcarrier, and $l^{th}$ spatial stream of the OFDM symbol in the complex plane;

$P_0$ is the average power of the constellation.

The vector error on a phase plane is shown in Figure 121 in IEEE 802.11a-1999 subclause 17.3.9.7.

The test shall be performed over at least 20 frames ($N_f$), and the RMS average shall be taken. The packets under test shall be at least 16 OFDM symbols long. Random data shall be used for the symbols.

### 20.3.10 PMD RX specifications

Subclauses 20.3.10.1 through 20.3.10.5 describe the receive specifications associated with the PMD sublayer.

#### 20.3.10.1 RX minimum input level sensitivity

The packet error rate (PER) shall be less than 10% at a PSDU length of 1000 bytes for rate-dependent input levels shall be the numbers listed in Table 021 or less. The minimum input levels are measured at the antenna connectors and are referenced as the average power per receive antenna.

**Table 021—Receiver minimum input level sensitivity**

| Constellation size | Code Rate | Minimum sensitivity (dBm) |
|---|---|---|
| BPSK | ½ | -82 |
| BPSK | ¾ | -81 |
| QPSK | ½ | -79 |
| QPSK | ¾ | -77 |
| 16-QAM | ½ | -74 |
| 16-QAM | ¾ | -70 |

| | | |
|---|---|---|
| 64-QAM | 2/3 | -66 |
| 64-QAM | ¾ | -65 |
| 64-QAM | 5/6 | -64 |

#### 20.3.10.2 RX maximum input level

The RX maximum input level shall be defined as the maximum at any or all antennas, and shall follow IEEE 802.11a-1999 subclause 17.3.10.4 for the 4920-5805 MHz band, and follow IEEE 802.11g-2003 subclause 19.5.3 for the 2400-2497 MHz band.

#### 20.3.10.3 CCA sensitivity

The CCA sensitivity of all Clause 20 compliant devices shall conform to IEEE 802.11a-2003 subclause 17.3.10.5. When operating in 40 MHz mode, the receiver shall also provide a secondary channel carrier sense. The start of a valid OFDM transmission at a receive level equal to or greater than the minimum 6 Mbit/s sensitivity (-82 dBm) shall cause the secondary channel CCA to indicate busy with a probability of >90% within 4us. The receiver shall hold the secondary channel CCA busy for any signal 20 dB above the minimum 6 Mbit/s sensitivity (-62 dBm).

### 20.3.11 PLCP TX procedure

The transmit PLCP is shown in Figure 029. In order to transmit data, PHY-TXSTART.request shall be enabled so that the PHY entity shall be in the transmit state. Further, the PHY shall be set to operate at the appropriate frequency through station management via the PLME. Other transmit parameters, such as DATARATE, TRANSMISSION_MODE, NUM_STREAMS, and TXPWR_LEVEL, are set via the PHY-SAP with the PHY-TXSTART.request(TXVECTOR), as described in 20.2.

A clear channel shall be indicated by PHY-CCA.indicate(IDLE). The MAC considers this indication before issuing the PHY-TXSTART.request. Transmission of the PPDU or A-PPDU shall be initiated after receiving the PHYTXSTART. request(TXVECTOR) primitive. The TXVECTOR elements for the PHY-TXSTART.request are the PLCP header parameters LENGTH, DATARATE, TRANSMISSION_MODE, NUM_STREAMS, CODE_TYPE, SERVICE, LPI, and BURST_DURATION, and the PMD parameter TXPWR_LEVEL.

The PLCP shall issue PMD_TXPWRLVL, PMD_RATE, PMD_NUM_STREAMS, and PMD_TRANSMISSION_MODE, primitives to configure the PHY. The PLCP shall then issue a PMD_TXSTART.request, and transmission of the PLCP preamble and PLCP header, based on the parameters passed in the PHY-TXSTART.request primitive will begin. Once PLCP preamble transmission is started, the PHY entity shall immediately initiate data scrambling and data encoding. The scrambled and encoded data shall then be exchanged between the MAC and the PHY through a series of PHYDATA.request(DATA) primitives issued by the MAC, and PHY-DATA.confirm primitives issued by the PHY. The modulation rate change, if any, shall be initiated from the SERVICE field data of the PLCP header, as described in 20.3.2. The PHY proceeds with PSDU transmission through a series of data octet transfers from the MAC. The PLCP header parameter, SERVICE, and PSDU are encoded by the convolutional encoder with the bit-stealing function described in 20.3.5.5. At the PMD layer, the data octets are sent in bit 0–7 order and presented to the PHY through PMD_DATA.request primitives. In the PMD, the GI shall be inserted in every OFDM symbol as a countermeasure against severe delay spread.

Transmission of a PSDU can be prematurely terminated by the MAC through the primitive PHY-TXEND.request. PHY-TXSTART shall be disabled by the issuance of the PHY-TXEND.request. Normal transmission of a PSDU occurs after the transmission of the final bit of the last PSDU octet, according to the number of bytes supplied in the PLCP header LENGTH.

Each PHY-TXEND.request is acknowledged with a PHY-TXEND.confirm primitive from the PHY. If the coded PSDU (C-PSDU) is not multiples of the OFDM symbol, bits shall be stuffed to make the C-PSDU length multiples of the OFDM symbol.

If an aggregated PPDU (A-PPDU) is being transmitted as indicated by the TXVECTOR LPI parameter, the PHY will wait for the next PHY_TXSTART.request from the MAC. The process of transmitting the subsequent MPDUs as part of the A-PPDU is identical to the first MPDU except that the PLCP will not issue PMD primitives to configure the PHY.

Normal termination of the A-PPDU occurs at the termination of the transmission of the last PSDU, indicated by the PHY PLCP header LPI field. A permaturely terminated PSDU transmission from the MAC will prematurely terminate the transmission of the A-PPDU.

The A-PPDU transmission shall be completed and the PHY entity shall enter the receive state (i.e., PHY-TXSTART shall be disabled).

A typical state machine implementation of the transmit PLCP is provided in Figure 027. Requests (.req) and confirmations (.confirm) are issued once with designated states.

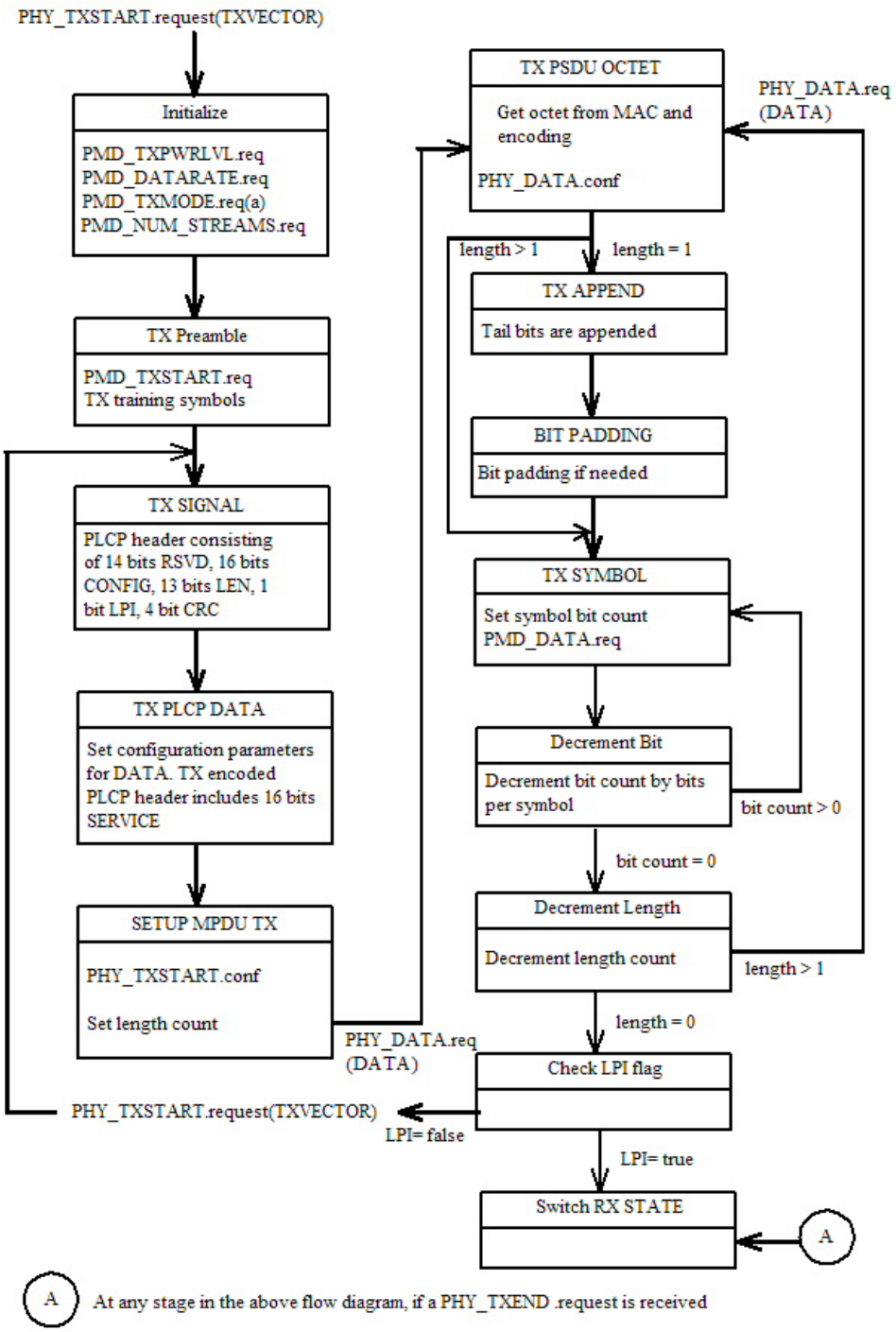



**Figure 027 –PLCP transmit state machine**

### 20.3.12 PLCP RX procedure

The receive PLCP is shown in Figure 030. In order to receive data, PHY-TXSTART.request shall be disabled so that the PHY entity is in the receive state. Further, through station management (via the PLME) the PHY is set to the appropriate frequency. Other receive parameters, such as RSSI and indicated DATARATE, TRANSMISSION_MODE, NUM_STREAMS, CODE_TYPE, LPI, and BURST_DURATION may be accessed via the PHY-SAP.

Upon receiving the transmitted PLCP preamble, PMD_RSSI.indicate shall report a significant received signal strength level to the PLCP. This indicates activity to the MAC via PHY_CCA.indicate. PHY_CCA.indicate(BUSY) shall be issued for reception of a signal prior to correct reception of the PLCP frame. The PMD primitive PMD_RSSI is issued to update the RSSI and parameter reported to the MAC.

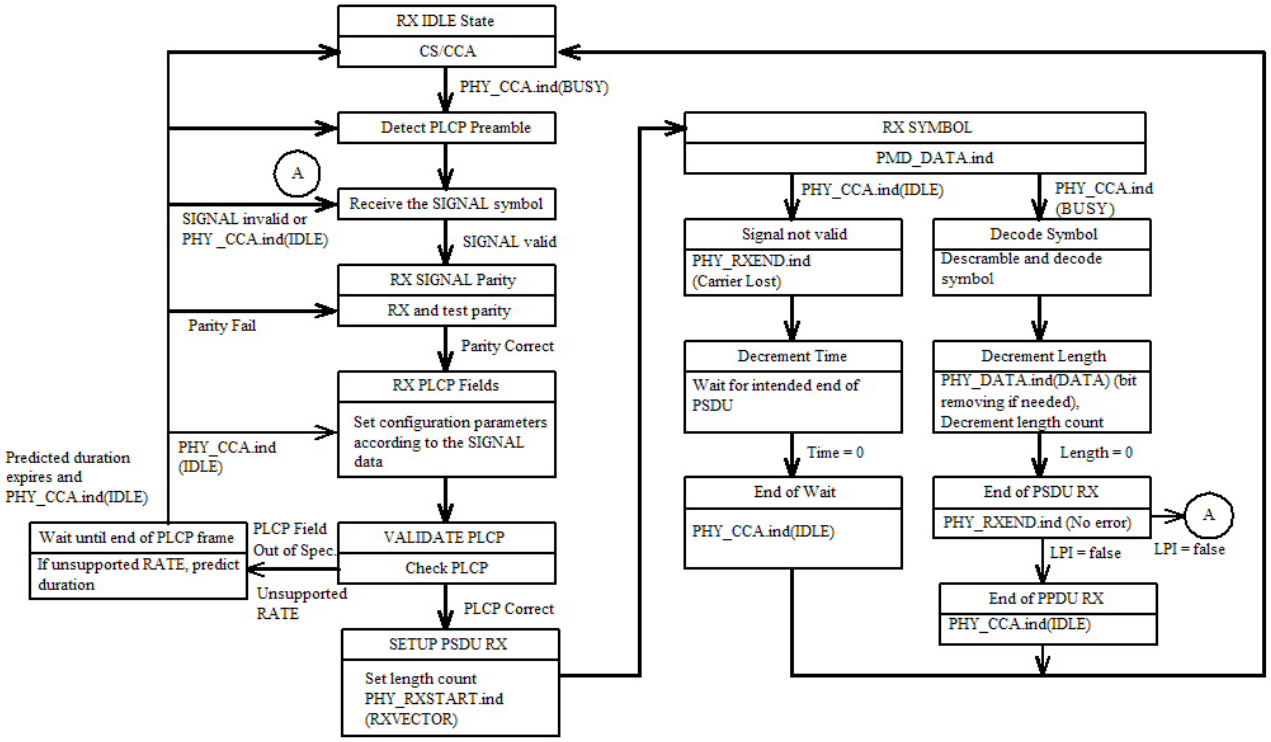



**Figure 028 – PLCP receive state machine**

After PHY-CCA.indicate is issued, the PHY entity shall begin receiving the training symbols and searching for the SIGNAL in order to set the length of the data stream, the demodulation type, and the decoding rate. Once the SIGNAL is detected without any errors detected by the CRC checker, FEC decode shall be initiated and the PLCP SERVICE fields and data shall be received, and decoded. Should the status of CCA return to the IDLE state during reception prior to completion of the full PLCP processing, the PHY receiver shall return to the RX IDLE state.

If the PLCP header reception is successful (and the SIGNAL field is completely recognizable and supported), a PHY-RXSTART.indicate(RXVECTOR) shall be issued. The RXVECTOR associated with this primitive includes the SIGNAL fields, the SERVICE field, the PSDU length in bytes, and the RSSI. Also, in this case, the HT PHY will ensure that the CCA shall indicate a busy medium for the intended duration of the transmitted frame, as indicated by the LENGTH field. The received PSDU bits are assembled into octets, decoded, and presented to the MAC using a series of PHY-DATA.indicate(DATA) primitive exchanges. The rate change indicated in the SIGNAL field shall be initiated from the SERVICE field data of the PLCP header, as described in 20.3.2. The PHY shall proceed with PSDU reception. After the reception of the final bit of the last PSDU octet indicated by the PLCP header LENGTH field, the receiver shall transition to the RX IDLE state if LPI is 1 or to the RX SIGNAL state if LPI is 0 in the RXVECTOR associated with this primitive, as shown in Figure 030. If the LPI is 1 in the RXVECTOR, a PHY-RXEND.indicate(NoError) primitive shall also be issued.

In the event that a change in the RSSI causes the status of the CCA to return to the IDLE state before the complete reception of the PSDU, as indicated by the PLCP LENGTH field, the error condition PHYRXEND.indicate(CarrierLost) shall be reported to the MAC. The HT PHY will ensure that the CCA

indicates a busy medium for the intended duration of the transmitted packet. If the indicated rate in the SIGNAL field is not receivable, a PHY-RXSTART.indicate will not be issued. The PHY shall issue the error condition PHY-RXEND.indicate(UnsupportedRate). If the PLCP header is receivable, but the FCS check of the PLCP header is not valid, a PHY-RXSTART.indicate will not be issued. The PHY shall issue the error condition PHY-RXEND.indicate(FormatViolation). Any data received after the indicated data length are considered pad bits (to fill out an OFDM symbol) and should be discarded. A typical state machine implementation of the receive PLCP is given in Figure 028.

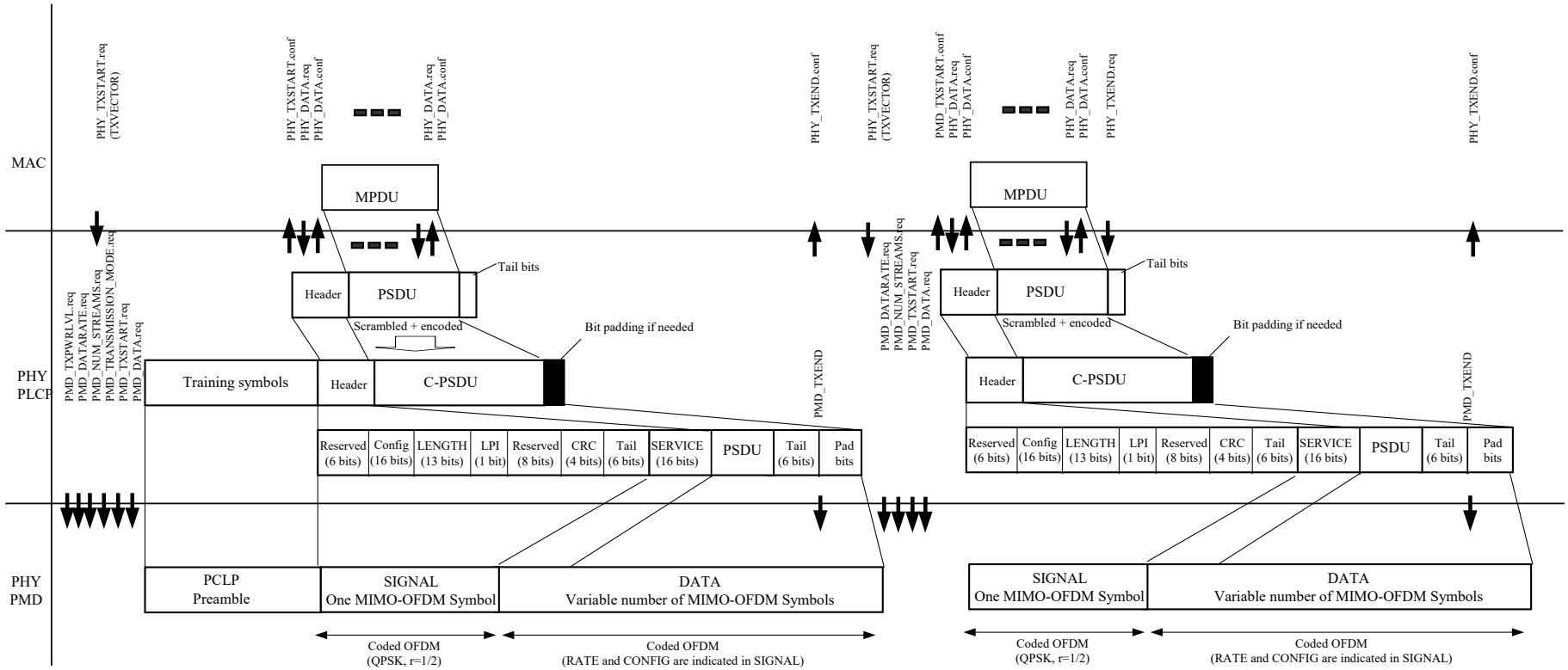



**Fig. 029 PLCP transmit procedure for A-PPDU transmission in greenfield 20 MHz modes**

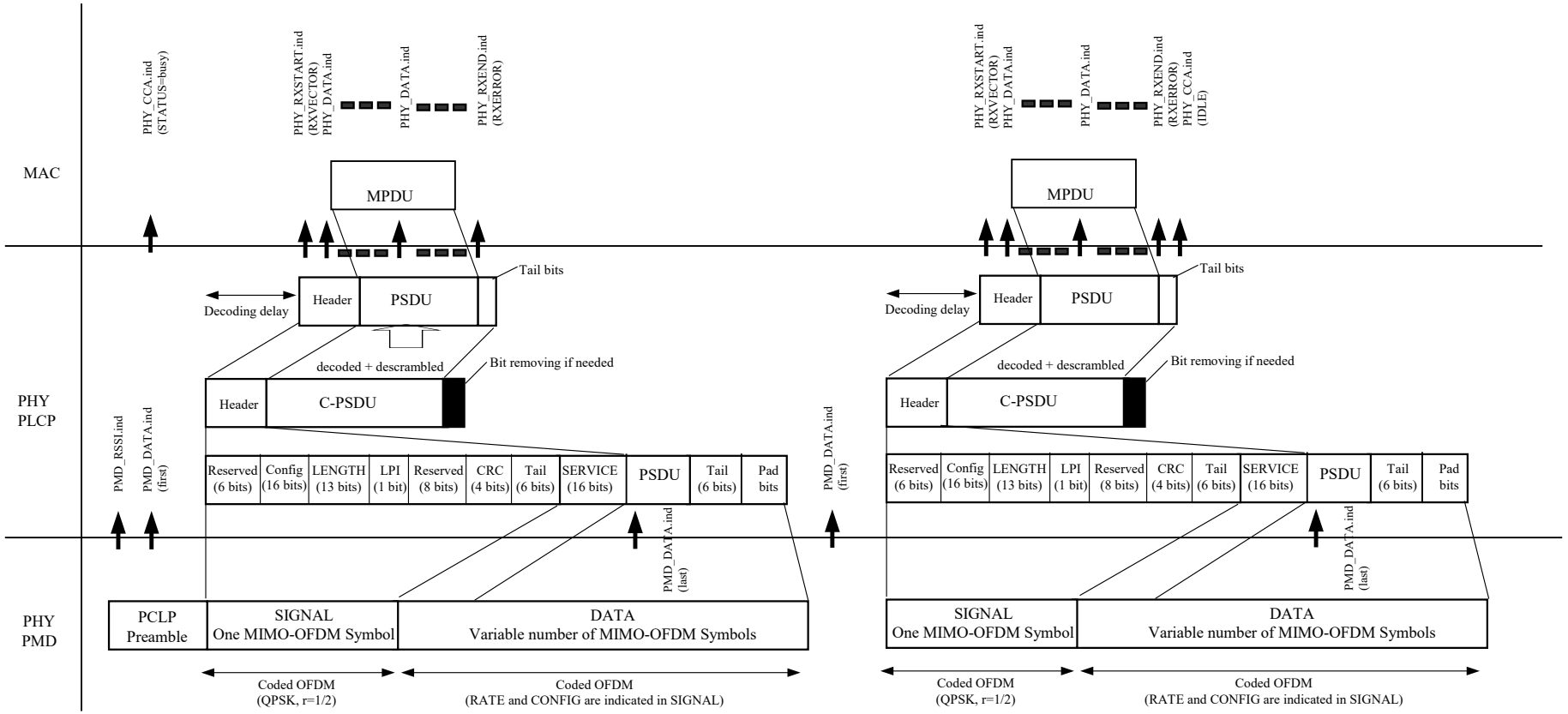



**Fig. 030 PLCP receive procedure for A-PPDU reception in greenfield 20 MHz modes**

# 20.4 MIMO-OFDM PMD operating specifications

### 20.4.1 PLME_SAP sublayer management primitives

Table 20.4.2T1 lists the MIB attributes that may be accessed by the PHY entities and the intralayer of higher level LMEs. These attributes are accessed via the PLME-GET, PLME-SET, PLME-RESET, and PLME-CHARACTERISTICS primitives defined in 10.4.

### 20.4.2 MIMO-OFDM management information base

All MIMO-OFDM PHY MIB attributes are defined in Clause 13, with specific values defined in Table 20.4.2.T1. The column titled "Operational semantics" in Table 20.4.2.T1 contains two types: static and dynamic. Static MIB attributes are fixed and cannot be modified for a given PHY implementation. Dynamic MIB attributes can be modified by some management entity.

**Table 20.4.2T1 MIB attribute default values/ranges**

| Managed Object | Default Value / Range | Operational Semantics |
|---|---|---|
| dot11 PHY Operation Table | | |
| dot11PHYtype | HTP (Value to be assigned) | Static |
| dot11CurrentRegDomain | Implementation dependent | Static |
| dot11TempType | Implementation dependent | Static |
| **dot11 PHY Antenna Table** | | |
| dot11CurrentTxAntenna | Implementation dependent | Dynamic |
| dot11DiversitySupport | Implementation dependent | Static |
| dot11CurrentRxAntenna | Implementation dependent | Dynamic |
| **Dot11 PHY Tx Power Table** | | |
| dot11NumberSupportedPowerLevels | Implementation dependent | Static |
| dot11TxPowerLevel1 | Implementation dependent | Static |
| dot11TxPowerLevel2 | Implementation dependent | Static |
| dot11TxPowerLevel3 | Implementation dependent | Static |
| dot11TxPowerLevel4 | Implementation dependent | Static |
| dot11TxPowerLevel5 | Implementation dependent | Static |
| dot11TxPowerLevel6 | Implementation dependent | Static |
| dot11TxPowerLevel7 | Implementation | Static |

| | | |
|---|---|---|
| | dependent | |
| dot11TxPowerLevel8 | Implementation dependent | Static |
| dot11CurrentTxPowerLevel | Implementation dependent | Dynamic |
| **dot11 Phy DSSS Table** | | |
| dot11CurrentChannel | Implementation dependent | Dynamic |
| **dot11 Reg Domains Supported Table** | | |
| dot11RegDomainsSupportedValue (s) | Implementation dependent | Static |
| **dot11 PHY Antennas List Table** | | |
| dot11SupportedTxAntenna | Implementation dependent | Static |
| dot11SupportedRxAntenna | Implementation dependent | Static |
| dot11DiversitySelectionRx | Implementation dependent | Dynamic |
| **dot11 Supported Data Rates Tx Table** | | |
| dot11SupportedDataratesTxValue | See Clause 10.4.4.2 rate code columns of Tables 003-009 and Table 018 | Static |
| **dot11 Supported Data Rates Rx Table** | | |
| dot11SupportedDataRatesRxValue | See Clause 10.4.4.2 rate code columns of Tables 003-009 and Table 018 | Static |
| **dot11 PHY HTP Table** | | |
| dot11CurrentFrequency | Implementation dependent | Dynamic |
| dot11SupportedTransmissionModes | Assign optional types in TRANSMISSION_MODE of Table 001 to bits in bit mask | Static |
| dot11SupportedNumStreams | X'0' = Support 1 and 2 streams<br>X'1' = Support 1, 2, and 3 streams<br>X'2' = Support 1, 2, and 4 streams<br>X'3' = Support 1, 2, 3, and 4 streams | Static |
| dot11SupportedCodeTypes | X'0' = convolutional only<br>X'1' = convolutional and LDPC | Static |

### 20.4.3 MIMO-OFDM TXTIME calculation

The value of the TXTIME parameter returned by the PLME-TXTIME.confirm primitive shall be calculated according to the following equation:

TXTIME = $TXTIME_{CONV}$ if CODE_TYPE is convolutional and $TXTIME_{LDPC}$ if CODE_TYPE is LDPC

where

$$TXTIME_{CONV} = T_{MIXED} + T_{PREAMBLE} + T_{SIGNAL} + T_{SYM} \times \text{Ceiling}\left((16 + 8 \times LENGTH + 6 \times N_{ES})/N_{DBPS}\right)$$

$$TXTIME_{LDPC} = T_{MIXED} + T_{PREAMBLE} + T_{SIGNAL} + T_{SYM} \cdot N_{S1}$$

$T_{MIXED}$ is 20μs if TRANSMISSION_MODE is a mixed-mode and 0μs if it is a greenfield mode

$T_{PREAMBLE}$ is 16μs if TRANSMISSION_MODE specifies $N_{TX} = 2$ and 28μs if TRANSMISSION_MODE specifies $N_{TX} = 3$ or 4

$T_{SIGNAL}$ is 4μs

$N_{DBPS}$ is derived from the DATARATE parameter (Ceiling is a function that returns the smallest integer value greater than or equal to its argument value)

$N_{S1}$ is defined in subclause 20.3.5.7.3.

### 20.4.4 MIMO-OFDM PHY characteristics

**Table 20.4.4.1—MIMO-OFDM PHY characteristics**

| Characteristic | Value |
|---|---|
| aSlotTime | 9 μs |
| aSIFSTime | 16 μs |
| aRIFSTime | 2 μs |
| aCCATime | <4 μs |
| aRxTxTurnaroundTime | Implementation dependent as long as the requirements of aSIFSTime are met. |
| aTxRxTurnaroundTime | Implementation dependent as long as the requirements of aSIFSTime are met. |
| aTxPLCPDelay | Implementation dependent as long as the requirements of aRxTxTurnaroundTime are met. |
| aRxPLCPDelay | Implementation dependent as long as the requirements of aSIFSTime and aCCATime are met |
| aRxTxSwitchTime | Implementation dependent |
| aTxRampOnTime | Implementation dependent as long as the requirements of aRxTxTurnaroundTime are met |
| aTxRampOffTime | Implementation dependent as long as the requirements of aSIFSTime are met |
| ATxRFDelay | Implementation dependent as long as the requirements of aRxTxTurnaroundTime are met |
| ARxRFDelay | Implementation dependent as long as the requirements of aSIFSTime and aCCATime are met |
| aAirPropagationTime | <<1 μs |
| aMACProcessingDelay | <2 μs |
| aPreambleLength | 16 μs |
| aPLCPHeaderLength | 4 μs |
| aMPDUMaxLength | 8191 |
| aCWmin | 15 |
| aCWmax | 1023 |

# 20.5 MIMO-OFDM operating specifications

## 20.5.1 Scope and field of application

This subclause describes the PMD services provided to the PLCP for the MIMO-OFDM PHY.

## 20.5.2 Overview of service

The MIMO-OFDM sublayer accepts PLCP sublayer service primitives and provides the actual means by which data is transmitted or received from the medium. The combined functions of the MIMO-OFDM PMD sublayer primitives and parameters for the receive function result in a data stream, timing information, and associated received signal parameters being delivered to the PLCP sublayer. A similar functionality is provided for data transmission.

## 20.5.3 Overview of interactions

The primitives associated with the PLCP sublayer to the MIMO-OFDM fall into two basic categories

a) Service primitives that support PLCP peer-to-peer interactions;
b) Service primitives that have local significance and that support sublayer-to-sublayer interactions.

## 20.5.4 Basic services and options

All of the service primitives described in this subclause are considered mandatory, unless otherwise specified.

### 20.5.4.1 PMD_SAP peer-to-peer service primitives

Table 20.5.4.1 indicates the primitives for peer-to-peer interactions.

**Table 20.5.4.1 PMD_SAP peer-to-peer services**

| Primitive | Request | Indicate | Confirm | Response |
|---|---|---|---|---|
| PMD_Data | X | X | | |

### 20.5.4.2 PMD_SAP sublayer-to-sublayer service primitives

Table 19.9.4.2 indicates the primitives for sublayer-to-sublayer interactions.

**Table 19.9.4.2 PMD_SAP sublayer-to-sublayer services**

| Primitive | Request | Indicate | Confirm | Response |
|---|---|---|---|---|
| PMD_TXSTART | X | | | |
| PMD_TXEND | X | | | |
| PMD_ANTSEL | X | | | |
| PMD_TXPWRLVL | X | | | |
| PMD_TRANSMISSION_MODE | X | | | |
| PMD_NUM_STREAMS | X | | | |
| PMD_DATARATE | X | | | |
| PMD_RSSI | | X | | |

## 20.5.4.3 PMD_SAP service primitive parameters

Table 19.9.4.3 shows the parameters used by one or more of the PMD_SAP service primitives.

**Table 20.5.4.3 List of parameters for the PMD primitives**

| Parameter | Associated primitive | Value | Description |
|---|---|---|---|
| TXD_UNIT | PMD_DATA.request | 0 to (2^n)-1, where n is the number of bits per symbol for the transmission mode, number of streams, and data rate specified in PMD_TRANSMISSION_MODE.request, PMD_NUM_STREAMS.request, and PMD_DATARATE.request primitives. | This parameter represents a single block of data, which, in turn, is used by the PMD to be encoded into a transmitted symbol. |
| RXD_UNIT | PMD_DATA.indicate | 0 to (2^n)-1, where n is the number of bits per symbol for the transmission mode, number of streams, and data rate specified in PMD_TRANSMISSION_MODE.request, PMD_NUM_STREAMS.request, and PMD_DATARATE.request primitives. | This parameter represents a single symbol that has been demodulated by the PMD entity. |
| TRANSMISSION_MODE | PMD_TRANSMISSION_MODE.request | See Table 001 in 20.2 | This parameter specifies to the PMD layer, which transmission mode is used. |
| ANT_STATE | PMD_ANTSEL.request | 1 to 256 | ANT_STATE selects which of the available antennas is used for transmission. The number of |

| | | | |
|---|---|---|---|
| | | | available antennas is determined from the MIB table parameters. |
| TXPWR_LEVEL | PMD_TXPWRLVL.request | 1-8 | TXPWR_LEVEL selects which of the optional transmit power levels should be used for the current PPDU transmission. The number of available power levels is determined from the MIB table parameters. |
| DATARATE | PMD_DATARATE.request | See Clause 10.4.4.2 rate code columns of Tables 003-009 and Table 018 | DATARATE selects which of the data rates is used for PSDU transmission. |
| RSSI | PMD_RSSI.indicate | 8 bits of RSSI (256 levels) | The RSSI is a measure of the RF energy received. Mapping of the RSSI values to actual received power is implementation dependent. |

### 20.5.5 PMD_SAP detailed service specification

The following subclauses describe the services provided by each PMD primitive.

#### 20.5.5.1 PMD_DATA.request

This primitive is the same as that defined in 17.5.5.1 and 18.4.5.1 except that the parameter TXD_UNIT is expanded in scope to reflect the supported transmission formats defined in 20.5.4.3.

#### 20.5.5.2 PMD_DATA.indicate

This primitive is the same as that defined in 17.5.5.2 and 18.4.5.2 except that the parameter RXD_UNIT is expanded in scope to reflect the supported transmission formats defined in 20.5.4.3.

#### 20.5.5.3 PMD_TRANSMISSION_MODE.request

This primitive is the same as that defined in 18.4.5.3 except that the parameter MODULATION of that section is expanded in scope to reflect the supported transmission formats defined in 20.5.4.3.

#### 20.5.5.4 PMD_TXSTART.request

This primitive is the same as that defined in 17.5.5.3 and 18.4.5.6.

#### 20.5.5.5 PMD_TXEND.request

This primitive is the same as that defined in 17.5.5.4 and 18.4.5.7.

#### 20.5.5.6 PMD_ANTSEL.request

This primitive is the same as that defined in 18.4.5.8, including the definition of the parameter ANT_STATE.

#### 20.5.5.7 PMD_TXPRWLVL.request

This primitive is the same as that defined in 17.5.5.5, including the definition of the parameter TXPWR_LEVEL.

#### 20.5.5.8 PMD_DATARATE.request

This primitive is the same as that defined in 17.5.5.6 and 18.4.5.10, except that the parameter DATARATE is expanded in scope to reflect the supported MIMO-OFDM transmission modes as defined in 20.5.4.3.

#### 20.5.5.9 PMD_RSSI.indicate

This primitive is the same as that defined in 17.5.5.7 and 18.4.5.11, including the parameter RSSI. This primitive is used to aid in link optimization algorithms such as roaming decisions.

# Annex A – LDPC Matrix Definitions

(normative)

**Table A.1**
**Matrix prototype of the rate-1/2 parity-check matrix.**
**Blocklength n=1944 bits, subblock size Z = 81 bits.**

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | - | - | 44 | - | - | - | 66 | 36 | 39 | 52 | 33 | 0 | - | - | - | - | - | - | - | - | - | - | D |
| 45 | - | - | - | - | 6 | - | - | 33 | 34 | 44 | 76 | 0 | 0 | - | - | - | - | - | - | - | - | - | - |
| - | - | 0 | - | - | 10 | - | - | 61 | 12 | 2 | 62 | - | 0 | 0 | - | - | - | - | - | - | - | - | - |
| - | - | - | - | 16 | - | - | 46 | 25 | 22 | 11 | 46 | - | - | 0 | 0 | - | - | - | - | - | - | - | - |
| - | 26 | - | - | - | - | - | 64 | 62 | 72 | 58 | 74 | - | - | - | 0 | 0 | - | - | - | - | - | - | - |
| - | - | - | 5 | - | - | 47 | - | 71 | 66 | 31 | 18 | - | - | - | - | 0 | 0 | - | - | - | - | - | - |
| 28 | - | - | - | - | - | 54 | 56 | 80 | 30 | - | 37 | - | - | - | - | - | 0 | 0 | - | - | - | - | - |
| - | - | 51 | - | - | 12 | - | 29 | - | 50 | 30 | 60 | - | - | - | - | - | - | 0 | 0 | - | - | - | - |
| - | - | 29 | - | 3 | - | - | 55 | - | 61 | 67 | 12 | - | - | - | - | - | - | - | 0 | 0 | - | - | - |
| - | 48 | - | - | - | - | 59 | 1 | 53 | - | 73 | 5 | - | - | - | - | - | - | - | - | 0 | 0 | - | - |
| - | 62 | - | 63 | - | - | - | 46 | 9 | 78 | 46 | - | - | - | - | - | - | - | - | - | - | 0 | 0 | - |
| 30 | - | - | - | 71 | - | - | 79 | - | 67 | 16 | 49 | - | - | - | - | - | - | - | - | - | - | 0 | 0 |

**Table A.2**
**Matrix prototype of the rate-2/3 parity-check matrix.**
**Blocklength n=1944 bits, subblock size Z = 81 bits.**

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 69 | 43 | 14 | 33 | 36 | 51 | 0 | 48 | - | 36 | - | 65 | - | - | 43 | - | 0 | - | - | - | - | - | - | D |
| 41 | 27 | 41 | 23 | 21 | 68 | - | - | 0 | - | 14 | - | 70 | - | - | 21 | 0 | 0 | - | - | - | - | - | - |
| 20 | 48 | 35 | 9 | 64 | 46 | - | - | - | 61 | - | - | - | 67 | 11 | - | - | 0 | 0 | - | - | - | - | - |
| 76 | 57 | 9 | 41 | 6 | 26 | 55 | 21 | 75 | - | - | 51 | - | - | - | 45 | - | - | 0 | 0 | - | - | - | - |
| 14 | 34 | 35 | 48 | 40 | 67 | - | - | - | 80 | - | - | 72 | 76 | - | - | - | - | - | 0 | 0 | - | - | - |
| 46 | 3 | 16 | 23 | 46 | 9 | 59 | - | - | - | 44 | 1 | - | - | - | 0 | - | - | - | - | 0 | 0 | - | - |
| 11 | 18 | 30 | 17 | 19 | 8 | - | 1 | - | - | - | - | 2 | - | 51 | - | - | - | - | - | - | 0 | 0 | - |
| 39 | 80 | 8 | 56 | 52 | 26 | - | - | 23 | - | 10 | - | - | 50 | - | - | - | - | - | - | - | - | 0 | 0 |

**Table A.3**
**Matrix prototypes of rate-3/4 parity-check matrice**
**Blocklength n=1944 bits, subblock size Z = 81 bits.**

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 53 | 16 | 71 | 59 | 29 | 51 | - | - | 10 | 12 | 45 | 44 | 60 | - | - | - | 2 | - | 0 | - | - | - | - | D |
| 33 | 78 | 29 | 4 | 62 | 55 | 29 | 48 | 15 | 23 | - | - | - | - | 5 | - | 58 | - | 0 | 0 | - | - | - | - |
| 49 | 48 | 47 | 19 | 3 | 3 | - | 53 | - | - | - | 70 | 18 | 41 | - | 21 | - | 61 | - | 0 | 0 | - | - | - |
| 35 | 57 | 48 | 21 | 20 | 27 | 80 | - | 63 | - | 39 | 42 | - | 5 | 40 | - | - | - | - | - | 0 | 0 | - | - |
| 19 | 24 | 36 | 20 | 79 | 49 | 24 | - | - | - | 2 | - | - | - | 9 | 47 | 19 | 46 | - | - | - | 0 | 0 | - |
| 36 | 37 | 56 | 14 | 2 | 40 | - | 47 | - | 34 | - | - | 68 | 17 | - | 49 | - | 22 | - | - | - | - | 0 | 0 |

**Table A.4**
**Matrix prototypes of rate-5/6 parity-check matrices.**
**Blocklength n=1944 bits, subblock size Z = 81 bits.**

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 4 | 55 | 12 | 0 | 30 | 11 | 49 | 0 | 51 | 57 | 52 | 0 | 33 | 39 | 60 | 0 | - | 19 | 33 | 0 | - | - | D |
| 60 | 0 | 5 | 35 | 76 | 0 | 55 | 34 | 8 | 0 | 21 | 42 | 21 | 0 | 20 | 5 | 33 | 0 | 29 | - | 0 | 0 | - | - |
| 48 | 14 | 0 | 46 | 53 | 20 | 0 | 28 | 20 | 37 | 0 | 4 | 77 | 48 | 0 | 67 | - | 28 | 0 | 52 | - | 0 | 0 | - |
| 22 | 48 | 68 | 0 | 72 | 64 | 75 | 0 | 38 | 70 | 7 | 0 | 59 | 75 | 69 | 0 | 47 | 56 | - | 0 | - | - | 0 | 0 |

# Annex B – Closed Loop Information Exchange

Text in this section is informative.

Closed loop methods that improve transmission by providing feedback information from receiver to transmitter are compatible with this amendment. Specific management frames to feedback information are given in sections 7.4.5. These management frames enable both transmission mode feedback and channel feedback.

Transmission mode feedback allows a receiving station to inform a transmitting station of the preferred mode for the current channel conditions. The particular choice of mode is determined by the receiving station. The transmitting station may or may not use the particular mode, depending on its capabilities. A receiving station may also decline to provide a preferred mode.

Channel feedback provides a mechanism for a transmitting station to learn the precise channel seen at the receiver. This information may either be used as part of a calibration, for systems that assume channel reciprocity, or as direct channel feedback. The usage of channel feedback information is implementation dependent. Receiving stations may either provide a complete channel estimate or a null response.

# Annex D – informative) ASN.1 encoding of the MAC and PHY.MIB

***In "SMT Station Config Table" of Annex D, Change `Dot11StationConfigEntry` to:***

```
Dot11StationConfigEntry ::=
SEQUENCE {
dot11StationID MacAddress,
dot11MediumOccupancyLimit INTEGER,
dot11CFPollable TruthValue,
dot11CFPPeriod INTEGER,
dot11CFPMaxDuration INTEGER,
dot11AuthenticationResponseTimeOut Unsigned32,
dot11PrivacyOptionImplemented TruthValue,
dot11PowerManagementMode INTEGER,
dot11DesiredSSID OCTET STRING,
dot11DesiredBSSType INTEGER,
dot11OperationalRateSet OCTET STRING,
dot11BeaconPeriod INTEGER,
dot11DTIMPeriod INTEGER,
dot11AssociationResponseTimeOut Unsigned32,
dot11DisassociateReason INTEGER,
dot11DisassociateStation MacAddress,
dot11DeauthenticateReason INTEGER,
dot11DeauthenticateStation MacAddress,
dot11AuthenticateFailStatus INTEGER,
dot11AuthenticateFailStation MacAddress,
dot11MultiDomainCapabilityImplemented TruthValue,
dot11MultiDomainCapabilityEnabled TruthValue,
```

```
dot11CountryString OCTET STRING,
dot11SpectrumManagementImplemented TruthValue,
dot11SpectrumManagementRequired Truthvalue,
dot11RSNAOptionImplemented TruthValue,
dot11RSNAPreauthenticationImplemented TruthValue,
dot11QosOptionImplemented TruthValue,
dot11ImmediateBlockAckOptionImplemented TruthValue,
dot11DelayedBlockAckOptionImplemented TruthValue,
dot11DirectOptionImplemented TruthValue,
dot11APSDOptionImplemented TruthValue,
dot11QAckOptionImplemented TruthValue,
dot11QBSSLoadOptionImplemented TruthValue,
dot11QueueRequestOptionImpelemented TruthValue,
dot11TXOPRequestOptionImplemented TruthValue,
dot11MoreDataAckOptionImpelemented TruthValue,
dot11AssociateinNQBSS TruthValue,
dot11DLSAllowedinQBSS TruthValue,
dot11DLSAllowed TruthValue,
dot11AMSDUOptionImplemented TruthValue }
```

***Insert the following elements to the end of dot11StationConfigEntry element definitions behind dot11RSNAPreauthenticationImplemented:***

```
dot11AMSDUOptionImplemented OBJECT-TYPE
SYNTAX TruthValue
MAX-ACCESS read-only
STATUS current
DESCRIPTION
"This attribute, when TRUE, indicates that the station
implementation is capable of supporting A-MSDU. The capability
is disabled, otherwise. The default value of this attribute
is FALSE."
::= { dot11StationConfigEntry 41 }
```

### A.4.3 IUT configuration

***Insert the following at the end of A.4:***

| Item | IUT configuration | References | Status | Support |
|---|---|---|---|---|
| CF13 | HTP supported | x.x | O | Yes No |

### A.4.x HTP Base Functionality

| Item | Protocol capability | References | Status | Support |
|---|---|---|---|---|
| HB1 | A-MSDU | x.x | CF13:M | Yes No |

# APPENDIX H

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# APPENDIX I

# IEEE P802.11
# Wireless LANs

# WWiSE Proposal: High throughput extension to the 802.11 Standard

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## Abstract

Changes and additions to IEEE Std. 802.11-1999 (Reaff 2003), as amended by published amendments IEEE802.11a, IEEE802.11g, IEEE802.11h and IEEE802.11i and by IEEE draft standard 802.11e/D9.0 are provided to support a new high throughput physical layer (PHY) for operation in the 2.4 and 5 GHz bands.

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# Telecommunications and information exchange between systems -
# Local and metropolitan area networks -
# Specific Requirements -

# Part 20: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications:

# High throughput extension for the 2.4 GHz and 5 GHz Bands

[This amendment is based on IEEE Std 802.11™, 1999 Edition (Reaff 2003), as amended by IEEE Std 802.11a™-1999 and IEEE Std 802.11g™-2003, and Draft Amendment IEEE P802.11e/D9.0]

## 3. Definitions

***Insert the following new definitions in alphabetical order, renumbering as necessary:***

**20 MHz transmission:** A frame transmission in which the modulation spans only one of the 20 MHz channels of a 40 MHz Channel Pair.

**40 MHz channel pair:** A pair of 20 MHz channels whose centre frequencies are separated by 20 MHz and which can be treated as a single channel for 40 MHz transmissions by a BSS, and where one of the 20 MHz channels will also be used for (non-overlapping) 20 MHz transmissions by the BSS.

**40 MHz transmission:** A frame transmission in which the modulation spans both 20 MHz channels of a 40 MHz channel pair.

**aggregated MSDU (A-MSDU):** A MSDU that encapsulates one or more MSDUs to be transmitted to the same destination.

**aggregated PPDU (A-PPDU):** A PPDU that contains one or more pairs of PLCP headers and PSDUs.

**HTP burst transmission:** A sequence of frames transmitted by a single high-throughput station in a single medium access. The frames may be transmitted as part of an A-PPDU, or with reduced or zero interfame spacing to enhance medium efficiency.

**primary channel:** The channel in a 40 MHz channel pair that will be used for 20 MHz transmissions as well as being part of the 40 MHz channel for 40 MHz transmissions.

**secondary channel:** The channel in a 40 MHz channel pair that is used only as part of the 40 MHz channel for 40 MHz transmissions, and which is not used for 20 MHz transmissions.

**HTP rate group:** A group of rates supported by a HTP PHY that use the same transmit bandwidth, the same number of transmit antennas, and the number of spatial streams.

**MIMO-OFDM:** Multiple input multiple output orthogonal frequency division multiplexing

# 4. Abbreviations and acronyms

***Insert the following acronyms alphabetically in the list in Clause 4:***

| | |
|---|---|
| A-MSDU | aggregated MSDU |
| A-PPDU | aggregated PPDU |
| ECC | error correction code |
| HT | high throughput |
| HTP | high-throughput PHY conforming to Clause 20 |
| LDPCC | low density parity check code |
| MIMO | multiple input multiple output |
| nHTP | non HTP PHY conforming to Clause 15 or Clause 17 or Clause 18 or Clause 19, but not to Clause 20 |
| RIFS | reduced interframe space |
| STBC | space time block code |
| ZIFS | zero interframe space |

# 6. MAC Service Definition

## 6.1 Overview of MAC services

### 6.1.4 Data service architecture (informative)

***Change the paragraph in 6.1.4 (.11e) as shown:***

The MAC data plane architecture (i.e., processes that involve transport of all or part of an MSDU) is shown in Figure 11g. During transmission, an MSDU goes through some or all of the following processes: frame delivery deferral during power save mode, aggregation, sequence number assignment, fragmentation, encryption, integrity protection, and frame formatting. IEEE 802.1X may block the MSDU at the Controlled Port. At some point the Data frames that contain all or part of the MSDU are queued per access category/TS. This queuing may be at any of the three points indicated in Figure 11g. During reception, a received data frame goes through processes of MPDU header + cyclic redundancy codecheck (CRC) validation, duplicate removal, possible reordering if the Block Ack mechanism is used, decryption, defragmentation, integrity checking, de-aggregation, and replay detection. After replay detection (or defragmentation if security is used), the MSDU is delivered to the MAC_SAP or to the DS. The IEEE 802.1X Controlled/ Uncontrolled Ports discard the MSDU if the Controlled Port is not enabled or if the MSDU does not represent an IEEE 802.1X frame. TKIP and CCMP MPDU frame order enforcement occurs after decryption, but prior to MSDU defragmentation; therefore, defragmentation will fail if MPDUs arrive out of order.

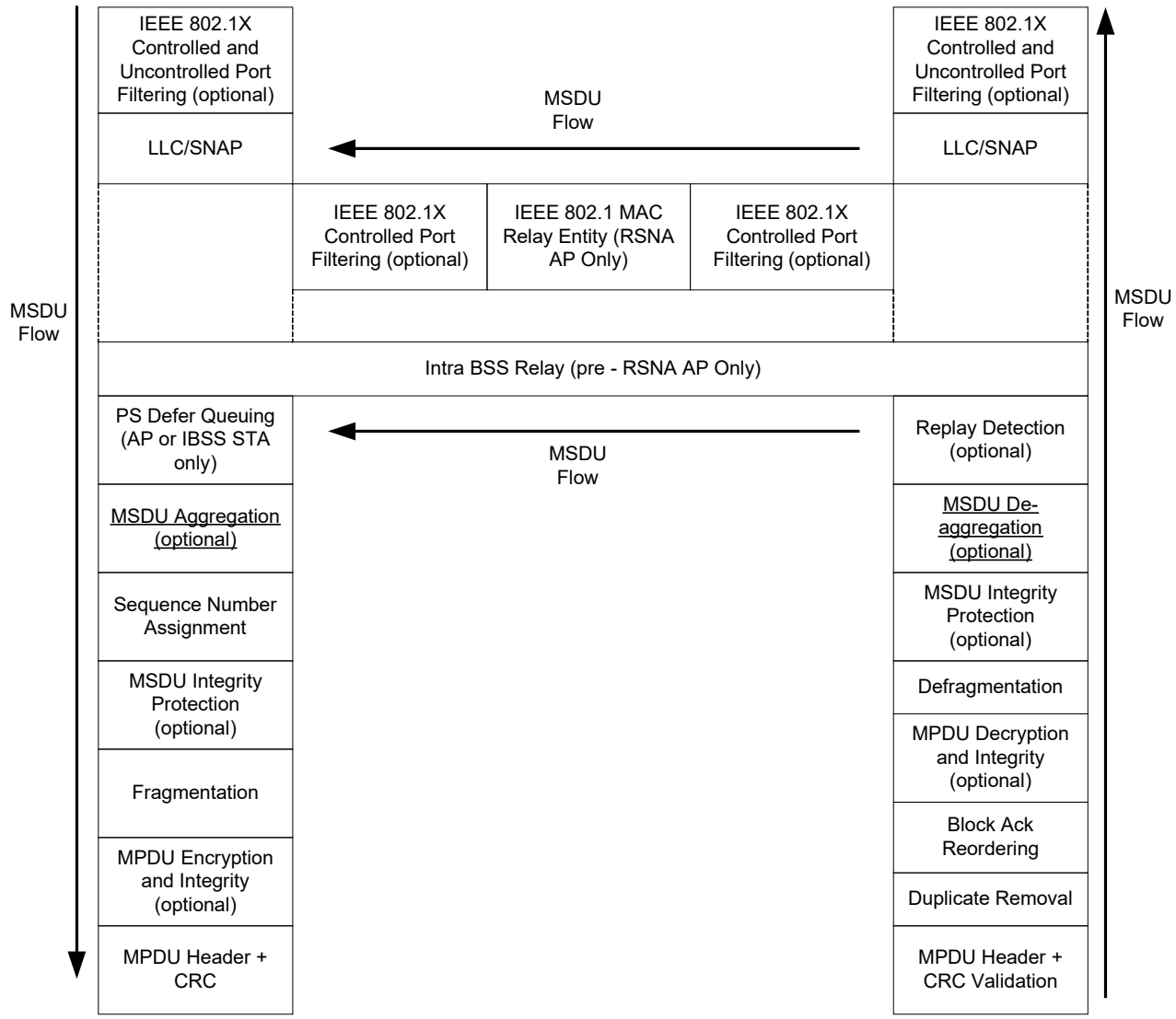



**Figure 11g – MAC data plane architecture**

## 6.2 Detailed service specification

### 6.2.1 MAC data services

### 6.2.1.1 MA-UNITDATA.request

#### 6.2.1.1.2 Semantics of the service primitive

***Change the third from the last paragraph as follows:***

The data parameter specifies the MSDU to be transmitted by the MAC sublayer entity. For IEEE 802.11, the length of the MSDU ~~must~~shall be less than or equal to ~~2304~~8100 octets.

# 7. Frame Formats

## 7.1 MAC frame formats

## 7.1.2 General frame format

***Change Figure 12(.11e) as follows:***

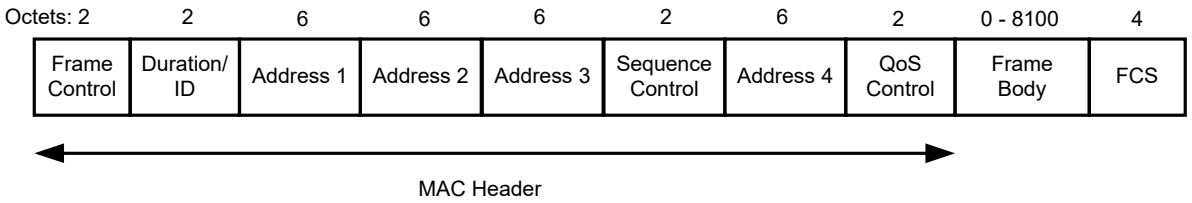



**Figure 12 – MAC frame format**

## 7.1.3 Frame fields

## 7.1.3.5 QoS Control field

***Change Table 3.1 in 7.1.3.5 (.11e) to appear as follows:***

**Table 3.1 – QoS Control field**

| Applicable Frame (sub) Types | Bits 0-3 | Bit 4 | Bit 5-6 | Bit 7 | Bits 8-15 |
|---|---|---|---|---|---|
| QoS (+)CF-Poll frames sent by HC | TID | EOSP | Ack Policy | Reserved | TXOP limit |
| QoS Data and QoS Data+CF-Ack frames sent by HC | TID | EOSP | Ack Policy | Aggregated MSDU Present | QAP PS Buffer State |
| QoS Null, QoS CFAck frames sent by HC | TID | EOSP | Ack Policy | Reserved | QAP PS Buffer State |
| QoS data type frames sent by non-AP QSTAs | TID | 0 | Ack Policy | Aggregated MSDU Present | TXOP duration requested |
| | TID | 1 | Ack Policy | Aggregated MSDU Present | Queue size |

## 7.2 Format of individual frame types

## 7.2.1 Control Frames

## 7.2.1.7 Block Acknowledgement Request (BlockAckReq) frame format

***Change the diagram of the BAR control field of 7.2.1.7 to appear as follows:***

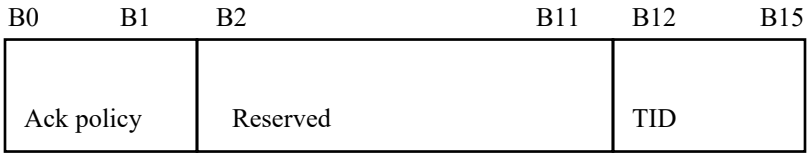



**Figure 21.2– BAR Control Field**

***Insert the following text and table immediately after Figure 21.2 within clause 7.2.1.7:***

The ACK Policy subfield of the BAR Control field contains the ACK policy for the BlockAckReq frame. The ACK policy subfield bits shall have the meaning indicated in table 3.3:

| Bits in BAR Control field | Meaning |
|---|---|
| Bit 0 Bit 1 | |
| 0 0 | Normal acknowledgement.<br>The addressed recipient returns an ACK as defined in 9.2.8 or a Block Acknowledgement frame after a SIFS period, according to the previously negotiated block ack policy as described in 11.5. The Ack Policy field is set to this value in all directed Block Ack Request frames in which the sender requires immediate acknowledgement, including those requiring an immediate Block Acknowledgement. |
| 1 0 | No Acknowledgement<br>The addressed recipient performs no immediate response action upon receipt of the frame. More details are provided in 9.11. The Ack Policy is set to this value in all BlockAckReq frames in which the sender does not require immediate, explicit acknowledgement. |
| 0 1 | Reserved |
| 1 1 | Reserved |

**Table 3.3**

## 7.2.1.8 Block Acknowledgement (BlockAck) frame format

***Change the diagram of the BA control field of 7.2.1.8 to appear as follows:***

The BA control field defined in Figure 21.5 consists of the TID and Ack Policy subfields as shown in figure 21.5.

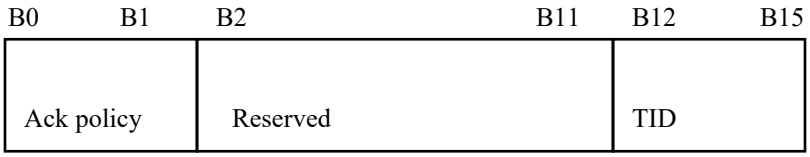



**Figure 21.5 – BA Control Field**

***Insert the following text and table immediately after Figure 21.5 within clause 7.2.1.8:***

The ACK Policy subfield of the BA Control field contains the ACK policy for the Block Acknowledgement frame. The ACK policy subfield bits shall have the meaning indicated in table 3.4:

| Bits in BAR Control field | Meaning |
|---|---|
| Bit 0 Bit 1 | |
| 0 0 | Normal acknowledgement.<br>The addressed recipient returns an ACK as defined in 9.2.8 after a SIFS period. The Ack Policy field is set to this value in all directed Block Acknowledgement frames in which the sender requires immediate acknowledgement. |
| 1 0 | No Acknowledgement<br>The addressed recipient performs no immediate response action |

| | |
|---|---|
| | upon receipt of the frame. More details are provided in 9.11. The Ack Policy is set to this value in all Block Acknowledgement frames in which the sender does not require immediate, explicit acknowledgement. |
| 0 1 | Reserved |
| 1 1 | Reserved |

**Table 3.4**

## 7.2.2 Data Frames

***Change the text, figures and tables in 7.2.2 (.11e) as shown:***

The frame format for a Data frame is dependent on the QoS subfield of the subtype field and is as defined in Figure 22.

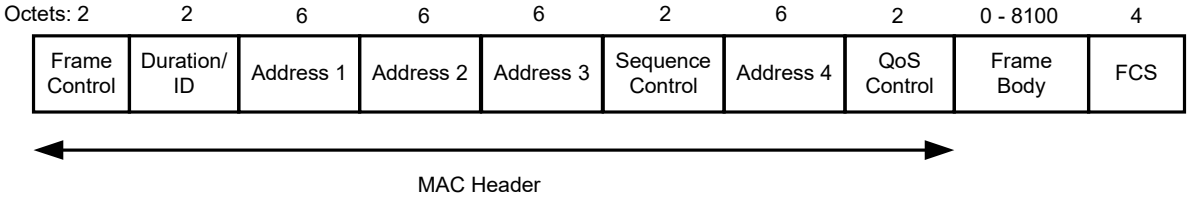



**Figure 22 – Data frame**

***Change the definitions as follows:***

The DA is the destination of the A-MSDU or MSDU (or fragment thereof) in the frame body field.

The SA is the address of the MAC entity which initiated the A-MSDU or MSDU (or fragment thereof) in the frame body field.

## 7.2.3 Management frames

## 7.2.3.1 Beacon frame format

***Insert the Channel Set entry and change the notes in Table 5(.11g) to read as follows:***

| Order | Information | Notes |
|---|---|---|
| 7 | DS Parameter Set | The DS Parameter Set information element is present within Beacon frames generated by STAs using Clause 15, Clause 18 and Clause 19 PHYs and by STAs using Clause 20 PHYs while operating in the 2.4GHz band. |
| 15 | Channel Set | The Channel Set information element is present within Beacon frames generated by APs using a Clause 20 PHY operating on a 40 MHz channel pair |
| 19 | ERP Information | The ERP Information element is present within Beacon frames generated by STAs using ERP PHYs and HTP PHYs and is optionally present in other cases. |

*Add a new clause 7.2.3.1.1 immediately after the existing clause 7.2.3.1 "Beacon Frame Format"*

### 7.2.3.1.1 Secondary Channel Beacon Format

An AP with a Clause 20 PHY operating on a 40 MHz channel pair may send a Beacon frame on the secondary channel as described in clause 9.13.2.1. In contrast to the normal sending of Beacon frames, the aim of sending a Beacon frame on the secondary channel is to discourage use of that channel (other than as the secondary channel of the 40 MHz channel pair) and as a result, the required frame body is substantially different.

The contents of the fields of the Beacon frame sent on the secondary channel shall be the same as those of the Beacon frame sent on the primary channel, with the exceptions noted below.

The Supported Rate Set Information Element shall consist of a single Clause 20 rate, marked as a basic rate.

**Table 7.2.3.1.1T1 – Beacon Frame Body when used as a Secondary Channel Beacon**

| Order | Information | Notes |
|---|---|---|
| 1 | Timestamp | |
| 2 | Beacon Interval | |
| 3 | Capability | |
| 4 | Service Set Identifier (SSID) | |
| 5 | Supported Rate Set | |
| 6 | CF Parameter Set | May optionally be included to further discourage use of this channel. |
| 5 | Channel Set | |

### 7.2.3.9 Probe Response frame format

*Insert the Channel Set entry and change the notes in Table 12(.11g) to read as follows:*

| Order | Information | Notes |
|---|---|---|
| 7 | DS Parameter Set | The DS Parameter Set information element is present within Probe Response frames generated by STAs using Clause 15, Clause 18 and Clause 19 PHYs and by STAs using Clause 20 PHYs while operating in the 2.4GHz band. |
| 11 | Channel Set | The Channel Set information element is present within Probe Response frames generated by APs using a Clause 20 PHY operating on a 40 MHz Channel Pair |
| 18 | ERP Information | The ERP Information element is present within Probe Response frames generated by STAs using ERP PHYs and HTP PHYs and is optionally present in other cases. |

## 7.3 Management frame body components

### 7.3.1 Fixed fields

## 7.3.1.4 Capability Information field

***Change the second paragraph in 7.3.1.4(.11e) as shown:***

The length of the Capability Information field is 2 octets. The format of the Capability Information field is defined as illustrated in Figure 27. No subfield is supplied for ERP as a STA supports ERP operation if it includes all the clause 19 mandatory rates in its supported rate set. No subfield is supplied for HTP (STAs employing a Clause 20 PHY), as a STA supports HTP operation if it includes all of the Clause 20 mandatory rates in its supported rate set.

## 7.3.2 Information Elements

***Add a new row to Table 20 "Element IDs" as follows, and adjust reserved ids appropriately***

| | |
|---|---|
| Channel Set | XXX-To be assigned by ANA before letter ballot |

***Add the following text to the end of clause 7.3.2 after the table of Element IDs***

Individual information elements may be extended in length by future versions of this standard by adding new fields to the end of an existing information element. STAs shall ignore any additional information beyond the expected end of an Information Element, and shall treat any such information element as legal.

## 7.3.2.13 ERP Information element

***Change the text of clause 7.3.2.13(.11g) as follows:***

~~The ERP Information element contains information on the presence of Clause 15 or Clause 18 stations in the BSS that are not capable of Clause 19 (ERP-OFDM) data rates. It also contains the requirement of the ERP Information element sender (AP in a BSS or STA in an IBSS) as to the use of protection mechanisms to optimize BSS performance and as to the use of long or short Barker preambles. See Figure 42E for a definition of the frame element.~~

The ERP Information element contains information on:

a) the presence of Clause 15 or Clause 18 stations in the BSS that are not capable of Clause 19 (ERP-OFDM) data rates
b) the requirement of the ERP Information element sender (the AP, or in an IBSS a STA) as to the use of protection mechanisms to optimize BSS performance in the presence of STA which have implemented a PHY from Clause 15 or Clause 18 and not including Clause 19 capability
c) the requirement of the ERP Information element sender (AP in a BSS or STA in an IBSS) as to the use of long or short Barker preambles
d) the presence of Clause 19 stations in the BSS, when the ERP Information element sender is an HTP STA
e) the requirement of the ERP Information element sender (AP in a BSS or STA in an IBSS) as to the use of OFDM-protection mechanisms to optimize BSS performance
f) the presence of Clause 17 stations in the BSS, when the ERP Information element sender is a HTP STA
g) the presence of Clause 17 stations in the secondary 20 MHz channel which potentially limits the ability of the HTP STA to utilize a 40 MHz wide channel, when the ERP Information element sender is a HTP STA

See Figure 42E for a definition of the ERP Information element.

If one or more NonERP STAs are associated in the BSS, the Use_Protection bit shall be set to 1 in transmitted ERP Information Elements.

If one or more Clause 19 or Clause 17 STAs are associated in the BSS, then the Use_OFDM_Protection bit shall be set to 1 in ERP Information Elements transmitted by HTP STAs and may be set to 1 in ERP Information Elements transmitted by nHTP STAs.

In an IBSS, the setting of the Use_Protection and Use_OFDM_Protection bits is left to the STA. In an IBSS, there is no uniform concept of association; therefore, a typical algorithm for setting the Use_Protection and Use_OFDM_Protection bits will take into account the traffic pattern and history on the network. If a member of an IBSS which is not an HTP STA detects one or more NonERP STAs that are members of the same IBSS, then the Use_Protection bit should be set to 1 in the ERP Information Element of transmitted Beacon and Probe Response frames. If a member of an IBSS which is a HTP STA

detects one or more Clause 19 STAs or one or more Clause 17 STAs that are members of the same IBSS, then the Use_OFDM_Protection bit should be set to 1 in the ERP Information Element of transmitted Beacon and Probe Response frames.

The NonERP_Present bit shall be set to 1 when a NonERP STA is associated with the BSS. Examples of when the NonERP present bit may additionally be set to 1 include, but are not limited to, when:

a) A NonERP infrastructure or independent BSS is overlapping (a NonERP BSS may be detected by the reception of a Beacon where the supported rates contain only Clause 15 or Clause 18 rates).

b) In an IBSS, if a Beacon frame is received from one of the IBSS participants where the supported rate set contains only Clause 15 or Clause 18 rates.

c) A management frame (excluding a Probe Request) is received where the supported rate set includes only Clause 15 or Clause 18 rates.

The OFDM_PRESENT bit shall be set to 1 in ERP Information Elements transmitted by HTP STA when a Clause 17 or Clause 19 STA is associated with the BSS. Examples of when the OFDM_PRESENT bit may additionally be set to 1 in an ERP Information Element transmitted by a HTP STA include, but are not limited to, when

a) A Clause 17 or Clause 19 infrastructure or independent BSS is overlapping. (A Clause 17 BSS may be detected by the reception of a Beacon where the supported rates contain only Clause 17 rates. A Clause 19 BSS may be detected by the reception of a Beacon where the supported rates contain at least one rate from the set of Clause 19 rates.)

b) In an IBSS, if a Beacon frame is received from one of the IBSS participants where the supported rate set contains only Clause 17 rates or at least one rate from the set of Clause 19 rates.

c) A management frame (excluding a Probe Request) is received where the supported rate set includes only Clause 17 rates or at least one rate from the set of Clause 19 rates.

The OFDM_PRESENT bit may optionally be set to 1 in ERP Information Elements transmitted by non-HTP STA.

~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs shall invoke the use of a protection mechanism after transmission or reception of the Use_Protection bit with a value of 1 in an MMPDU to or from the BSS that the ~~ERP AP or ERP STA~~ ERP AP, ERP STA, HTP AP or HTP STA has joined or started. ~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs may additionally invoke protection mechanism use at other times.

~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs may disable protection mechanism use after transmission or reception of the Use_Protection bit with a value of 0 in an MMPDU to or from the BSS that the ~~ERP APs or ERP STAs~~ ERP AP, ERP STA, HTP AP or HTP STA has joined or started.

HTP APs and HTP STAs shall invoke the use of an OFDM protection mechanism after transmission or reception of the Use_OFDM_Protection bit with a value of 1 in an MMPDU to or from the BSS that the HTP AP or HTP STA has joined or started. HTP APs and HTP STAs may additionally invoke OFDM protection mechanism use at other times.

HTP APs and HTP STAs may disable OFDM protection mechanism use after transmission or reception of the Use_OFDM_Protection bit with a value of 0 in an MMPDU to or from the BSS that the HTP AP or HTP STA has joined or started.

When there are no NonERP STAs associated with the BSS and the ERP Information Element sender's dot11ShortPreambleOptionImplemented MIB variable is set to true, then the Barker_Preamble_Mode bit may be set to 0. The Barker_Preamble_Mode bit shall be set to 1 by the ERP Information Element sender if one or more associated NonERP STAs are not short preamble capable as indicated in their Capability Information field, or if the ERP Information Element senders dot11ShortPreambleOptionImplemented MIB variable is set to false.

If a member of an IBSS detects one or more non-short preamble-capable STAs that are members of the same IBSS, then the Barker_Preamble_Mode bit should be set to 1 in the transmitted ERP Information Element.

~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs shall use long preambles when transmitting Clause 15, Clause 18, and Clause 19 frames after transmission or reception of an ERP Information Element with a Barker_Preamble_Mode value of 1 in an MMPDU to or from the BSS that the ~~ERP APs or ERP STAs~~ ERP AP, ERP STA, HTP AP or HTP STA has joined or started, regardless of the value of the short preamble capability bit from the same received or transmitted MMPDU that contained the ERP Information Element. ~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs may additionally use long preambles when transmitting Clause 15, Clause 18, and Clause 19 frames at other times. ~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs may use short preambles when transmitting Clause 15, Clause 18, and Clause 19 frames after transmission or reception of an ERP Information Element with a Barker_Preamble_Mode value of 0 in an MMPDU to or from the BSS that the ~~ERP APs or ERP STAs~~ ERP AP, ERP STA, HTP AP or HTP STA has joined or started, regardless of the value of the short preamble capability bit from the same received or transmitted MMPDU. ~~NonERP STAs and NonERP APs~~STAs which are neither ERP nor HTP and APs which are neither ERP nor HTP may also follow the rules given in this paragraph.

The Secondary_Channel_Used bit may be set to 0 in ERP Information Elements transmitted by HTP STAs or HTP APs if no frames with a Clause 17 BSSID have been received within the last two seconds on the secondary 20 MHz channel of the BSS that the HTP AP or HTP STA has joined or started, otherwise, the Secondary_Channel_Used bit shall be set to 1. nHTP STAs and nHTP APs shall always set the Secondary_Channel_Used bit to 0 if they transmit ERP Information elements.

Recommended behavior for setting the Use_Protection bit is contained in 9.10.

The ERP Information element shall have the form shown in Figure 42E.

| B0-B7 | B0-B7 | B0 | B1 | B2 | B3 | B4 | B5 | B6 | B7 |
|---|---|---|---|---|---|---|---|---|---|
| ElementID | Length(1) | NonERP Present | Use_protection | Barker preamble mode | OFDM_present | Use_OFDM _Protection | Secondary_ Channel_ Used | R6 | R7 |

**Figure 42E**

~~Bits r3 through r7 are reserved, set to 0, and are ignored on reception. Note that the length of this element is flexible and may be expanded in the future.~~

Bits r6 and r7 are reserved, set to 0, and are ignored on reception. Note that the length of this element is flexible and may be expanded in the future.

## 7.3.2.22.1 Basic Report

***Change one of the reserved bits in figure 46o "Map Field Format" to be "Secondary Channel"***

***Add the following after the definition of the "Unmeasured bit"***

— Secondary Channel bit, which shall be set to 1 when at least one valid Secondary Channel Beacon (as described in clause 9.13.2.1) was received during the measurement period from another BSS. Otherwise the Secondary Channel bit shall be set to zero.

***Add the following new clauses as the last sub-clauses of 7.3.2 "Information Elements"***

## 7.3.2.25 Channel Set

The Channel Set information element is used to convey information about the channels from which a 40 MHz Channel Pair are formed. The Primary Channel field shall contain the channel number of the primary channel. The Secondary Channel shall contain the channel number of the secondary channel.

This information element may be extended in later versions of this standard.

See Figure 000n:

| | Element ID | Length | Primary Channel | Secondary Channel |
|---|---|---|---|---|
| Octets: | 1 | 1 | 1 | 1 |

**Figure 000n- Channel Set element format**

# 9. MAC sublayer functional description

## 9.1 MAC architecture

***Insert the following subclause after clause 9.1.3(.11e) and renumber existing subclauses 9.1.4(.11e) through 9.1.5(.11e) to be subclauses 9.1.5 through 9.1.6***

## 9.1.4 MSDU aggregation

One or more MSDUs being sent to the same receiver can be aggregated into a single A-MSDU. Aggregation of more than one frame can improve system efficiency as seen at the MAC sub-layer due to the fact that the overheads associated with channel access (e.g. PLCP preamble, MAC header, IFS spacing, etc.) can be amortized over two or more MSDUs. Frames with address types of Broadcast ,Multicast, or Unicast frames can be aggregated with other frames of the same address type, but not with frames of different address type due to the requirement to share the receiver address. Aggregation is optional and the process is considered a "sub-process" between MSDU queuing and sequence number assignment in Figure 11g of Clause 6.1.4.

A STA shall only use MSDU aggregation where it knows that the receiver supports MSDU aggregation. A STA shall not aggregate MSDUs that have different values of priority as indicated by the MA-UNITDATA.request primitive. A STA may aggregate MSDUs with different values of destination address as long as they would have the same value in the Address 1 field had they been sent as individual MPDUs.

To form an A-MSDU, two or more MSDUs are aggregated together, separated by a sub-frame header. This is shown in Figure 001n. The resulting A-MSDU is therefore the combination of all MSDUs in the A-MSDU along with a sub-frame header for each constituent MSDU.

The destination address of the A-MSDU is the address of the STA that is the next immediate intended receiver of the aggregated frame. The source address of the A-MSDU is the MAC address of the STA that created the A-MSDU.

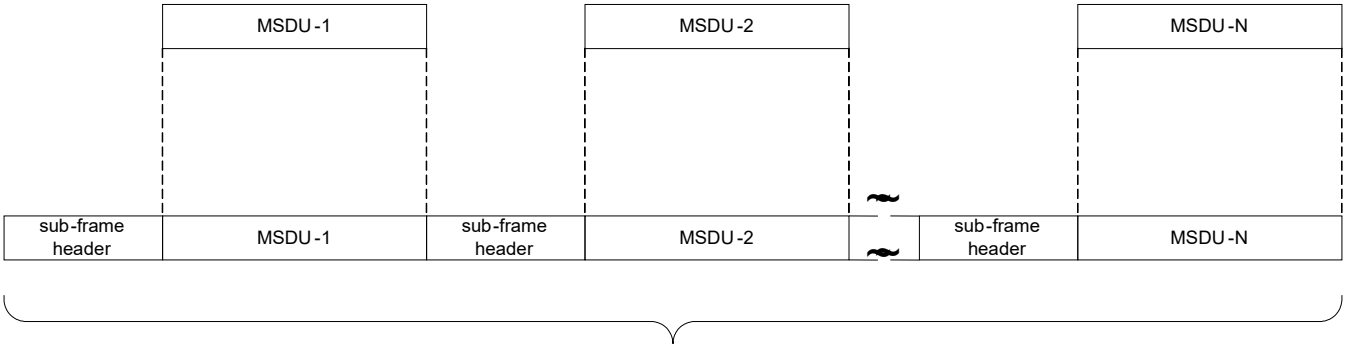



**Figure 001n – Formation of an A-MSDU**

The format for the sub-frame header is given in Figure 002n. The sub-frame header is 14 octets in length and consists of a 16-bit MSDU length field, a 6-octet source address of the constituent MSDU, and a 6-octet destination address of the constituent MSDU. The MSDU length field indicates the length, in octets, of the constituent MSDU.

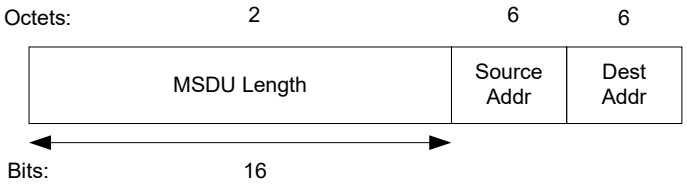



**Figure 002n – Sub-Frame Header**

A data frame bearing an A-MSDU within its frame body is identified by a '1' in the Aggregated MSDU bit of the QoS Control Field (Clause 7.1.3.5). For data frames containing a non-aggregated MSDU, this bit will be zero.

After aggregation, the procedures for handling an A-MSDU are no different from an MSDU including sequence number assignment, optional MSDU integrity protection, and fragmentation, with the single exception of the Aggregated MSDU bit described above. Once formed, A-MSDUs shall not be un-aggregated by the transmitter, as there are no facilities for individual sequencing or retransmission of the constituent MSDUs.

A method for determining when to engage optional MSDU aggregation is out of scope for this standard.

***Insert the following subclause after clause 9.1.3(.11e) and renumber existing subclauses 9.1.6(.11e) to be subclauses 9.1.7***

## 9.1.6 HTP Burst Transmission overview

The high-throughput PHY defines burst transmission formats that permit more efficient usage of the medium. A HTP burst transmission is performed in a single medium access, and permits frames to be sent to different destination addresses. These formats shall only be used to transmit frames to other HTP STAs, and may be used as part of any kind of TXOP. The medium spacing before and after a HTP burst transmission shall be governed by the rules covering the spacing before and after a non-burst transmission in the TXOP.

A HTP burst transmission consists of a sequence of frames transmitted by a single HTP STA without intervening frames by any other STA. The frames of the HTP burst transmission shall be transmitted using a single HTP rate group as defined in 20.3.2.2. During a HTP burst transmission, the MAC may utilise ZIFS or RIFS and/or instruct the PHY to aggregate multiple frames into a single A-PPDU. These formats are illustrated in Figure 003n.

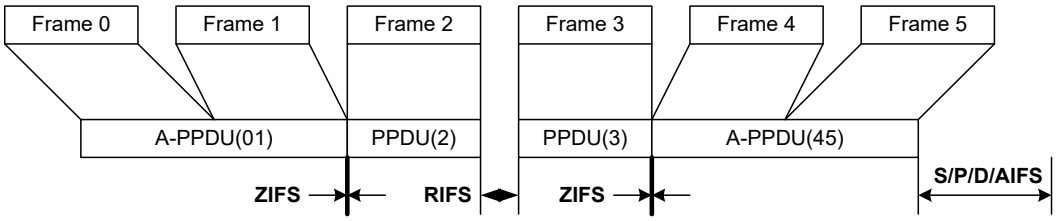



**Figure 003n – HTP Burst transmission**

Frames may be aggregated into a single A-PPDU, or separated by ZIFS if they are being transmitted at the same TXPWR_LEVEL. A frame that uses a different TXPWR_LEVEL as the previous frame in the HTP burst transmission may use RIFS.

## 9.2 DCF

## 9.2.3 Interframe Space (IFS)

***Change the text in clause 9.2.3(.11e) as follows***

The time interval between frames is called the IFS. A STA shall determine that the medium is idle through the use of the carrier sense function for the interval specified. Two interframe spaces, ZIFS and RIFS, are defined for use between frames in a HTP burst transmission, and another five IFSs are defined to provide priority levels for access to the wireless media. To obtain access to the medium, a STA shall determine that the medium is idle through the use of the carrier sense function for the interval specified. ~~Five different IFSs are defined to provide priority levels for access to the wireless media; they~~ The

interframe spaces are listed in order, from the shortest to the longest except for AIFS. Figure 49 shows some of these relationships.

a) ZIFS Zero Interframe Space
b) RIFS Reduced Interframe Space
c) Short Interframe Space
d) PIFS Point Coordination Function (PCF) Interframe Space
e) DIFS Distributed Coordination Function (DCF) Interframe Space
f) AIFS Arbitration Interframe Space (used by the QoS facility)
g) EIFS Extended Interframe Space

***Insert the following subclauses after clause 9.2.3(.11e) and renumber existing subclauses 9.2.3.1(.11e) through 9.2.3.5(.11e) to be subclauses 9.2.3.3 through 9.2.3.7.***

### 9.2.3.1 ZIFS

The ZIFS may be used for the second or subsequent frame of a HTP burst transmission if the frame will be transmitted at the same power as the immediately previous frame.

### 9.2.3.2 RIFS

The RIFS may be used for the second or subsequent frame of a HTP burst transmission if the frame will be transmitted at a different power than the immediately previous frame.

## 9.2.12 Determination of PLME aCWmin characteristics

***Modify the first paragraph of clause 9.2.12 as follows:***

In the case of the Clause 19 Extended Rate PHY and Clause 20 High Throughput PHY, the aCWmin value is dependent on the requestor's characteristic rate set. The characteristic rate set is equal to the IBSS's supported rate set when the STA is operating as a member of an IBSS. It is equal to the AP's supported rate set when the STA is associated with an AP. At all other times, it is equal to the STA's mandatory rate set. The MAC variable aCWmin is set to aCWmin(0) if the characteristic rate set includes only rates in the set 1, 2, 5.5, 11 otherwise, aCWmin is set to aCWmin(1). If the returned value for aCWmin is a scalar, then the MAC always sets the variable aCWmin to the returned scalar value of aCWmin.

## 9.6 Multirate support

***Make the following changes to paragraph 7 of clause 9.6(.11g) "Multirate Support":***

To allow the transmitting STA to calculate the contents of the Duration/ID field, a STA responding to a received frame shall transmit its Control Response (either CTS or ACK) frames at the highest rate in the BSSBasicRateSet that is less than or equal to the rate of the immediately previous frame in the frame exchange sequence (as defined in 9.7) and that is of the same modulation ~~type~~ class (see Clause 9.6.1) as the received frame. If no rate in the basic rate set meets these conditions, then the control frame sent in response to a received frame shall be transmitted at the highest mandatory rate of the PHY that is less than or equal to the rate of the received frame, and that is of the same modulation ~~type~~ class as the received frame. In addition, the Control Response frame shall be sent using the same PHY options as the received frame, unless they conflict with the requirement to use the BSSBasicRateSet.

***Add new clause 9.6.1 immediately following the existing clause 9.6***

## 9.6.1 Modulation Classes

In order to determine the rules for response frames given in clause 9.6, the following modulation classes are defined. Each row defines a modulation class. Modulation types within the same row have the same modulation class, while modulation types in different rows have different modulation classes.

**Table 9.6.1T Modulation Classes**

| Modulation Class | Description |
|---|---|
| 1 | Clause 16 Infrared PHY |
| 2 | Clause 14 Frequency Hopping Spread Spectrum PHY |
| 3 | Clause 15 DSSS PHY, and Clause 18 High Rate DSSS PHY |
| 4 | Clause 19.6 ERP-PBCC PHY |
| 5 | Clause 19.7 DSSS-OFDM |
| 6 | Clause 19.5 ERP-OFDM PHY |
| 7 | Clause 17 Orthogonal Frequency Division Multiplexing PHY in the 5GHz band |
| 8 | Clause 20 High Throughput PHY (20 MHz transmissions) |
| 9 | Clause 20 High Throughput PHY (40 MHz transmissions) |

## 9.9 HCF

## 9.9.1 HCF contention-based channel access (EDCA)

## 9.9.1.4 Multiple frame transmission in an EDCA TXOP

***Change the first paragraph of subclause 9.9.1.4(.11e) as follows:***

Multiple frames may be transmitted in an acquired EDCA TXOP following the rules in 9.9.1.3. if there are more than one frame pending in the AC for which the channel has been acquired. However, those frames that are pending in other ACs shall not be transmitted in this EDCA TXOP. If a QSTA has in its transmit queue an additional frame of the same AC as the one just transmitted, and the duration of transmission of that frame plus any expected acknowledgement for that frame is less than the remaining medium occupancy timer value, then the QSTA may commence transmission of that frame ~~at SIFS after the completion of the immediately preceding frame exchange sequence~~ after the completion of the appropriate interframe space from the end of the immediately preceding frame exchange sequence. The intention of using the multiple frame transmission shall be indicated by the QSTA through the setting of the duration/ID values in one of the following two ways (see 7.1.4):

## 9.9.2 HCF controlled channel access

## 9.9.2.1 HCF controlled channel access procedure

## 9.9.2.1.2 CAP generation

***Change the second paragraph of subclause 9.9.2.1.2(.11e) as follows***

~~During a CFP or a TXOP in CP, after each data, QoS data or management type frame with a group address in the Address1 field, the HC shall wait for at least one PIFS period, and shall only continue to transmit if the WM is idle.~~ After the last frame of all ~~other non-final~~ frame exchange sequences ~~(e.g., sequences that convey unicast QoS data or management type frames)~~ during a TXOP, the holder of the current TXOP shall wait for one SIFS period before transmitting the first frame of the next frame exchange sequence, unless the frame exchange is part of a HTP burst transmission when the rules identified in clause 9.1.6 apply. The HC may sense the channel and reclaim the channel after a duration of PIFS after the TXOP, if the channel remains idle. A CAP ends when the HC does not reclaim the channel after a duration of PIFS after the end of a TXOP.

## 9.9.2.2 TXOP structure and timing

***Change the first paragraph of subclause 9.9.2.2(.11e) as follows***

Any QoS data type frame of a subclass that includes CF-Poll contains a TXOP limit in its QoS control field. The ensuing polled TXOP is protected by the NAV set by the Duration field of the frame that contained the QoS (+) CF-Poll function, as shown in Figure 62.4. Within a polled TXOP a QSTA may initiate the transmission of one or more frame exchange sequences, with all such sequences being part of a HTP burst transmission, or being nominally separated by a SIFS interval.

The QSTA shall not initiate transmission of a frame unless the transmission, and any acknowledgement or other immediate response expected from the peer MAC entity, are able to complete prior to the end of the remaining TXOP duration. All transmissions, including the response frames, within the polled TXOP are considered to be the part of the TXOP and the HC shall account for these when setting the TXOP limit. If the TXOP Limit subfield in the QoS Control field of the QoS data type frame that includes CF-Poll is set to 0, then the QSTA to which the frame is directed to shall respond with either one MPDU or one QoS Null frame.

## 9.10 Block acknowledgment

## 9.10.1 Introduction (Informative)

***Change the first paragraph of subclause 9.9.10.1(.11e) as follows***

The Block Acknowledgement (Block Ack) mechanism allows a block of QoS Data MPDUs to be transmitted between two QSTAs without intervening ACK frames ~~each separated by a SIFS period, between two QSTAs~~. The mechanism is for improving the channel efficiency by aggregating several acknowledgements into one frame. There are two types of Block Ack mechanisms: immediate and delayed. Immediate Block Ack is suitable for high-bandwidth, low latency traffic while the delayed Block Ack is suitable for applications that tolerate moderate latency. In this clause, the QSTA with data to send using the Block Ack mechanism is referred to as the originator and the receiver of that data as the recipient.

## 9.10.3 Data and acknowledgement transfer

***Change the first paragraph of subclause 9.9.10.1(.11e) as follows***

After setting up for the Block exchange following the procedure in 9.10.2, the originator may transmit a Block of QoS data type frames ~~separated by SIFS period,~~ with the total number of frames not exceeding the Buffer Size subfield in the associated ADDBA response frame. Each of the frames shall have the Ack policy subfield in the QoS Control set to "Block Acknowledgement". The RA field of the frames shall be the recipient's *unicast* address. The originator requests acknowledgement of outstanding QoS Data type frames by sending a BlockAckReq frame. The recipient shall maintain a Block Ack record for the block.

## 9.12 Frame exchange sequences

***Edit Table 22.1(.11e) <HCF sequence> and replace all "=" with"-".***

***Remove definiton 36 from end of Table 22.4(.11e) (no PIFS spacing defined anymore).***

***Replace the last sentence of the text in subclause 9.12 as follows(.11e) with:***

Individual frames within each of these sequences ~~are separated by a SIFS~~ may be send as part of a HTP burst transmission if the frames meet the rules identified in clause 9.16., otherwise a SIFS separation is used unless an "=" sign appears between frames in the table, in which case, PIFS is used.

## 9.13 Protection mechanism

***Delete two paragraphs from the text of clause 9.13 as follows:***

If a protection mechanism is being used, a fragment sequence may only employ ERP-OFDM modulation for the final fragment and control response.

The rules for calculating RTS/CTS NAV fields are unchanged when using RTS/CTS as a protection mechanism.

***Insert the following new subclause after clause 9.13:***

## 9.13.1 OFDM Protection

The intent of an OFDM protection mechanism is to ensure that an HTP STA does not transmit an MPDU of type Data or an MMPDU, using a Clause 20 rate which is not also a Clause 17 or Clause 19 rate unless it has attempted to update the NAV or cause a PHY-CCA.indicate(status=BUSY) to be elicited by receiving Clause 17 or Clause 19 STAs.

The updated NAV period shall be longer than or equal to the total time required to send the data and any required response frames.

The PHY-CCA.indicate(status=BUSY) shall be longer than or equal to the total time required to send the data and any required response frames.

HTP STAs shall use OFDM protection mechanisms (such as RTS/CTS or CTS-to-self employing a Clause 19 or Clause 17 rate) for Clause 20-only rate MPDUs of type Data or MMPDUs when the Use_OFDM_Protection field of transmitted or received ERP Information elements is set to 1 and the BSSID of the frame which contained the ERP Information element is the same as the BSS which the HTP STA has joined or started. Clause 19 rates shall be employed when the BSS is operating in a Clause 19 channel. Clause 17 rates shall be employed when the BSS is operating in a Clause 17 channel.

OFDM Protection mechanism frames shall conform to at least one of the following conditions:
The frame shall be sent using one of the mandatory Clause 19 or Clause 17 rates and using one of the mandatory Clause 17 or Clause 19 waveforms, so that all known ERP or Clause 17 STAs in the BSA will know the duration of the exchange even if they cannot detect the Clause 20 frames using their CCA function
The frame shall be sent using a Clause 17 preamble and signal field (additional, non-clause 17 preamble and signal field may be present following the Clause 17 preamble and signal field)
The frame shall be sent using a Clause 19 preamble and signal field (additional, non-clause 19 preamble and signal field may be present following the Clause 19 preamble and signal field)

In the case of a BSS composed of only HTP STAs, but with knowledge of a neighboring co-channel BSS having nHTP traffic, the AP may require either or both of protection mechanisms and OFDM protection mechanisms to protect the BSSs traffic from interference. This will provide propagation of NAV of PHY-CCA.indicate(status=BUSY) to all associated STAs and all STAs in a neighboring co-channel BSS within range through BSS basic rate set modulated messages. Frames that propagate the NAV throughout the BSS include RTS/CTS/ACK frames, all data frames with the “more fragments” field set to 1, all data frames sent in response to PS-Poll that are not preceded in the frame sequence by a data frame with the “more fragments” field set to 1, Beacon frames with nonzero CF time, +CF-POLL frames, various QOS frames, and CF-End frames. Frames that propagate PHY-CCA.indicate(status=BUSY) throughout the BSS include any frames which commence with an appropriately chosen preamble and signal field.

If any of the rates in the BSSBasicRateSet of the OFDM protection mechanism frame transmitting STAs BSS are Clause 17 or Clause 19 rates, then the OFDM protection mechanism frames shall be sent at one of those Clause 17 or Clause 19 basic rates, unless either condition b) or condition c) from above has been met, in which case, no rate restrictions apply.

OFDM Protection Mechanisms shall not be used where the frame transmission will be protected by the Protection Mechanism defined in clause 9.13

***Insert new clause 9.14 and sub-clauses as follows:***

## 9.14 40 MHz Channel Pairs

Clause 20 defines a mode in which High Throughput PHYs can transmit a frame utilising a 40 MHz channel pair in order to achieve lower frame durations than if a single 20 MHz channel was used. This clause describes the MAC support for this feature in an infrastructure BSS. 40 MHz transmissions shall only be used when the STA has joined or started an Infrastructure BSS.

A 40 MHz channel pair consists of two 20 MHz channels, and a BSS operating on a 40 MHz Channel Pair will make use of one of these channels (called the primary channel) for 20 MHz transmissions. The other channel (called the secondary channel) will not be used by the BSS for 20 MHz transmissions.

### 9.14.1 40 MHz Fundamentals of Operation

A 40 MHz channel pair consists of two 20 MHz channels, on each of which there could be 20 MHz transmissions (from an overlapping BSS on either channel, or from 20 MHz transmissions on the primary channel), and on each of which the Carrier Sense mechanism described in clause 9.2.1 could be run. However, it is not possible to combine two Carrier Sense mechanisms without degrading the effective priority of 40 MHz transmissions to such an extent that they would provide no benefit.

For this reason the MAC models a 40 MHz channel pair as a single 20 MHz channel (the primary channel) in which some transmissions happen to "overflow" into the Secondary Channel. There is no requirement for a STA to consider the state of the Secondary Channel when transmitting.

A STA shall control access to the 40 MHz channel pair through performing the Carrier Sense mechanism on the primary channel. A STA shall not change the transmission time of a frame due to the state of the Carrier Sense mechanism on the secondary channel. A STA may change the transmission rate or modulation class of the frame based on the state of the Carrier Sense mechanism on the secondary channel, where allowed by clause 9.6.

An AP shall indicate that it is operating on a 40 MHz channel pair by including the Channel Set information element in its Beacon frames. An AP shall not change the information contained in the Channel Set information element without invoking the channel move procedure described in clause 11.6.7. A STA that has joined a BSS and that wishes to use 40 MHz transmissions shall check the setting of the Secondary_Channel_Used bit in the ERP Information Element in the last valid Beacon frame received from the BSS, and shall not use 40 MHz transmissions where the Secondary_Channel_Used bit is set to 1.

A STA shall not send a 20 MHz transmission to a member STA of a BSS on the secondary channel of that BSS. A STA that has joined or started a BSS operating on a 40 MHz channel pair shall discard all 20 MHz transmissions received on the secondary channel. A STA shall not join a BSS on its secondary channel.

### 9.14.2 Coexistence with non High Throughput STAs on the secondary channel

As there is no requirement for a STA to consider the Carrier Sense state of the secondary channel before transmitting, the likelihood of collisions with 20 MHz transmissions from an overlapping BSS in the secondary channel is greatly increased. A STA shall not initiate a frame sequence making use of 40 MHz transmissions if there is significant evidence of collisions on the secondary channel. The algorithm for determining significant evidence of collisions is implementation dependant.

An AP that detects significant evidence of collisions on the secondary channel may invoke the channel move procedure described in clause 11.6.7.

#### 9.14.2.1 Secondary Channel Beacon

In order to reduce the chance of the secondary channel being used by an overlapping BSS, an AP may send a Beacon frame using the secondary channel with contents chosen to discourage use of the secondary channel by other BSSes.

The frame body of such a beacon is shown in Clause 7.2.3.1.1. These beacons contain a rate set consisting of a single clause 20 basic rate, and so should not cause non-clause 20 STAs to attempt to associate with the AP on the secondary channel.

When transmitting a beacon on the secondary channel, the AP may observe the channel access mechanisms described elsewhere in clause 9 for the transmission of Beacon frames, or it may transmit the Beacon frame without consideration of the state of the secondary channel.

### 9.14.3 Beacon Transmission

An AP operating on a 40 MHz channel pair shall send Beacon frames (with the exception of Secondary Channel Beacon frames) on the primary channel using a 20 MHz transmission.

### 9.14.4 Limits on Channel Numbering

Both the primary and secondary Channels shall be legal 20 MHz channels in the 5GHz band. For a primary channel number "n", the secondary channel number shall be either "n+4" or "n-4".

# 10. Layer management

## 10.4 PLME SAP interface

## 10.4.3 PLME_CHARACTERISTICS.confirm

### 10.4.3.2 Semantics of the service primitive

***Change the primitive description as follows:***

The primitive provides the following parameters:

```
PLME-CHARACTERISTICS.confirm(
                                    aSlotTime,
                                    aSIFSTime,
                                    aRIFSTime,
                                    aCCATime,
                                    aRxTxTurnaroundTime,
                                    aTxPLCPDelay,
                                    aRxPLCPDelay,
                                    aRxTxSwitchTime,
                                    aTxRampOnTime,
                                    aTxRampOffTime,
                                    aTxRFDelay,
                                    aRxRFDelay,
                                    aAirPropagationTime,
                                    aMACProcessingDelay,
                                    aPreambleLength,
                                    aPLCPHeaderLength,
                                    aMPDUDurationFactor,
                                    aMPDUMaxLength,
                                    aCWmin,
                                    aCWmax
                                    )
```

***Add the following entry to the table:***

| | | |
|---|---|---|
| aRIFSTime | integer | The minimum time (in microseconds) that the PHY requires between PSDUs that are transmitted with differing TXPWR_LEVELs within a HTP burst transmission. |

## 10.4.4 PLME-DSSSTESTMODE.request

### 10.4.4.2 Semantics of the service primitive

***Change the sixth row in the table in 10.4.4.2 as shown:***

| | | | |
|---|---|---|---|
| DATA_RATE | Integer | 2, 4, 11, 12,<br>18, 22, 24,<br>36, 44, 48,<br>66, 72, 73-92, 96,<br>97-106, 108, 109-121 | Selects among rates and transmission modes<br>02 = 1 Mbit/s<br>04 = 2 Mbit/s<br>11 = 5.5 Mbit/s<br>12 = 6 Mbit/s<br>18 = 9 Mbit/s<br>22 = 11 Mbit/s<br>24 = 12 Mbit/s<br>36 = 18 Mbit/s<br>44 = 22 Mbit/s<br>48 = 24 Mbit/s<br>66 = 33 Mbit/s<br>72 = 36 Mbit/s<br>96 = 48 Mbit/s<br>108 = 54 Mbit/s<br>73-92, 97-106, 109-121 = See Tables 003-009 and 016 in subclause 20.3.2.2 |

# 20. High throughput PHY specification for the 2.4 and 5 GHz bands

## 20.1 Overview

This clause specifies the PHY entity for a multiple input multiple output orthogonal frequency division multiplexing (MIMO-OFDM) system and the additions that have to be made to the base standard to accommodate the MIMO-OFDM PHY. The radio frequency LAN system is aimed for both the 2.4 GHz band and the 5 GHz bands, as specified in subclause 20.3.8.3

### 20.1.1 Introduction

The MIMO-OFDM system provides a wireless LAN with mandatory data payload communication capabilities of up to 135 Mbit/s and with optional modes capable of supporting data rates up to 540 Mbit/s. The MIMO-OFDM PHY draws from the basic OFDM PHY defined in Clause 17, and builds its extensions to two, three, and four transmit antenna modes (hereafter known as 2TX, 3TX, and 4TX, respectively), operating in 20 MHz bandwidth. Additionally, 1TX, 2TX, 3TX, and 4TX modes are also defined for operation in 40 MHz bandwidth.

### 20.1.2 Operational Modes

The radio portion of all Clause 20 compliant MIMO-OFDM PHY systems shall implement all mandatory and optional data rates defined in Clause 17, all mandatory data rates defined in Clause 19, and all optional data rates of the OFDM-based ERP defined in Clause 19, in their respective bands of operation. In addition, support for transmitting and receiving data using the MIMO-OFDM PHY defined in this Clause is mandatory for all rates specified for the 2TX, 20 MHz mode. Support for 3TX and 4TX modes in 20 MHz, and 1TX, 2TX, 3TX, and 4TX modes in 40 MHz shall be optional.

### 20.1.3 Scope

This subclause describes the PHY services provided to the IEEE 802.11 wireless LAN MAC by the MIMO-OFDM system. The MIMO-OFDM PHY layer consists of two protocol functions, defined as follows:

a) A PHY convergence function, which adapts the capabilities of the physical medium dependent (PMD) system to the PHY service. This function is supported by the physical layer convergence procedure (PLCP), which defines a method of mapping the IEEE 802.11 PHY sublayer service data units (PSDU) into a framing format suitable for sending and receiving user data and management information between two or more stations using the associated PMD system.

b) A PMD system whose function defines the characteristics and method of transmitting and receiving data through a wireless medium between two or more stations, each using the MIMO-OFDM PHY.

### 20.1.4 MIMO-OFDM PHY functions

The architecture of the MIMO-OFDM PHY is depicted in the ISO/IEC basic reference model shown in Figure 141 of 18.4.1. The MIMO-OFDM PHY contains three functional entities: the PMD function, the PHY convergence function (PLCP), and the layer management function.

The MIMO-OFDM PHY service is provided to the MAC through the PHY service primitives defined in Clause 12. Interoperability is addressed by use of the carrier sense mechanism specified in 9.2.1 and the protection mechanism in 9.10. This mechanism allows non-MIMO-OFDM stations to know of MIMO-OFDM traffic that they cannot demodulate so they may defer the medium to that traffic.

## 20.2 PHY-specific service parameter list

The architecture of the IEEE 802.11 MAC is intended to be PHY independent. Some PHY implementations require PHY-dependent MAC state machines running in the MAC sublayer in order to meet certain PMD requirements. The PHY-dependent MAC state machine resides in a sublayer defined as the MAC sublayer management entity (MLME). In certain PMD implementations, the MLME may need to interact with the PLME as part of the normal PHY SAP primitives. These interactions are defined by the PLME parameter list currently defined in the PHY service primitives as TXVECTOR and

RXVECTOR. The list of these parameters, and the values they may represent, are defined in the specific PHY specifications for each PMD. This subclause addresses the TXVECTOR and RXVECTOR for the MIMO-OFDM PHY.

The parameters in Table 001 are defined as part of the TXVECTOR parameter list in the PHY-TXSTART.request service and PLME-TXTIME.request primitives.

**Table 001—TXVECTOR parameters**

| Parameter | Value |
|---|---|
| DATARATE | The rate used to transmit the PSDU in Mbit/s. Allowed value depends on the values of TRANSMISSION_MODE and NUM_STREAMS parameters<br><br>Values: 6.75, 10.125, 13.5, 20.25, 27, 40.5, 54, 60.75, 81, 108, 121.5, 135, 162, 182.25, 202.5, 216, 243, 270, 324, 364.5, 405, 432, 486, 540 |
| LENGTH | The length of the PSDU in octets<br><br>Range: 1-8191 |
| TRANSMISSION_ MODE | The mode used for transmission of the PPDU. Determines the preamble type used.<br><br>Enumerated type: 2TX20GF, 3TX20GF, 4TX20GF, 2TX20MM, 3TX20MM, 4TX20MM, 1TX40GF, 2TX40GF, 3TX40GF, 4TX40GF, 1TX40MM, 2TX40MM, 3TX40MM, 4TX40MM. |
| NUM_STREAMS | The number of independent spatial streams transmitted.<br><br>Values: 1, 2, 3, 4. |
| CODE_TYPE | Convolutional or LDPC<br><br>Values: 0 (convolutional), 1 (LDPC) |
| SERVICE | The scrambler initialization vector.<br><br>16 null bits |
| TXPWR_LEVEL | The transmit power level. The definition of these levels is up to the implementer.<br><br>Range: 1-8 |
| LPI | Indicates that this is the last PSDU to be aggregated into the current PPDU<br><br>Values: true, false |
| BURST_ DURATION | The length in microseconds of the BURST_DURATION field in the mixed mode preamble. Only used when a mixed mode TRANSMISSION_MODE is selected.<br><br>Range: 0-4095 |

The parameters in Table 002 are defined as part of the RXVECTOR parameter list in the PHY-RXSTART.indicate service primitive. When implementations require the use of these vectors, some or all of these parameters may be used in the vectors.

**Table 002—RXVECTOR parameters**

| Parameter | Value |
|---|---|
| DATARATE | The rate at which the PSDU was received in Mbit/s. Allowed value depends on the values of TRANSMISSION_MODE and NUM_STREAMS parameters<br><br>Values: 6.75, 10.125, 13.5, 20.25, 27, 40.5, 54, 60.75, 81, 108, 121.5, 135, 162, 182.25, 202.5, 216, 243, 270, 324, 364.5, 405, 432, 486, 540 |
| LENGTH | The length of the PSDU in octets.<br><br>Range: 1-8191 |
| TRANSMISSION _MODE | The transmission type detected during reception of the PPDU |

| | |
|---|---|
| | Enumerated type: 2TX20GF, 3TX20GF, 4TX20GF, 2TX20MM, 3TX20MM, 4TX20MM, 1TX40GF, 2TX40GF, 3TX40GF, 4TX40GF, 1TX40MM, 2TX40MM, 3TX40MM, 4TX40MM. |
| NUM_STREAMS | The number of independent spatial streams transmitted.<br><br>Values: 1,2,3,4. |
| CODE_TYPE | Convolutional or LDPC<br><br>Values: 0 (convolutional), 1 (LDPC) |
| SERVICE | Null |
| RSSI | The RSSI is a measure of the RF energy received by the MIMO-OFDM PHY, averaged across all RX antennas. The 8-bit value is in the range of 0 to RSSI maximum as described in 17.2.3.2. |
| LPI | Indicates that this is the last PSDU to be aggregated into the current PPDU<br><br>Values: true, false |
| BURST_ DURATION | The length in microseconds of the BURST_DURATION field in the mixed mode preamble. Only valid when a mixed mode TRANSMISSION_MODE is used.<br><br>Range: 0-4095 |

## 20.3 MIMO-OFDM PLCP sublayer

### 20.3.1 Introduction

This subclause provides a convergence procedure by which PSDUs are converted to and from PPDUs at the transmitter and receiver. During transmission, the PSDU shall be appended with a PLCP preamble and header to create the PPDU. At the receiver, the PLCP preamble and header are processed to aid in the demodulation and delivery of the PSDU.

Stations implementing the MIMO-OFDM PHY shall use one of two methods of access to the medium. The medium may be reserved solely via a MAC mechanism, as defined in subclause 9.13. Alternatively, a special PLCP frame format may be used to cause non-MIMO-OFDM stations to defer the medium to MIMO-OFDM traffic. Hereafter, these two methods of access shall be known as greenfield and mixed-mode, respectively.

### 20.3.2 PLCP frame format

Figure 001 shows the format of the PPDU used with greenfield access in the 1TX mode of operation in 40 MHz and the 2TX modes of operation in both 20 and 40 MHz. The PPDU consists of a MIMO-OFDM PLCP preamble, MIMO-OFDM PLCP header, PSDU, and may consist of appended tail bits and pad bits.

The MIMO-OFDM PLCP preamble is composed of a sequence of short and long training symbols. The format of the PLCP preamble is defined in subclause 20.3.3 for each mode of operation in the MIMO-OFDM PHY.

The MIMO-OFDM PLCP header is composed of the SIGNAL-N field and the SERVICE field. The SIGNAL-N field is defined in 20.3.4 and consists of 54 bits that specify all configuration and length-related parameters associated with PPDU transmission. The SERVICE field is composed of 16 bits and is defined in subclause 20.3.5.1.

The SERVICE field of the PLCP header and the PSDU (with tail and pad bits appended, if necessary) are denoted as DATA and may constitute multiple MIMO-OFDM symbols. These symbols are transmitted according to the configuration parameters specified in the SIGNAL-N field.

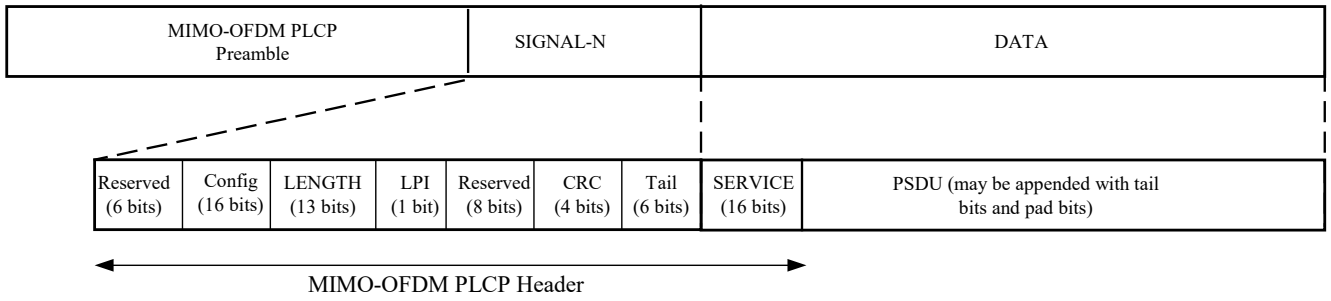



**Figure 001 – PPDU frame format: Greenfield access in the 1TX (40 MHz) and 2TX (20 and 40 MHz) modes**

Figure 002 shows the format of the PPDU used with greenfield access in the 3TX and 4TX modes of operation in both 20 and 40 MHz. In these modes the MIMO-OFDM PLCP preamble field is extended according to subclause 20.3.3 in order to provide training from the additional transmit antennas.

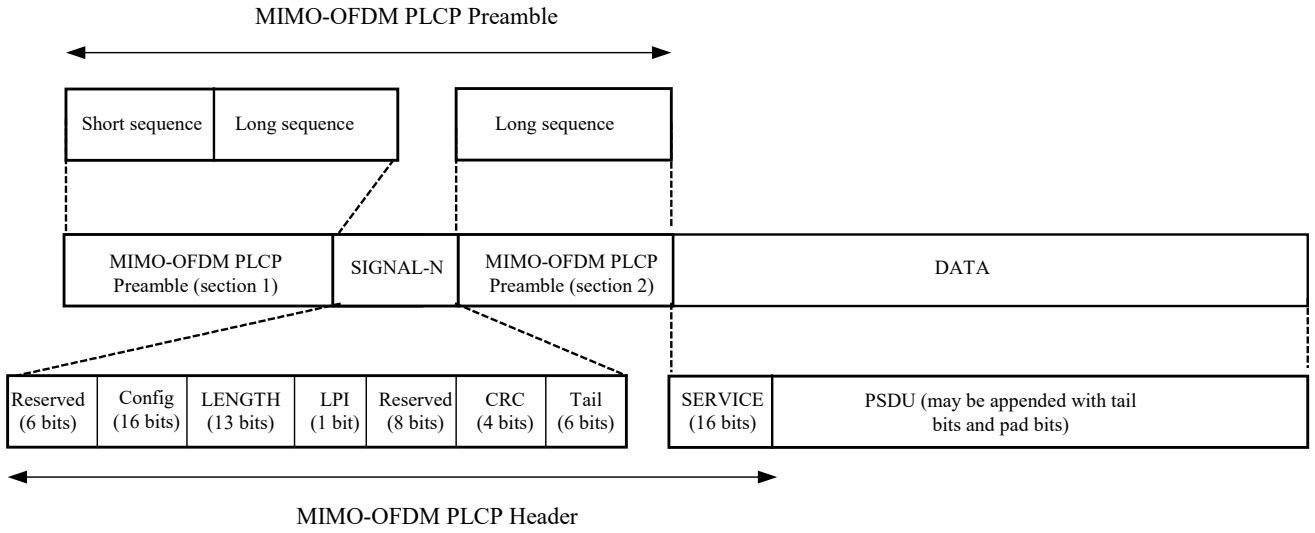



**Figure 002 – PPDU frame format: Greenfield access in the 3TX and 4TX modes (20 and 40 MHz)**

Figure 003 shows the format of the PPDU used with mixed-mode access in the 1TX mode of operation in 40 MHz and the 2TX modes of operation in both 20 and 40 MHz. The PLCP header in these modes consists of an additional SIGNAL-MM field that conveys information about the MIMO-OFDM PPDU transmission to non-MIMO-OFDM stations, causing them to defer the medium for the duration of the MIMO-OFDM transmission. The SIGNAL-MM field is defined in subclause 20.3.4.

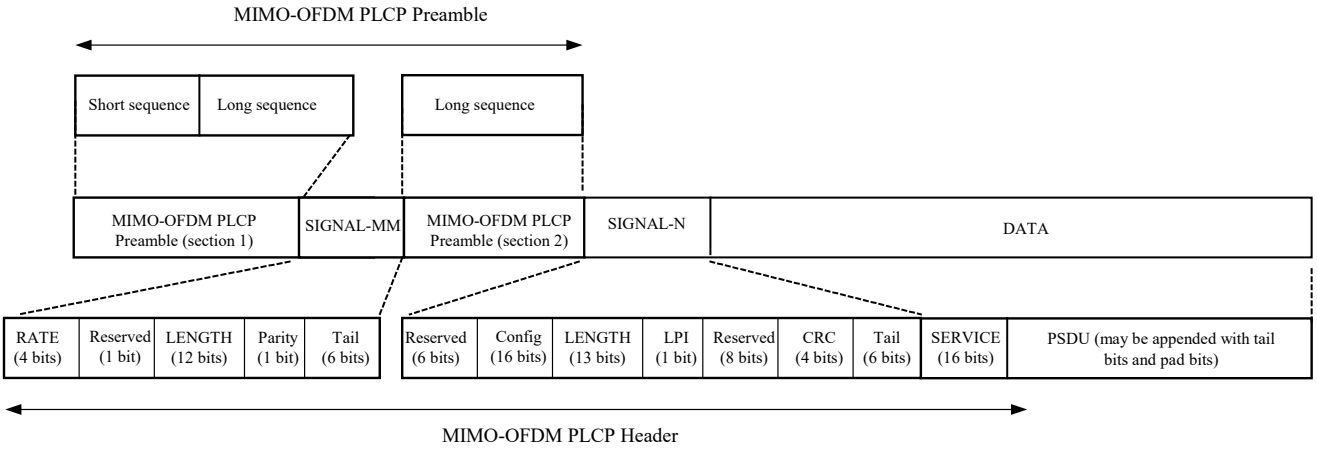



**Figure 003 – PPDU frame format: Mixed mode access in the 1TX (40 MHz) and 2TX (20 and 40 MHz) modes**

Figures 004 and 005 shows the format of the PPDU used with mixed mode access in the 3TX and 4TX modes, operating in 20 MHz and 40 MHz, respectively.

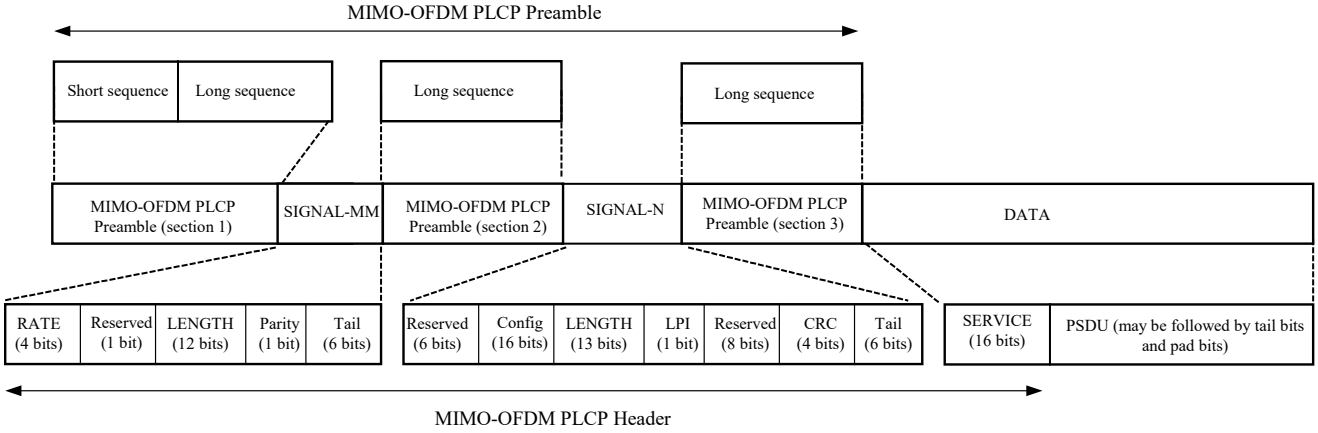



**Figure 004– PPDU frame format: Mixed mode access in the 3TX and 4TX modes (20 MHz)**

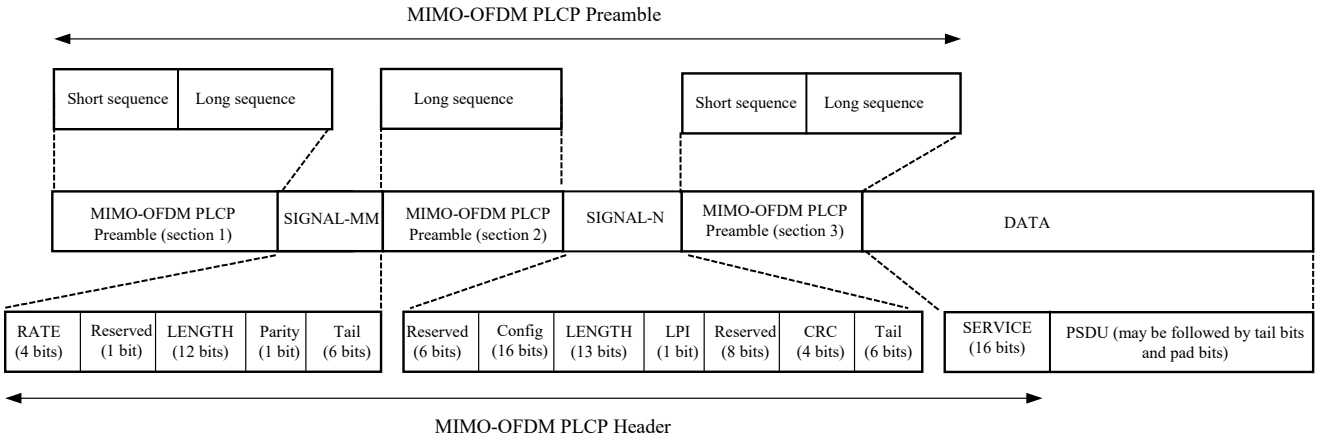



**Figure 005– PPDU frame format: Mixed mode access in the 3TX and 4TX modes (40 MHz)**

### 20.3.2.1 Overview of the PPDU encoding process

The encoding process is composed of many detailed steps, which are described fully in later subclauses, as noted below. The following overview intends to facilitate understanding the details described in these subclauses:

a) Produce the PLCP preamble fields for each transmit antenna based on the TRANSMISSION_MODE field of the TXVECTOR. Refer to 20.3.3 for details.

b) Produce the PLCP header field from the LENGTH, DATARATE, TRANSMISSION_MODE, NUM_STREAMS, CODE_TYPE, and SERVICE fields of the TXVECTOR by filling the appropriate bit fields, as described in subclause 20.3.4 and subclause 20.3.5.1.

c) Calculate from the DATARATE, TRANSMISSION_MODE, and NUM_STREAMS fields of the TXVECTOR, the number of data bits per MIMO-OFDM symbol ($N_{DBPS}$), the coding rate (R), the number of bits in each OFDM subcarrier per antenna ($N_{BPSC}$), the number of coded bits per MIMO-OFDM symbol ($N_{CBPS}$), the number of spatial streams ($N_{SS}$), and the number of encoding streams ($N_{ES}$).

d) Extend the data bit string with "zero" bits (at least 6 bits for each encoding stream) so that the resulting length will be a multiple of the number of data bits per OFDM symbol ($N_{DBPS}$).

e) Initiate the scrambler with a pseudorandom non-zero state; generate a sequence of scrambled data bits as defined in subclause 20.3.5.4.

f) Demultiplex every other bit of the "data" to the $N_{ES}$ encoding streams, with bit 0 directed to the first encoder.

g) Replace the six scrambled "zero" bits following the "data" of each parallel encoding stream with six nonscrambled "zero" bits (These bits return the convolutional encoder to the "zero state" and are denoted as "tail bits.").

h) Encode each extended, scrambled parallel encoding stream data string with a convolutional encoder (R = 1/2). Omit (puncture) some of the encoder output string (chosen according to "puncturing pattern") to reach the desired "coding rate", as defined in subclause 20.3.5.5.

i) Divide the parallel encoded bit strings into groups of $N_{CBPS} / N_{ES}$ bits and multiplex them alternately between the $N_{ES}$ encoders' outputs to obtain a single aggregated bit string.

j) Divide the aggregated bit string into groups of $N_{CBPS}$ bits. Within each group, perform an "interleaving" (reordering) of the bits according to the rule specified in subclause 20.3.5.6. The interleaving parameters are independent of $N_{ES}$.

k) Divide the resulting coded and interleaved data string into groups of $N_{BPSC}$ bits. For each of the bit groups, convert the bit group into a complex number according to the modulation encoding tables.

l) Divide the complex number string into groups of $N_{SD} \times N_{SS}$ complex numbers, where $N_{SD}$ is the number of data subcarriers per OFDM symbol, and $N_{SS}$ is the number of spatial streams to be transmitted. Map the complex numbers to antennas and subcarriers, as specified in subclause 20.3.5.8. The first $N_{SD}$ complex numbers are modulated on the subcarriers of the first transmit antenna.

m) Insert $N_{SP}$ subcarriers as pilots on each transmit antenna, according to subclause 20.3.5.9.

n) For each group of subcarriers, and on each TX antenna, convert the subcarriers to time domain using inverse Fourier transform. Prepend to the Fourier-transformed waveform a circular extension of itself thus forming a guard interval (GI), and truncate the resulting periodic waveform to a single OFDM symbol length by applying time domain windowing. Refer to 20.3.2.4 for details.

o) Append the OFDM symbols for each antenna one after another, starting with the SIGNAL symbols defined in subclause 20.3.4, and with fields of the PLCP preamble inserted in between if necessary. Refer to 20.3.3 for details.

p) Up-convert the resulting "complex baseband" waveform on each antenna to an RF frequency according to the center frequency of the desired channel and transmit. Refer to 20.3.2.4 and 20.3.8.1 for details.

### 20.3.2.2 RATE-dependent parameters

When the number of transmitted spatial streams $N_{SS}$ is equal to the number of transmit antennas $N_{TX}$, the RATE-dependent modulation parameters shall be set according to the values defined in Tables 003, 004, and 005 respectively for the 2TX, 3TX, and 4TX modes in 20 MHz. The RATE-dependent parameters for the 1TX, 2TX, 3TX, and 4TX modes in 40 MHz shall be set according to the values defined in Tables 006, 007, 008, and 009, respectively.

The number of parallel encoding streams $N_{ES}$ shall be 2 for all modes in 40 MHz in which the number of spatial streams $N_{SS}$ is greater than two. $N_{ES}$ shall be 1 for all other modes.

**Table 003—Rate-dependent parameters for 20 MHz, $N_{SS}$ = 2 ($N_{ES}$ = 1)**

| Data rate (Mbits/s) | Modulation | Coding rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data subcarriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 54 | 16-QAM | 1/2 | 4 | 54 | 2 | 432 | 216 | 73 |
| 81 | 16-QAM | 3/4 | 4 | 54 | 2 | 432 | 324 | 74 |
| 108 | 64-QAM | 2/3 | 6 | 54 | 2 | 648 | 432 | 75 |
| 121.5 | 64-QAM | 3/4 | 6 | 54 | 2 | 648 | 486 | 76 |
| 135 | 64-QAM | 5/6 | 6 | 54 | 2 | 648 | 540 | 77 |

**Table 004—Rate-dependent parameters for 20 MHz, $N_{SS}$ = 3 ($N_{ES}$ = 1)**

| Data rate (Mbits/s) | Modulation | Coding rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data subcarriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 81 | 16-QAM | 1/2 | 4 | 54 | 2 | 648 | 324 | 78 |
| 121.5 | 16-QAM | 3/4 | 4 | 54 | 2 | 648 | 486 | 79 |
| 162 | 64-QAM | 2/3 | 6 | 54 | 2 | 972 | 648 | 80 |
| 182.25 | 64-QAM | 3/4 | 6 | 54 | 2 | 972 | 729 | 81 |
| 202.5 | 64-QAM | 5/6 | 6 | 54 | 2 | 972 | 810 | 82 |

**Table 005—Rate-dependent parameters for 20 MHz, $N_{SS}$ = 4 ($N_{ES}$ = 1)**

| Data rate (Mbits/s) | Modulation | Coding rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data subcarriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 108 | 16-QAM | 1/2 | 4 | 54 | 2 | 864 | 432 | 83 |
| 162 | 16-QAM | 3/4 | 4 | 54 | 2 | 864 | 648 | 84 |
| 216 | 64-QAM | 2/3 | 6 | 54 | 2 | 1296 | 864 | 85 |
| 243 | 64-QAM | 3/4 | 6 | 54 | 2 | 1296 | 972 | 86 |
| 270 | 64-QAM | 5/6 | 6 | 54 | 2 | 1296 | 1080 | 87 |

**Table 006—Rate-dependent parameters for 40 MHz, $N_{SS}$ = 1 ($N_{ES}$ = 1)**

| Data rate (Mbits/s) | Modulation | Coding rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data subcarriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 54 | 16-QAM | 1/2 | 4 | 108 | 4 | 432 | 216 | 88 |
| 81 | 16-QAM | 3/4 | 4 | 108 | 4 | 432 | 324 | 89 |
| 108 | 64-QAM | 2/3 | 6 | 108 | 4 | 648 | 432 | 90 |
| 121.5 | 64-QAM | 3/4 | 6 | 108 | 4 | 648 | 486 | 91 |
| 135 | 64-QAM | 5/6 | 6 | 108 | 4 | 648 | 540 | 92 |

**Table 007—Rate-dependent parameters for 40 MHz, $N_{SS}$ = 2 ($N_{ES}$ = 1)**

| Data rate (Mbits/s) | Modulation | Coding rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$ ) | Number of data subcarriers ($N_{SD}$ ) | Numb er of pilots ($N_{SP}$ ) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$ ) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$ ) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 108 | 16-QAM | 1/2 | 4 | 108 | 4 | 864 | 432 | 97 |
| 162 | 16-QAM | 3/4 | 4 | 108 | 4 | 864 | 648 | 98 |
| 216 | 64-QAM | 2/3 | 6 | 108 | 4 | 1296 | 864 | 99 |
| 243 | 64-QAM | 3/4 | 6 | 108 | 4 | 1296 | 972 | 100 |
| 270 | 64-QAM | 5/6 | 6 | 108 | 4 | 1296 | 1080 | 101 |

**Table 008—Rate-dependent parameters for 40 MHz, $N_{SS}$ = 3 ($N_{ES}$ = 2)**

| Data rate (Mbits/s) | Modulation | Coding rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$ ) | Number of data subcarriers ($N_{SD}$ ) | Numb er of pilots ($N_{SP}$ ) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$ ) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$ ) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 162 | 16-QAM | 1/2 | 4 | 108 | 4 | 1296 | 648 | 102 |
| 243 | 16-QAM | 3/4 | 4 | 108 | 4 | 1296 | 972 | 103 |
| 324 | 64-QAM | 2/3 | 6 | 108 | 4 | 1944 | 1296 | 104 |
| 364.5 | 64-QAM | 3/4 | 6 | 108 | 4 | 1944 | 1458 | 105 |
| 405 | 64-QAM | 5/6 | 6 | 108 | 4 | 1944 | 1620 | 106 |

**Table 009—Rate-dependent parameters for 40 MHz, $N_{SS}$ = 4 ($N_{ES}$ = 2)**

| Data rate (Mbits/s) | Modulation | Coding rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$ ) | Number of data subcarriers ($N_{SD}$ ) | Numb er of pilots ($N_{SP}$ ) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$ ) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$ ) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 216 | 16-QAM | 1/2 | 4 | 108 | 4 | 1728 | 864 | 109 |
| 324 | 16-QAM | 3/4 | 4 | 108 | 4 | 1728 | 1296 | 110 |
| 432 | 64-QAM | 2/3 | 6 | 108 | 4 | 2592 | 1728 | 111 |
| 486 | 64-QAM | 3/4 | 6 | 108 | 4 | 2592 | 1944 | 112 |
| 540 | 64-QAM | 5/6 | 6 | 108 | 4 | 2592 | 2160 | 113 |

### 20.3.2.3 Timing related parameters

Table 010 is a list of timing parameters associated with the MIMO-OFDM PLCP.

**Table 010—Timing-related parameters**

| Parameter | Value (20 MHz modes) | Value (40 MHz modes) | Remarks |
|---|---|---|---|
| $N_{SD}$ : Number of data subcarriers | 54 | 108 | |
| $N_{SP}$ : Number of pilot subcarriers | 2 | 4 | |
| $N_{ST}$ : Number of subcarriers, total | 56 | 112 | $N_{ST} = N_{SD} + N_{SP}$ |
| $N_{OT}$: Index of outermost populated subcarrier | 28 | 58 | |

| | | | |
|---|---|---|---|
| $N_{TX}$: Number of transmit antennas | 2,3,4 | 1,2,3,4 | |
| $\Delta_F$: Subcarrier frequency spacing | 0.3125 MHz | 0.3125 MHz | $\Delta_F$ = 20/64 = 40/128 MHz |
| $T_{FFT}$ : IFFT/FFT period | 3.2 µs | 3.2 µs | $T_{FFT} = 1/\Delta_F$ |
| $T_{GI}$ : GI duration | 0.8 µs | 0.8 µs | ($T_{FFT}$ /4) |
| $T_{GI2}$ : Training symbol guard duration | 1.6 µs | 1.6 µs | |
| $T_{SYM}$ : Symbol interval | 4 µs | 4 µs | ($T_{GI}$ + $T_{FFT}$ ) |

### 20.3.2.4 Mathematical conventions in the signal descriptions

The transmitted signal will be described in a complex baseband signal notation. The RF (radio frequency) signal issued from the antenna is related to the complex baseband signal by the following relation:

$$r_{RF}(t) = \mathrm{Re}\{r(t)\exp(j2\pi f_c t)\} \quad (1)$$

where Re(.) represents the real part of the complex argument, and $f_c$ denotes the carrier frequency. The actual RF signal over the air is the sum of RF signals emanated from each transmit antenna.

The transmitted baseband signal from any antenna is composed of contributions from several OFDM symbols, including preamble, signal, and data. Each symbol is constructed as an inverse Fourier transform of a set of coefficients $C_k$, with $C_k$ defined later as data, pilots, or training symbols in subclause 20.3.3 through 20.3.5:

$$r_{SYMBOL}(t) = w_{SYMBOL}(t)\sum_{k=-N_{OT}}^{N_{OT}} C_k \exp(j2\pi k\Delta_F(t - T_{GUARD})). \quad (2)$$

The parameters $\Delta_F$ and $N_{OT}$ are defined in Table 010. The resulting waveform is periodic with a period of $T_{FFT} = 1/\Delta_F$. Shifting the time by $T_{GUARD}$ creates the "cyclic prefix" used in OFDM to avoid ISI from the previous symbol. Three kinds of $T_{GUARD}$ are defined: for the short training sequence (= 0µs), for the long training sequence (=$T_{GI2}$), and for data OFDM symbols (=$T_{GI}$). Informative considerations related to the windowing function $w_{SYMBOL}(t)$ and other implementation aspects, as specified in subclause 17.3.2.4, may also apply on a per-antenna basis in the MIMO-OFDM PHY.

The common way to implement the inverse Fourier transform, as shown in Equation (2), is by an inverse Fast Fourier Transform (IFFT) algorithm. If, for example, a 128-point IFFT is used to implement the 40 MHz transmission modes, the coefficients 3 to 58 are mapped to the same numbered IFFT inputs, while the coefficients -58 to -3 are copied into IFFT inputs 70 to 125. The rest of the inputs, 59 to 69, 1, 2, 126, 127, as well as the 0 (dc) input, shall be set to zero. This mapping is illustrated in Figure 006. After performing an IFFT, the output is cyclically extended to the desired length.

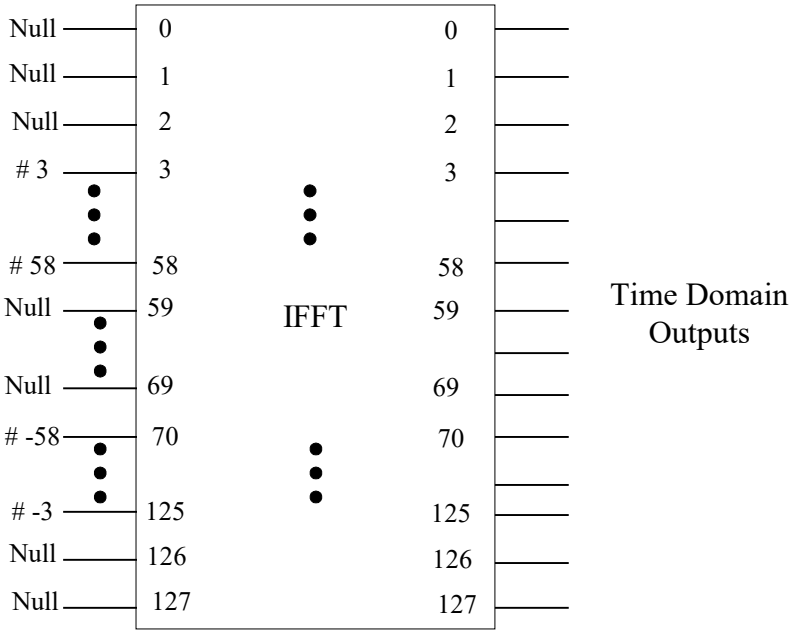


**Figure 006– Inputs and outputs of 128-point IDFT for 40 MHz data transmission**

### 20.3.3 PLCP preamble (SYNC)

The PLCP preamble field is used for synchronization. It consists of a sequence of short symbols and long symbols that are transmitted simultaneously from all transmit antennas, as described in this subclause.

Figure 007 shows the PLCP preamble format for greenfield 2TX mode in 20 MHz. The PLCP preamble is followed in this mode by the SIGNAL-N field and DATA. The total duration of the training symbols is 16 μsec. The short MIMO-OFDM training sequence transmitted from the first antenna consists of 12 subcarriers, which are modulated by elements of the sequence $SS_{20}$, given by

$SS_{20}[-28,28] = \sqrt{7/3} \times$ {0, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, –1–j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 0}. (3)

The second antenna transmits a cyclically shifted version of the sequence transmitted from the first antenna, such that the first sample of the short sequence transmitted from the second antenna is the sample that is transmitted 400 nsec after the start of the short sequence on the first antenna. This is denoted by "(400 ns cs)" in Figure 007. More generally, an indicator "S (x ns cs)" in Figures 007 through 016 denotes that the transmitted sequence is obtained by cyclically shifting by x nsec, the time-domain sequence corresponding to frequency domain sequence S. The indicator "GI" or "GI2" in these figures denotes respectively the last $T_{GI}$ or $T_{GI2}$ duration of waveform of the immediately ensuing OFDM symbol, prepended to the OFDM symbol as a guard interval.

The short sequence is followed by a long OFDM training sequence which is generated by modulating the elements of the sequence

$LS_{20}$ [-28..28] = {1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 0, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, -1, -1} (4)

according to the equation

$$r_{LONG}(t) = w_{TLONG}(t) \sum_{k=-N_{ST}/2}^{N_{ST}/2} LS_{20}[k] \exp\left(j2\pi k\Delta_F \left(t - T_{GI2}\right)\right) \quad (5)$$

where $T_{GI2}$ = 1.6 μsec. Two periods of the long symbol are transmitted for improved channel estimation accuracy. The long training sequence is also transmitted simultaneously from both antennas. The second antenna transmits a 1600 nsec cyclically shifted version of the long training symbols transmitted from the first antenna.

The PLCP preamble format for 2TX mixed-mode operation in 20 MHz is shown in Figure 008. The definition of the long and short sequences, as well as relative cyclic shifts between transmit antennas in this mode shall follow the description provided in Figure 008. The first and second TX antennas simultaneously transmit the first and second rows respectively of the MIMO-OFDM training structure shown in the figure.

Figure 009 and 010 define the PLCP preamble format for the 3TX and 4TX modes in 20 MHz, with greenfield access and mixed-mode access respectively. In the 3TX modes, only the first three rows shown in the corresponding MIMO-OFDM training structure are transmitted.

Figures 011, 013, and 015 show the PLCP preamble format for the 1TX, 2 TX, and 3TX/4TX greenfield modes in 40 MHz. The short sequence in these modes are obtained by modulating the elements of the sequence

$SS_{40GF}$ [-58,58] = $\sqrt{2}$ ×{0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0} (6)

on the subcarriers of the OFDM signal. The ensuing long sequence for 40 MHz greenfield operation is defined by the sequence

$LS_{40GF}$[-58..58] = {1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, -1, -1}. (7)

The mixed mode training structures for 1TX, 2TX, and 3TX/4TX modes in 40 MHz are defined in Figure 012, 014, and 016 respectively. The additional short and long sequences used in these modes are defined by the following frequency domain sequences:

$SS_{40MM}$[-58..58] = $\sqrt{7/3}$ ×{0, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, –1–j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, –1–j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 0}, (8)

$LS_{40MM}$[-58..58] = {1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 0, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, 1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, -1, -1}. (9)

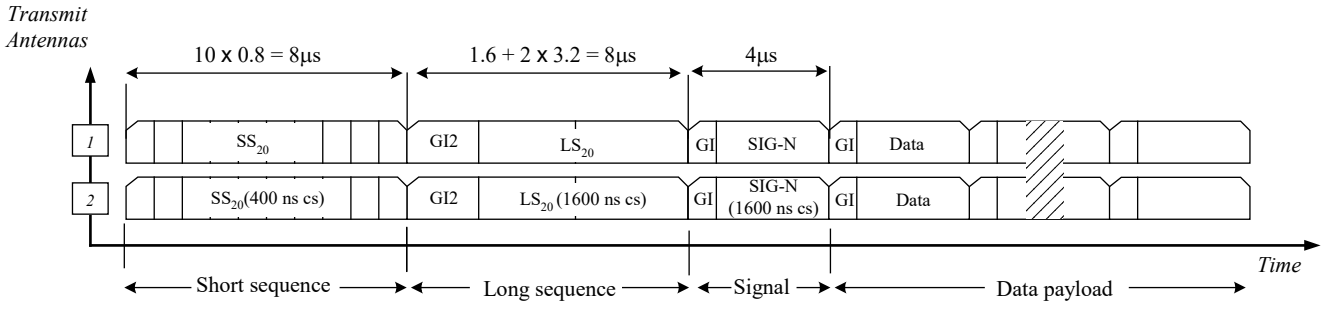



**Figure 007 – MIMO-OFDM Training structure for $N_{TX}$ = 2, 20 MHz, greenfield operation**

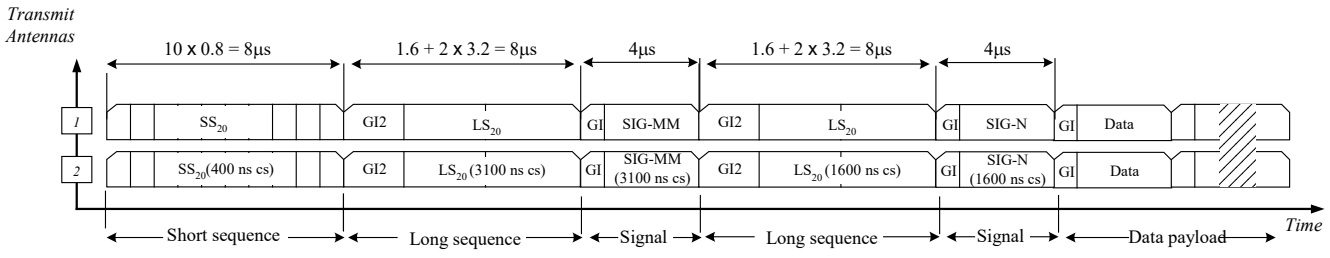



**Figure 008 – MIMO-OFDM Training structure for $N_{TX}$ = 2, 20 MHz, mixed mode operation**

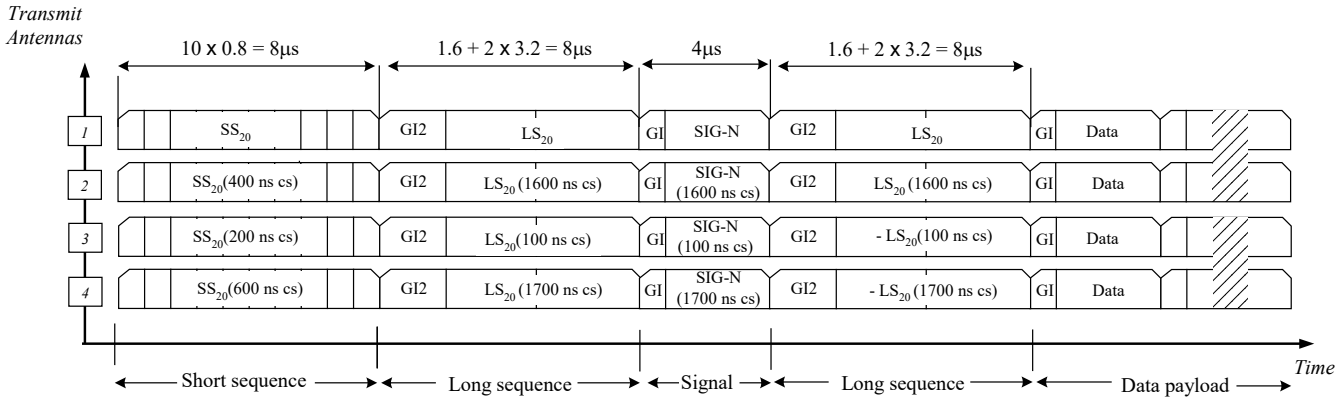


**Figure 009 – MIMO-OFDM Training structure for $N_{TX}$ = 3 and 4, 20 MHz, greenfield operation**

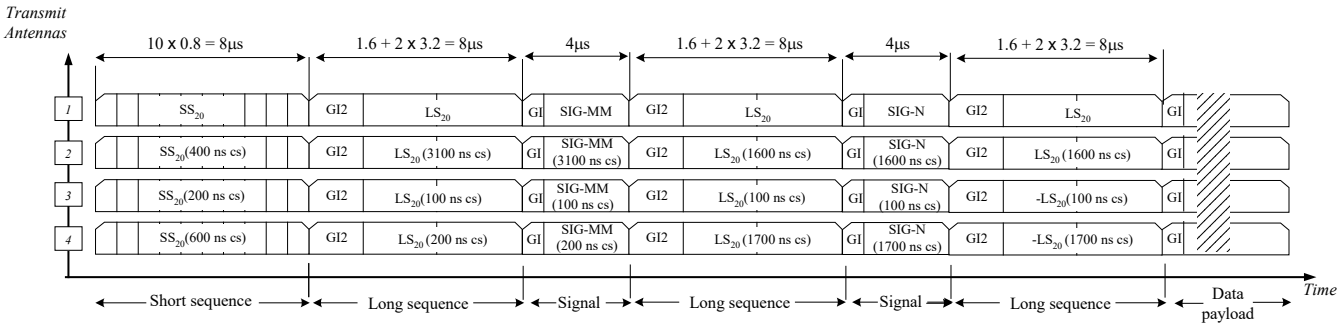



**Figure 010 – MIMO-OFDM Training structure for $N_{TX}$ = 3, 4, 20 MHz, mixed mode operation**

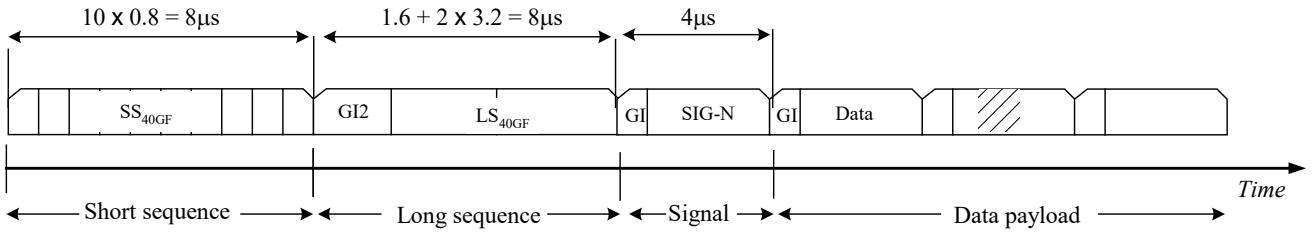



**Figure 011 – MIMO-OFDM Training structure for $N_{TX}$=1, 40 MHz, greenfield operation**

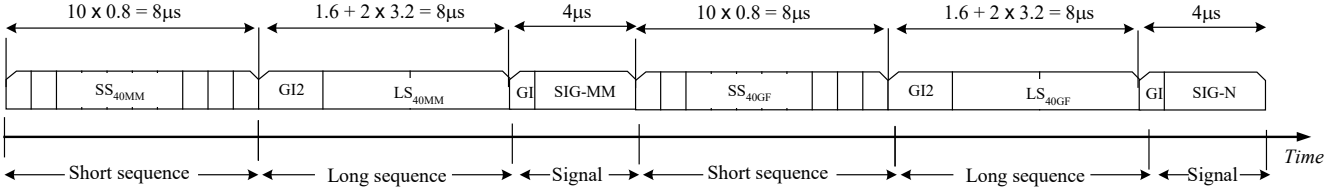



**Figure 012 – MIMO-OFDM Training structure for $N_{TX}$=1, 40 MHz, mixed mode operation**

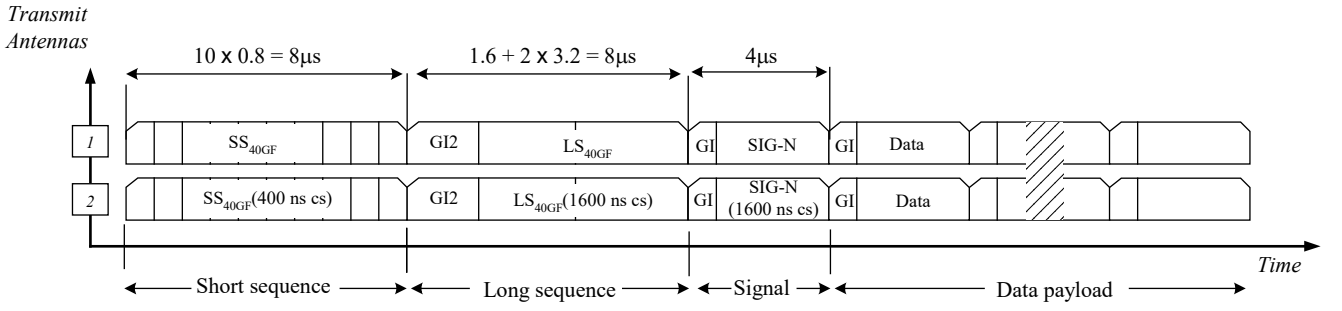



**Figure 013 – MIMO-OFDM Training structure for $N_{TX}$ = 2, 40 MHz, greenfield operation**

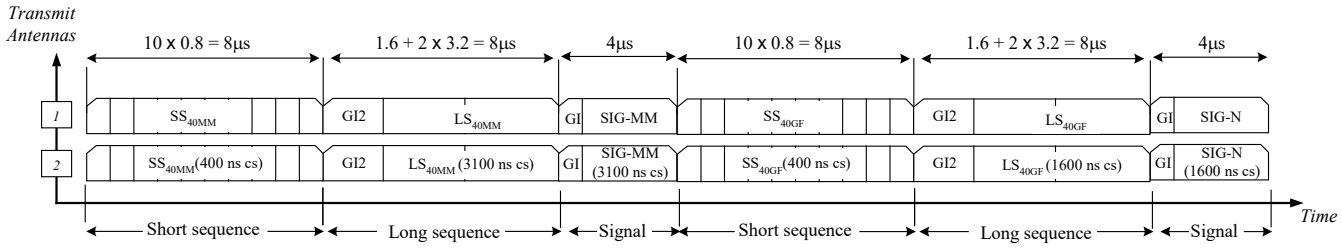



**Figure 014 – MIMO-OFDM Training structure for $N_{TX}$ = 2, 40 MHz, mixed mode operation**

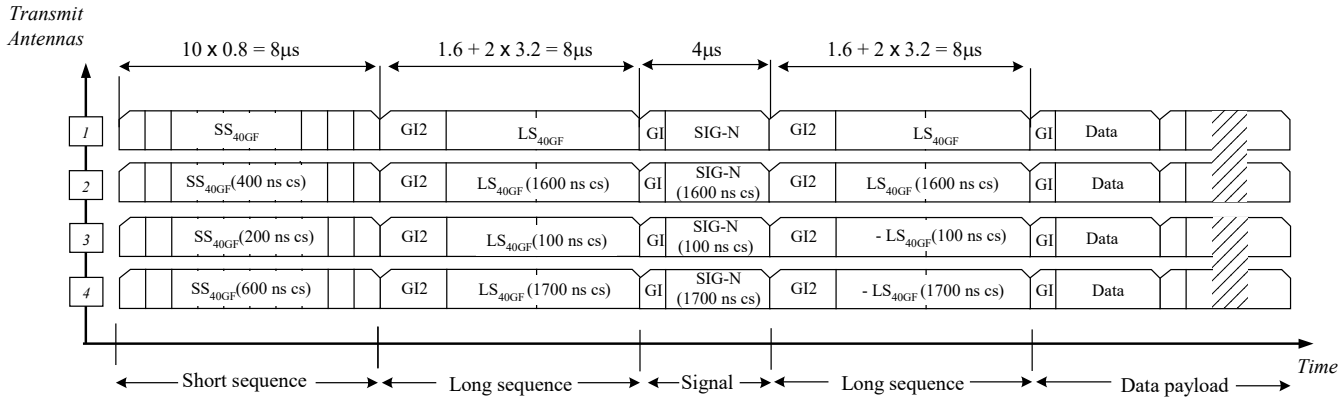



**Figure 015 – MIMO-OFDM Training structure for $N_{TX}$ = 3 and 4, 40 MHz, greenfield operation**

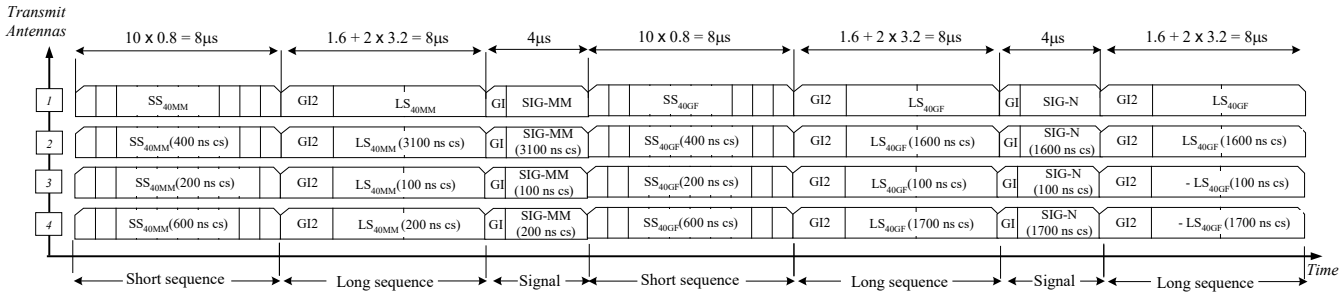



**Figure 016 – MIMO-OFDM Training structure for $N_{TX}$ = 3, 4, 40 MHz, mixed mode operation**

### 20.3.4 Signal fields (SIG-N and SIG-MM)

The SIGNAL-N field (SIG-N) is composed of a single MIMO-OFDM symbol that provides all length and configuration parameters associated with a MIMO-OFDM PPDU. The SIGNAL-N field is composed of 54 bits, which shall be interpreted according to the bit assignment specified in Figure 017 and Table 011.

**Table 011—SIG-N field bit assignment**

| Bits | Field | Subfield | Parameter | Values |
|---|---|---|---|---|
| b0 : b5 | RSVD | | Reserved bits | 111111, Bits shall be ignored at the receiver |
| b6 : b21 | CONFIG | | Configuration | |
| b6: b8 | | NSS | Number of spatial streams | 000: 1, 001: 2, 010: 3, 011: 4 |
| b9 : b11 | | NTX | Number of transmit antennas | 000: 1, 001: 2, 010: 3, 011: 4 |
| b12 : b13 | | BW | Bandwidth | 00: 20 MHz, 01: 40 MHz |
| b14: b16 | | CR | Code rate | 000: 1/2, 001: 2/3, 010: 3/4, 011: 5/6 |

| | | | | |
|---|---|---|---|---|
| b17 : b18 | | CT | ECC type | 00 : convolutional, 01 : LDPC |
| b19 : b21 | | CON | Constellation type | 000: BPSK, 001: QPSK, 010: 16-QAM, 011: 64-QAM |
| b22 : b34 | LEN | | Length | Number of bytes in the payload |
| b35 | LPI | | Last PSDU indicator | 1 indicates that this is the last PSDU to be aggregated into the current PPDU |
| b36 : b43 | RSVD | | Reserved | 00000000, Bits shall be ignored at the receiver |
| b44 : b47 | CRC | | Cyclic Redundancy Check | CRC calculated on bits 0-43 using generator polynomial $x^4+x+1$ |
| b48 : b53 | TAIL | | | 000000 |

In all 20 MHz modes, the encoding of the single SIG-N MIMO-OFDM symbol shall be performed with QPSK modulation of the subcarriers of the first antenna and shall use convolutional coding at R = 1/2. In all 40 MHz modes, the encoding of the single SIG-N MIMO-OFDM symbol shall be performed with BPSK modulation of the subcarriers of the first antenna and shall use using convolutional coding at R = 1/2. The contents of the SIG-N field are not scrambled.

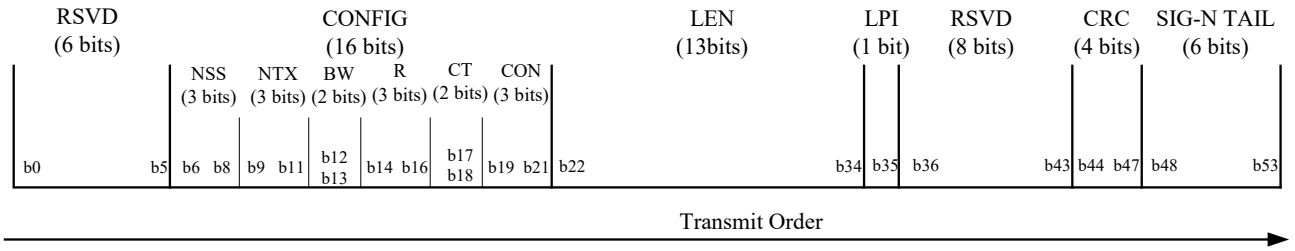



**Figure 017 – SIG-N field bit assignment**

The SIG-N MIMO-OFDM symbol is transmitted simultaneously from all TX antennas in all modes, with the same values of relative cyclic shift between antennas as are used to transmit the long training symbol preceding the SIG-N symbol. The value of the cyclic shift in each operating mode is specified in Figures 007 through 016 in subclause 20.3.3.

With mixed-mode access, another symbol, denoted as SIGNAL-MM (SIG-MM) is sent in the PLCP header. The SIG-MM field is encoded and transmitted from the first antenna as per IEEE 802.11a-1999 subclause 17.3.4. The remaining antennas simultaneously transmit the same OFDM symbol, with relative cyclic shifts defined in subclause 20.3.3. The reserved bit in the SIG-MM field shall be set to signal a MIMO-OFDM PPDU transmission. The duration for which the medium will be used by the MIMO-OFDM PPDU transmission is signaled to non MIMO-OFDM stations via the LENGTH and RATE fields of the SIG-MM symbol.

In 40 MHz mixed-mode operation, the SIG-MM field shall be transmitted such that it can be decoded by non-MIMO-OFDM stations operating in either the upper or the lower 20 MHz band.

### 20.3.5 DATA field

The DATA field contains the SERVICE field, the PSDU, the TAIL bits, and the PAD bits, if needed, as described in 20.3.5.2 and 20.3.5.4. All bits in the DATA field except the TAIL bits are scrambled, as described in 20.3.5.4.

#### 20.3.5.1 Service field (SERVICE)

The IEEE 802.11 SERVICE field has 16 bits, which shall be denoted as bits 0-15. The bit 0 shall be transmitted first in time. The bits 0-6 of the SERVICE field, which are transmitted first, are set to zeros and are used to synchronize the descrambler in the receiver. The remaining 9 bits (7-15) of the SERVICE field shall be reserved for future use. All reserved bits shall be set to zero. Refer to Figure 112, IEEE 802.11a-1999 subclause 17.3.5.1.

#### 20.3.5.2 PPDU tail bits

The PPDU tail bits shall follow IEEE 802.11a-1999 subclause 17.3.5.2.

### 20.3.5.3 PAD bits

The number of bits in the DATA field shall be a multiple of $N_{CBPS}$, the number of coded bits in an OFDM symbol. To achieve that, the length of the message is extended so that it becomes a multiple of $N_{DBPS}$, the number of data bits per OFDM symbol. At least 6 bits per encoding stream ($N_{ES}$) are appended to the message, in order to accommodate the TAIL bits, as described in 20.3.5.2. The number of MIMO-OFDM symbols, $N_{SYM}$; the number of bits in the DATA field, $N_{DATA}$; and the number of pad bits, $N_{PAD}$, are computed from the length of the PSDU (LENGTH) as follows:

$$N_{SYM} = \text{Ceiling}((16 + 8 \times \text{LENGTH} + 6 \times N_{ES})/N_{DBPS}) \quad (10)$$

$$N_{DATA} = N_{SYM} \times N_{DBPS} \quad (11)$$

$$N_{PAD} = N_{DATA} - (16 + 8 \times \text{LENGTH} + 6 \times N_{ES}) \quad (12)$$

The appended bits (“pad bits”) are set to “zeros” and are subsequently scrambled with the rest of the bits in the DATA field.

### 20.3.5.4 PLCP data scrambler and descrambler

The PPDU data scrambler and descrambler shall follow IEEE 802.11a-1999 subclause 17.3.5.4.

### 20.3.5.5 Convolutional encoder

The DATA field, composed of SERVICE, PSDU, tail, and pad parts, shall be coded with a convolutional encoder that conforms to IEEE 802.11a-1999 subclause 17.3.5.5 for code rates of R = 1/2, 2/3, and 3/4. Additionally, the code rate of R = 5/6 shall be implemented according to the puncturing pattern illustrated in Figure 018.

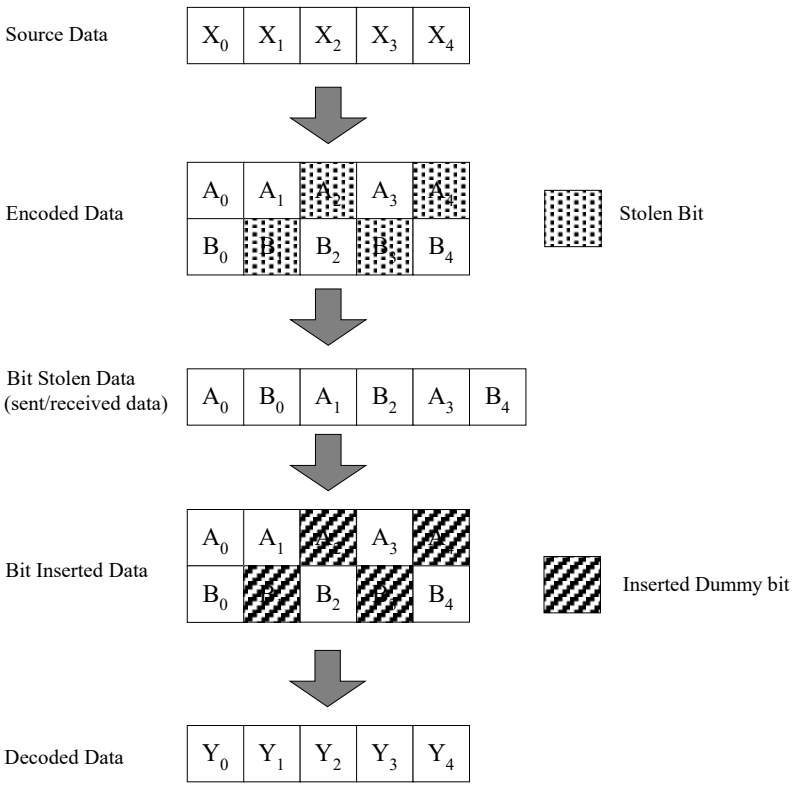



**Figure 018 – An illustration of the bit stealing and bit insertion procedure for R = 5/6**

### 20.3.5.6 Interleaver

All encoded bits shall be interleaved by a block interleaver with a block size equal to the number of bits in a single MIMO-OFDM symbol, $N_{CBPS}$. The interleaver is defined by the following series of permutations.

We shall denote by $k$ the index of the coded bits before interleaving, $k = 0, 1 \ldots N_{CBPS}-1$. $n = 0, 1 \ldots N_{SS}-1$ denotes the index of the spatial streams. The bits are first distributed across spatial streams by inputting the bit with index $k_n \times N_{SS} + n$ into the $n$th spatial stream. This is illustrated in Figure 019.

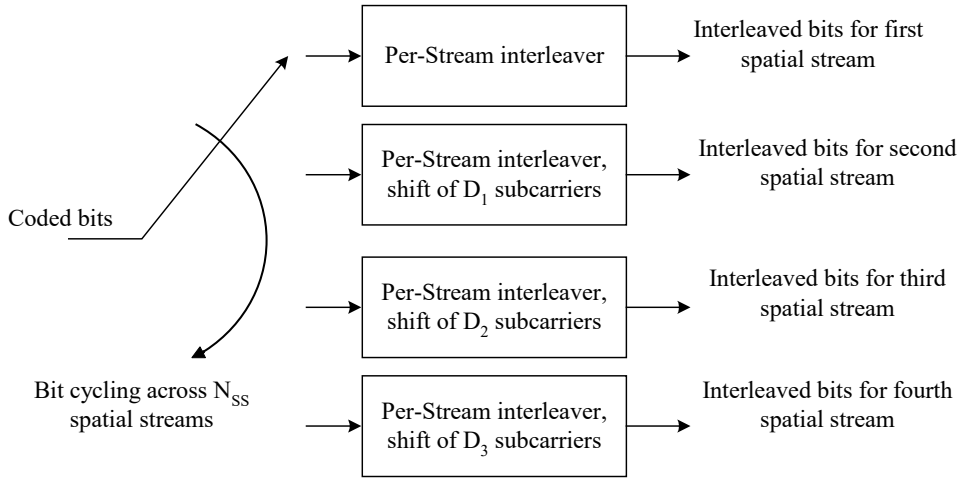



**Figure 019 – Illustration of the interleaver function**

The interleaver for spatial stream $n$ within its block of $N_{CBPS}/N_{SS}$ bits is defined by the following relations.

$$k = k_n \times N_{ss} + n$$

$$i = ((N_{CBPS}/N_{SS})/I_{DEPTH})\ (k_n \bmod I_{DEPTH}) + \text{floor}\ (k_n/I_{DEPTH}) \qquad k_n = 0, 1 \ldots (N_{CBPS}/N_{SS})-1$$

$$j = s \times \text{floor}(i/s) + (i + N_{CBPS}/N_{SS} - \text{floor}\ (I_{DEPTH} \times i / (N_{CBPS}/N_{SS}))) \bmod s \qquad s = \max(N_{BPSC}/2,1)$$

$$j_n = (j + N_{CBPS}/N_{SS} - 2sD_n) \bmod (N_{CBPS}/N_{SS}). \qquad (13)$$

The parameter $D_n$ which denotes the shift in subcarriers for spatial stream $n$ is given by

$$D_n = 5n. \qquad (14)$$

The interleaving depth $I_{DEPTH}$ shall conform to the values given in Table 012.

**Table 012—Interleaving parameters**

| $N_{SS}$ | $N_{SD}$ | $I_{DEPTH}$ |
|---|---|---|
| 1, 2, 3, 4 | 54 | 6 |
| 2,3,4 | 108 | 6 |
| 1 | 108 | 12 |

The deinterleaver, which performs the inverse relation, is defined by the following series of permutations.

$$k_d = \bmod (k_n + N_{CBPS}/N_{SS} + 2sD_n) \bmod (N_{CBPS}/N_{SS})$$

$$i_d = s\ \text{floor}(k_d / s) + (k_d + \text{floor}\ (I_{DEPTH} \times k_d / (N_{CBPS}/N_{SS}))) \bmod s$$

$$j_{dn} = I_{DEPTH} \times i_d - ((N_{CBPS}/N_{SS}) - 1) \times \text{floor}\ (I_{DEPTH} \times i_d / (N_{CBPS}/N_{SS})). \qquad (15)$$

where s and $D_n$ are as defined for the interleaver.

### 20.3.5.7 Low density parity check codes (optional ECC)

This subclause describes the LDPCCs to be optionally used in the MIMO-OFDM system as high-performance ECC technique, instead of the convolutional code (20.3.5.5). The rate-dependent parameters in subclause 20.3.2.2 shall still apply.

When this subclause applies, the following clauses are to be considered no more applicable:

20.3.2.1: changes needed, as described in 20.3.5.7.3;
20.3.5.2: not used;
20.3.5.3: replaced by 20.3.5.7.3;
20.3.5.5: replaced by 20.3.5.7.4;
20.3.5.6: not used.

#### 20.3.5.7.1 LDPCC Code Rates and Block Sizes

The supported code rates, information block size, and coded block size are described in Table 013.

**Table 013— LDPCC parameters**

| Coding rate (R) | LDPC information bits (bits) | LDPC codeword length (bits) |
|---|---|---|
| 1/2 | 972 | 1944 |
| 2/3 | 1296 | 1944 |
| 3/4 | 1458 | 1944 |
| 5/6 | 1620 | 1944 |

#### 20.3.5.7.3 LDPCC PPDU encoding process

a) Produce the PLCP preamble fields for each transmit antenna based on the TRANSMISSION_MODE field of the TXVECTOR. Refer to 20.3.3 for details.

b) Produce the PLCP header field from the LENGTH, DATARATE, and SERVICE fields of the TXVECTOR by filling the appropriate bit fields, as described in subclause 20.3.4 and subclause 20.3.5.1.

c) Compute the integer number of LDPCC codewords to be transmitted, $L_1$, and the possible remainder $K_1$.

$$L_1 = \text{ceil}( (\text{LENGTH} \times 8 + 16)/1944/R),$$

$$K_1 = \text{rem}( (\text{LENGTH} \times 8 + 16) ,1944 \times R). \quad (16)$$

d) If $K_1 > 0$ compute the number of zeros for padding in order to encode the last codeword as

$$N_{P1} = 1944 \times R - K_1. \quad (17)$$

These bits will not be transmitted nor scrambled. If $K_1 > 0$, the last frame has an effective information frame (i.e. information frame excluding padded zeros) of size $K_1$, generally less than *k.* The last codeword includes a fixed number of parity bits equal to $p = (1944 – k)$. This implies the code rate for the last codeword is different from the overall target code rate and is given by:

$$\frac{K_1}{K_1 + (1944 - k)}. \quad (18)$$

e) Compute the number of coded bits to be transmitted (including the shortened codeword) as

$$L_2 = \begin{cases} 1944 \times L_1, & K_1 = 0 \\ 1944 \times L_1 + 1944 \times (1 - R) + K_1, & K_1 \neq 0 \end{cases} \quad (19)$$

f) Compute the integer number of MIMO-OFDM symbols $N_{S1}$ and the possible reminder $R_{S1}$:

$$N_{S1} = \text{ceil}(L_2/N_{CBPS}),$$

$$R_{S1} = \text{rem}(L_2, N_{CBPS}). \quad (20)$$

g) If $R_{S1} > 0$ append $N_{P2}$ zeros to info bits in order to fill an integer number of MIMO-OFDM symbols

$$N_{P2} = N_{CBPS} - R_{S1.} \quad (21)$$

h) The service field at the beginning of the resulting sequence is used to initialize a scrambler, which is then used to scramble the rest of the sequence including the zeros appended in step g).

k) The resulting PSDU is then coded by the LDPCC at the proper code rate (R) and block size (i.e. 1944 bits for all frames). The last codeword is encoded extending the info bits with $N_{P1}$ zeros; these $N_{P1}$ bits are not transmitted. The last $N_{P2}$ bits are not encoded.

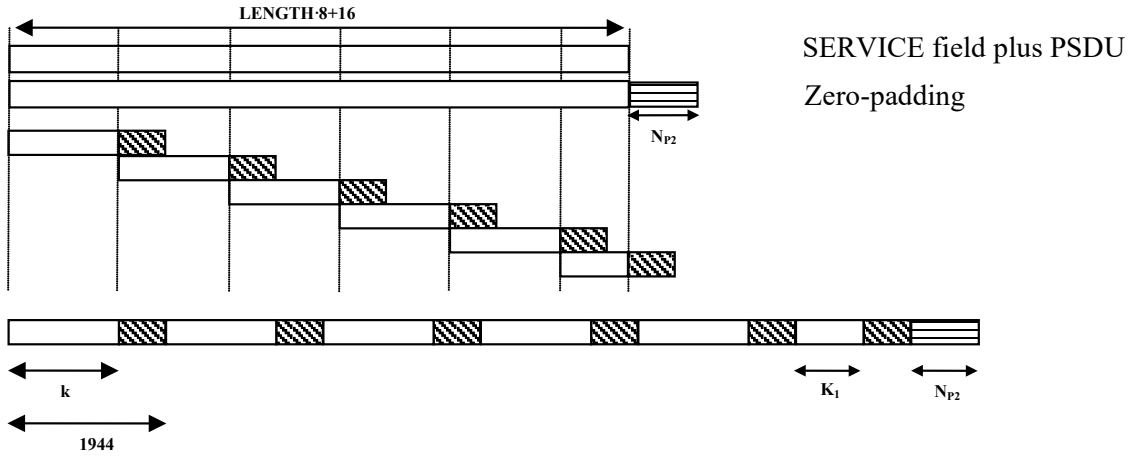



**Figure 020 – LDPC PPDU encoding**

### 20.3.5.7.4 LDPCC Encoder

A characteristic feature of the considered LDPCCs is that combining rows of the parity-check matrix (**H**) for the lowest rate code produces **H** for higher rates. This is equivalent to replacing a group of check nodes with a single check node that sums all the edges coming into each of the original check nodes. Direct consequences are that all code rates have the same block length and the same variable node degree distribution.

The LDPCC encoder is systematic, i.e. encodes an information block of size *k*, $I=(i_0, i_1, \ldots i_{(k-1)})$ into a codeword **C** of size *n* $\mathbf{C}=(i_0, i_1, \ldots i_{(k-1)}, p_0, p_1, \ldots, p_{(n-k-1)})$ by adding *n-k* parity bits obtained so that $\mathbf{H} \cdot \mathbf{c}^T = \mathbf{0}$.

*k* and *n* are defined in Table 013 according to the selected rate.

The parity check matrix used to generate all the code rates is rate 1/2 (i.e. number of rows *n-k* = 972, number of columns *n* = 1944). This belongs to the class of the so-called structured parity check matrices (compared to "random" generated codes). More specifically, the matrix can be partitioned into square sub-blocks of size 27x27 which are either cyclic permutations of the diagonal identity matrix or null sub-matrices. A few of them – specifically 2 in the rate 1/2 matrix described in Table A.1 – may contain two (cyclically shifted) diagonals.

In addition, in order to enable a simple encoding process, the parity-check matrices include a block lower triangular structure at the right-hand side. This allows a linear-complexity encoder (based on back substitution). More precisely, the parity-check matrix is of the type:

$$H_{(n-k)\times n} = [A_{(n-k)\times k}\ B_{(n-k)\times(n-k)}] \tag{22}$$

where $B$ is block lower triangular, i.e. has the structure reported in Fig. 021.

$$B_{(n-k)\times(n-k)} = \begin{pmatrix} b_{11} & 0 & \cdots & 0 \\ b_{21} & b_{22} & 0 & \\ & b_{32} & \ddots & \vdots \\ \vdots & & \ddots & 0 \\ & & \ddots & 0 \\ b_{(n-k)1} & & \cdots & b_{(n-k)(n-k)} \end{pmatrix},$$

$b_{ij}$ =circulant permutation matrix; $(i,j)$ sub-matrix indexes.

**Figure 021 – lower triangular part of the parity check matrix**

In order to generate variable rate LDPCCs, the following criteria apply:

a) Row-combining of rows who do not have a '1' in the same position (this implies a same resulting variable node degree distribution for all the code rates).
b) The selection of rows to be summed preserves the lower triangular structure of the right-hand side of the matrix through all the rates.

Taking into account above-mentioned criteria, the code rates are obtained as follows:

- Code rate 2/3:
row $i$ (the rows are enumerated from top to bottom) is generated by summing row $i$ of **H** of rate 1/2 code and the row with index $i+M/2$ where $M$ is the total number of check equations in rate 1/2 code, for all the rows where $i < M/3$.

- Code rate 3/4:
row $i$ is generated by summing row $i$ of **H** of rate 1/2 code and the row with index $i+M/2$ where $M$ is the total number of **H** rows (i.e. check equations) in rate 1/2 code.

- Code rate 5/6:
Rows are summed three at a time as: row $i$ plus the row with index $i+M/3$ plus the row with index $I + 2M/3$.

The codes are designed to avoid length 4 cycles and to avoid small stopping sets.

### 20.3.5.7.5 Parity check matrix

In Table A.1 in Annex A the rate 1/2 parity check matrix is reported. All the other rates can be derived by properly combining its rows as explained in 20.3.5.7.4.

The table describes the "matrix prototype", i.e. a structure of size 36x72 where the basic elements are squared sub-matrices whose size is 27x27. Each sub matrix is either a null matrix or a cyclic permutation of the identity matrix (or the lower bidiagonal matrix at the right hand bottom of the matrix).

Figure 022 illustrates some examples (for a 10x10 matrix) of the basic circular permutation matrix $S_i$., clarifying how cyclic shift indexes $i$ are to be interpreted. The last line in Table A.1, indicated as "st", indicates the staircase (or bi-diagonal) structure ($S_d$ in Fig. 021).

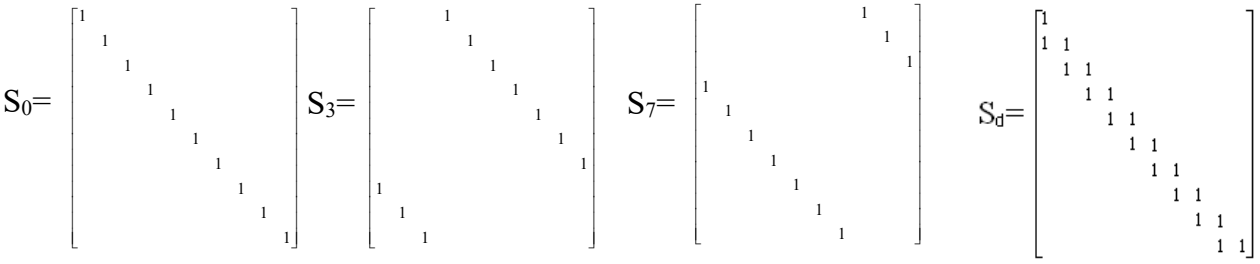



**Figure 022 – Structure of the cyclic permutations of the identity matrix. Matrix $S_i$ is produced by cyclically shifting the columns of the identity matrix to the right *i* places.**

Table A.1 follows the following format: Row number - Column number - Cyclic shift to the right (of columns). Rows are enumerated from top to bottom, columns from left to right.

### 20.3.5.8 Subcarrier modulation mapping

The subcarrier modulation mapping shall follow IEEE 802.11a-1999 clause 17.3.5.7 for each transmit antenna.

### 20.3.5.9 Pilot tones

The subcarriers with index -21 and +21 are dedicated in all 20 MHz modes to transmit pilot signals during each OFDM symbol, in order to increase robustness against frequency offsets and phase noise. In the 40 MHz modes, 4 subcarriers are dedicated to transmitting pilots. These subcarriers have indexes -42, -14, +14, and +42.

The relative polarity of the pilots transmitted from various antennas shall be determined using the following relations. We shall number the MIMO-OFDM symbols transmitted in a PSDU sequentially, with $n = 0$ denoting the first symbol that follows the PLCP preamble. We shall use $p_n$ to denote the $n$th element of the sequence $p_{0\ldots126v}$ specified in equation (25) of IEEE 802.11a-1999 subclause 17.3.5.9. We define the following matrices:

$$A=\begin{bmatrix}+1 & +1 & +1 & -1\\ +1 & -1 & +1 & +1\end{bmatrix}$$

$$B=\begin{bmatrix}+1 & +1 & -1 & -1\\ +1 & -1 & +1 & -1\\ -1 & +1 & +1 & -1\end{bmatrix}$$

$$C=\begin{bmatrix}+1 & +1 & +1 & -1\\ +1 & +1 & -1 & +1\\ +1 & -1 & +1 & +1\\ -1 & +1 & +1 & +1\end{bmatrix} \quad (23)$$

Furthermore, we define $a_{i,j}$, $b_{i,j}$, and $c_{i,j}$ as the element on the $i$th row and $j$th column of the matrices A, B, and C, respectively. For example, $i = 0, 1, 2$; $j = 0, 1, 2, 3$ for matrix B. Then the pilot values sent from the $m$th antenna ($m = 1, 2, \ldots 4$) during the $n$th OFDM symbol in the 20 MHz modes shall be given by the corresponding value in Table 014, multiplied with $p_{n \bmod 127}$. The pilot value in the 40 MHz modes shall be given by the corresponding value in Table 015, multiplied with $p_{n \bmod 127}$.The value of the pilot signals sent during the SIG-N symbol defined in 20.3.4 shall be obtained by setting $n = 0$ in this subclause.

**Table 014—Pilot value sent from *m*th antenna during *n*th OFDM symbol in 20 MHz modes**

| Subcarrier index | 2TX mode | 3TX mode | 4TX mode |
|---|---|---|---|
| -21 | $a_{m-1,\ n \bmod 2}$ | $b_{m-1,\ n \bmod 4}$ | $c_{m-1,\ n \bmod 4}$ |
| +21 | $a_{m-1,\ (n+1) \bmod 2}$ | $b_{m-1,\ (n+1) \bmod 4}$ | $c_{m-1,\ (n+1) \bmod 4}$ |

**Table 015—Pilot value sent from *m*th antenna during *n*th OFDM symbol in 40 MHz modes**

| Subcarrier index | 1TX mode | 2TX mode | 3TX mode | 4TX mode |
|---|---|---|---|---|
| -42 | +1 | $a_{m-1,\ n \bmod 4}$ | $b_{m-1,\ n \bmod 4}$ | $c_{m-1,\ n \bmod 4}$ |
| -14 | +1 | $a_{m-1,\ (n+1) \bmod 4}$ | $b_{m-1,\ (n+1) \bmod 4}$ | $c_{m-1,\ (n+1) \bmod 4}$ |
| +14 | +1 | $a_{m-1,\ (n+2) \bmod 4}$ | $b_{m-1,\ (n+2) \bmod 4}$ | $c_{m-1,\ (n+2) \bmod 4}$ |
| +42 | -1 | $a_{m-1,\ (n+3) \bmod 4}$ | $b_{m-1,\ (n+3) \bmod 4}$ | $c_{m-1,\ (n+3) \bmod 4}$ |

Figure 023 provides an illustration of the relative polarity of pilot signals transmitted in the 2TX, 20 MHz mode of operation

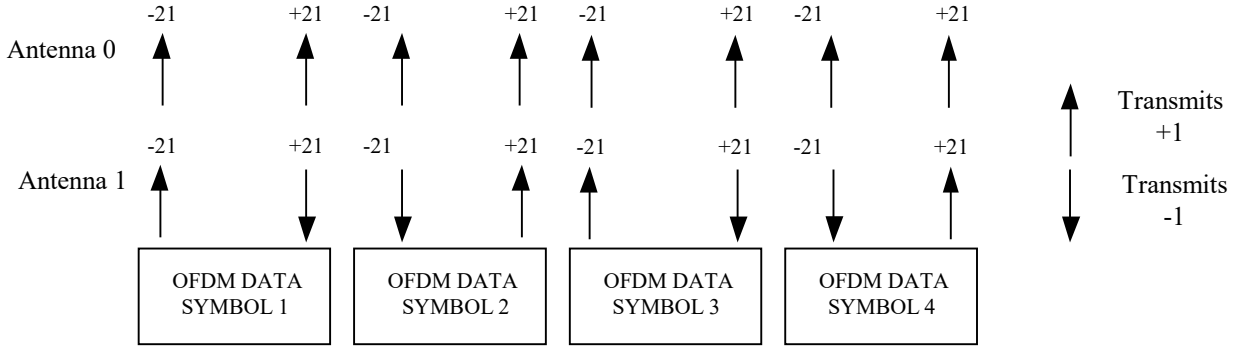



**Figure 023 – An illustration of the relative polarity of pilot signals in the 2TX, 20 MHz mode. "-21" and "+21" indicate the subcarrier indexes on which pilot signals are sent**

### 20.3.5.10 Space-time block coding (STBC)

This subclause defines a set of robust transmission rates which are applicable when $N_{TX,}$ the number of TX antennas, is greater than $N_{SS,}$ the number of transmitted spatial streams. These rates are based on space time block coding.

Implementation of all rates specified in Table 016 for $N_{TX}$=2, $N_{SS}$=1 in 20 MHz is mandatory. Implementation of all other modes defined in this subclause is optional.

The space time block encoding scheme for $N_{TX}$ =2, $N_{SS}$ =1 in 20 MHz and 40 MHz is defined as follows. The bits output from the interleaver of the (single) spatial stream are mapped to the subcarriers of the first antenna, according to subclause 20.3.5.8. We denote the pair of complex numbers transmitted on subcarrier *k* from this antenna during the *j-1*th and *j*th OFDM symbol as $s_{j-1}$ and $s_j$ respectively. Then the corresponding transmission from the second antenna, on the same subcarrier index and during the same OFDM symbols, shall be $-s^*_j$ and $s^*_{j-1}$ where * denotes complex conjugate. This encoding scheme shall hereafter be referred to as the "STBC encoding rule".

Since encoding takes place across pairs of MIMO-OFDM symbols in this subclause, the number of pad bits inserted in subclause 20.3.5.3 shall be sufficient to ensure that an even number of MIMO-OFDM symbols are transmitted in the PPDU.

**Table 016—Rate-dependent parameters for 20 MHz, $N_{TX}$ = 2, $N_{SS}$ = 1**

| Data rate (Mbits/s) | Modulation | Coding rate (R) | Coded bits per subcarrier per antenna | Number of data subcarriers ($N_{SD}$ ) | Number of pilots ($N_{SP}$ ) | Coded bits per MIMO-OFDM symbol | Data bits per MIMO-OFDM symbol | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|

| | | | ($N_{BPSC}$) | | | ($N_{CBPS}$) | ($N_{DBPS}$) | |
|---|---|---|---|---|---|---|---|---|
| 6 .75 | BPSK | 1/2 | 1 | 54 | 2 | 54 | 27 | 114 |
| 10.125 | BPSK | 3/4 | 1 | 54 | 2 | 54 | 40.5 | 115 |
| 13.5 | QPSK | 1/2 | 2 | 54 | 2 | 108 | 54 | 116 |
| 20.25 | QPSK | 3/4 | 2 | 54 | 2 | 108 | 81 | 117 |
| 27 | 16-QAM | 1/2 | 4 | 54 | 2 | 216 | 108 | 118 |
| 40.5 | 16-QAM | 3/4 | 4 | 54 | 2 | 216 | 162 | 119 |
| 54 | 64-QAM | 2/3 | 6 | 54 | 2 | 324 | 216 | 120 |
| 60.75 | 64-QAM | 3/4 | 6 | 54 | 2 | 324 | 243 | 121 |

The RATE-dependent parameters for 20 MHz, $N_{TX} = 3$, $N_{SS} = 2$ are defined in Table 003. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8.

The RATE-dependent parameters for 20 MHz, $N_{TX} = 4$, $N_{SS} = 2$ are defined in Table 003. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream, and on the third and fourth antennas using bits from the second spatial stream.

The RATE-dependent parameters for 20 MHz, $N_{TX} = 4$, $N_{SS} = 3$ are defined in Table 004. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8. Bits from the third spatial stream shall be mapped to subcarriers of the fourth transmit antenna, according to subclause 20.3.5.8.

The RATE-dependent parameters for 40 MHz, $N_{TX} = 2$, $N_{SS} = 1$ are defined in Table 006. In this configuration, the STBC encoding rule shall be applied on the first and second antennas.

The RATE-dependent parameters for 40 MHz, $N_{TX} = 3$, $N_{SS} = 2$ are defined in Table 007. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8.

The RATE-dependent parameters for 40 MHz, $N_{TX} = 4$, $N_{SS} = 2$ are defined in Table 007. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream, and on the third and fourth antennas using bits from the second spatial stream.

The RATE-dependent parameters for 40 MHz, $N_{TX} = 4$, $N_{SS} = 3$ are defined in Table 008. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8. Bits from the third spatial stream shall be mapped to subcarriers of the fourth transmit antenna, according to subclause 20.3.5.8.

### 20.3.6 Clear channel assessment

PLCP shall provide the capability to perform CCA and report the result to the MAC. The CCA mechanism shall detect a "medium busy" condition with a performance specified in 20.3.10.5. This medum status report is indicated by the primitive PHY_CCA.indicate.

### 20.3.7 PLCP data modulation and modulation rate change

The PLCP preamble shall be transmitted using a set of OFDM-modulated fixed waveforms, specified in subclause 20.3.3 for each transmit antenna for each mode of operation defined in the MIMO-OFDM PHY. The SIG-N field, composed of 54 bits, shall indicate the bandwidth, modulation, code rate, code type, number of TX antennas, and number of spatial streams that shall be used to transmit the MPDU. The transmitter (receiver) shall initiate the modulation constellation, code rate, code type, and other configuration parameters according to the CONFIG indicated in the SIG-N field. The MPDU transmission rate shall be set by the DATARATE parameter in the TXVECTOR, issued with the PHY-TXSTART.request primitive described in 20.2.

### 20.3.8 PMD operating specifications

Subclauses 20.3.8.1 through 20.3.8.8 provide general specifications for the various modes and options defined in the MIMO-OFDM PMD sublayer. These specifications apply to both the receive and transmit functions and general operation of the MIMO-OFDM PHY.

#### 20.3.8.1 TX Block diagram

The general block diagram of the transmitter for the MIMO-OFDM PHY is shown in Figure 024. The blocks that are shaded in the figure may be replicated $N_{TX}$ times in a MIMO-OFDM system with $N_{TX}$ transmit antennas.

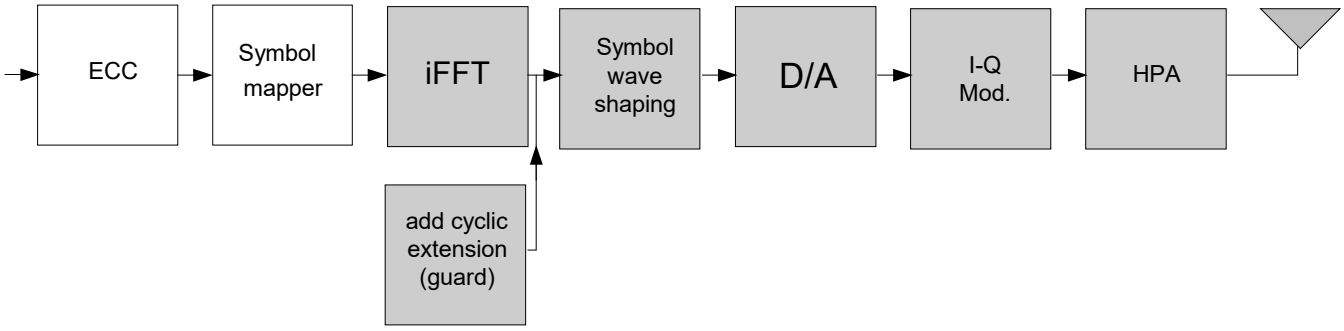



**Figure 024 – Transmitter block diagram for the MIMO-OFDM PHY**

#### 20.3.8.2 Regulatory requirements

All systems shall comply with the local regulatory requirements for operation in the band in which they are implemented. For 2.4 GHz operation, refer to FCC 15.247, 15.249, 15.205, and 15.209 for the USA; ETS 300-328 for Europe; and MPHPT article 49-20 for Japan. For 5 GHz operation in the USA, refer to FCC CFR47, Part 15, sections 15.205 and 15.209; and Subpart E, sections 15.401-15.407.

The documents listed here are provided for information only, and are subject to change or revision at any time.

#### 20.3.8.3 Operating channel frequencies

The range of operating frequencies for the MIMO-OFDM PHY shall be 2400-2497 MHz and 4920-5805 MHz. The channel numbering shall be as defined in IEEE 802.11b-1999 clause 18.4.6.2, and clause 17.3.8.3.2 of IEEE P802.11j/D1.5, May 2004. The relationship between center frequency and channel number is given by the following equations:

$$\text{Channel center frequency} = 5000 + (\text{channel number}) \times 5 \text{ (MHz) for center frequency} > 5000 \text{ MHz} \quad (24)$$

$$\text{Channel center frequency} = 4000 + (\text{channel number}) \times 5 \text{ (MHz) for } 4900 \leq \text{center frequency} \leq 5000 \text{ MHz} \quad (25)$$

40 MHz operation shall be restricted to the 5 GHz band only. Each 40 MHz channel shall occupy two 20 MHz channels, with the center frequency of the 40 MHz transmission selected to be midway between the center frequencies of the two occupied 20 MHz channels. For example, if the two occupied 20 MHz channels are centered at channel number 149 and 153, then the 40 MHz transmission shall be centered at channel number 151.

#### 20.3.8.4 Spurious emissions

The spurious emissions shall conform to IEEE 802.11a-1999 subclause 17.3.8.4

#### 20.3.8.5 TX RF delay

The TX RF delay shall follow IEEE 802.11a-1999 subclause 17.3.8.5.

#### 20.3.8.6 Slot time

The slot time shall follow IEEE 802.11a-1999 subclause 17.3.8.6 for 5 GHz bands and IEEE 802.11g-1999 subclause 19.4.4 for 2.4 GHz bands.

#### 20.3.8.7 Transmit and receive antenna port impedance

The transmit and receive antenna port impedance for each transmit and receive antenna shall follow IEEE 802.11a-1999 subclause 17.3.8.7.

#### 20.3.8.8 Transmit and receive operating temperature range

The transmit and receive temperature range shall follow IEEE 802.11a-1999 subclause 17.3.8.8.

### 20.3.9 PMD TX specifications

Subclauses 20.3.9.1 through 20.3.9.7 describe the transmit specifications associated with the PMD sublayer. In general, these are specified by primitives from the PLCP, and the transmit PMD entity provides the actual means by which the signals required by the PLCP primitives are imposed into the medium.

#### 20.3.9.1 TX power levels

The maximum allowable output power shall conform to national regulatory constraints on the maximum radiated power allowed in any frequency band.

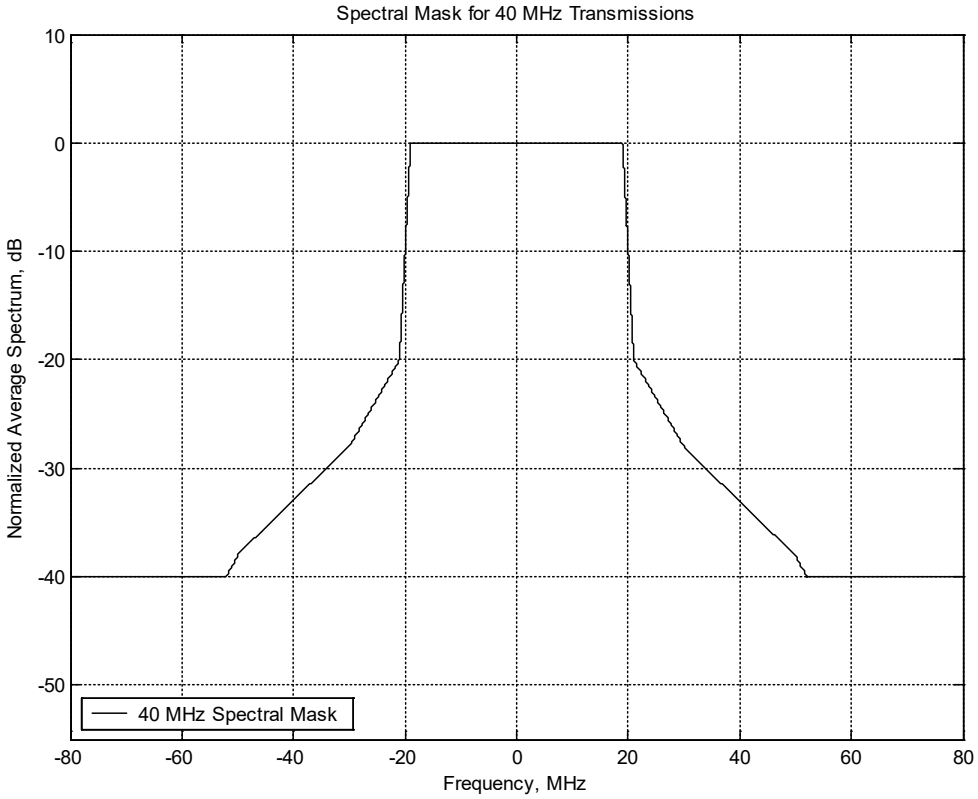



**Figure 025 –Transmit spectrum mask for 40 MHz transmissions**

#### 20.3.9.2 TX spectrum mask

The transmitted spectral density of the transmitted signal shall conform to subclause IEEE 802.11a-1999 17.3.9.2 for all 20 MHz transmissions. The transmitted spectrum for 40 MHz transmissions shall have a 0 dBr bandwidth not exceeding 38

MHz, -20 dBr at 21 MHz frequency offset, -28 dBr at 30 MHz frequency offset, -38 dBr at 50 MHz frequency offset, and -40 dBr at 52 MHz frequency offset and above. The transmitted spectral density of the 40 MHz transmitted signal shall fall within the spectral mask shown in Figure 025. The measurements shall be made using a 100 kHz resolution bandwidth and a 30 kHz video bandwidth.

#### 20.3.9.3 TX spurious

Spurious transmissions from Clause 20 compliant devices shall conform to national regulations.

#### 20.3.9.4 TX center frequency tolerance

The transmitted center frequency tolerance shall be ±20 ppm maximum for 5 GHz bands and ±25 ppm for 2.4 GHz bands. The transmit center frequency and the symbol clock frequency for all transmit antennas shall be derived from the same reference oscillator.

.

#### 20.3.9.5 TX symbol clock frequency tolerance

The symbol clock frequency tolerance shall be ±20 ppm maximum for 5 GHz bands and ±25 ppm for 2.4 GHz bands. The transmit center frequency and the symbol clock frequency for all transmit antennas shall be derived from the same reference oscillator.

#### 20.3.9.6 Modulation accuracy

Transmit modulation accuracy specifications are described in this subclause. The test method is described in 20.3.9.7.

#### 20.3.9.6.1 TX center frequency leakage

TX center frequency leakage shall follow IEEE 802.11a-1999 subclause 17.3.9.6.1 for all 20 MHz modes of transmission. For 40 MHz modes, the center frequency leakage shall not exceed -18 dB relative to overall transmitted power, or, equivalently, +2 dB relative to the average energy of the rest of the subcarriers.

#### 20.3.9.6.2 TX spectral flatness

For 20 MHz transmissions, the average energy of the constellation in each of the spectral lines -16…-1 and +1…+16 will deviate no more than ±2 dB of their average energy. The average energy of the constellations in each of the spectral lines -28…-17 and +17…+28 will deviate no more than +2/-4 dB from the average energy of the spectral lines -16…-1 and +1…+16.

For 40 MHz transmissions, the average energy of the constellation in each of the spectral lines -32…-3 and +3…+32 will deviate no more than ±2 dB of their average energy. The average energy of the constellations in each of the spectral lines -58…-33 and +33…+58 will deviate no more than +2/-4 dB from the average energy of the spectral lines -32…-3 and +3…+32.

#### 20.3.9.6.3 TX constellation error

The relative constellation RMS error, averaged over subcarriers, transmit spatial streams, OFDM frames, and packets, shall not exceed a constellation and code rate dependent value according to Table 017 for the all modes in which the number of spatial streams is equal to the number of transmit antennas.

**Table 017—Allowed relative constellation error versus constellation type and code rate**

| Constellation size | Code Rate | Relative constellation error (dB) |
|---|---|---|
| 16-QAM | 1/2 | -17 |
| 16-QAM | 3/4 | -20 |
| 64-QAM | 2/3 | -24 |
| 64-QAM | 3/4 | -26 |
| 64-QAM | 5/6 | -27 |

### 20.3.9.7 TX modulation accuracy (EVM) test

The transmit modulation accuracy test shall be performed by instrumentation capable of converting the transmitted signals into a stream of complex samples at 20 Msamples/s or more for 20 MHz modes, and 40 Msamples/s or more for 40 MHz modes, with sufficient accuracy in terms of I/Q arm amplitude and phase balance, DC offsets, phase noise, etc. A possible embodiment of such a setup is converting the signals to a low IF frequency with a microwave synthesizer, sampling the signals with a digital oscilloscope and decomposing them digitally into quadrature components.

The test procedure for this requirement is as follows: Matrices $H_{1TX}$, $H_{2TX}$, $H_{3TX}$, and $H_{4TX}$ are defined to give the connections from the transmit antennas to the receive antennas for the 1TX, 2TX, 3TX, and 4TX cases respectively. They are specified as follows:

$$H_{1TX} = \alpha \cdot 1$$

$$H_{2TX} = \alpha \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

$$H_{3TX} = \alpha \begin{bmatrix} -1 & 2 & 2 \\ 2 & -1 & 2 \\ 2 & 2 & -1 \end{bmatrix}$$

$$H_{4TX} = \alpha \begin{bmatrix} -1 & 1 & 1 & 1 \\ 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \end{bmatrix} \quad (25)$$

The elements of the above matrices $h_{ij}$ specify the connection from the $j^{th}$ transmitter to the $i^{th}$ receiver, where $h_{ij}$ is the element of the $i^{th}$ row and $j^{th}$ column where i=1,..,$N_{RX}$ and j=1,..,$N_{TX}$. The attenuation α is chosen to ensure an appropriate received signal power at the test equipment. Figure 026 shows an example test setup for a 2TX mode.

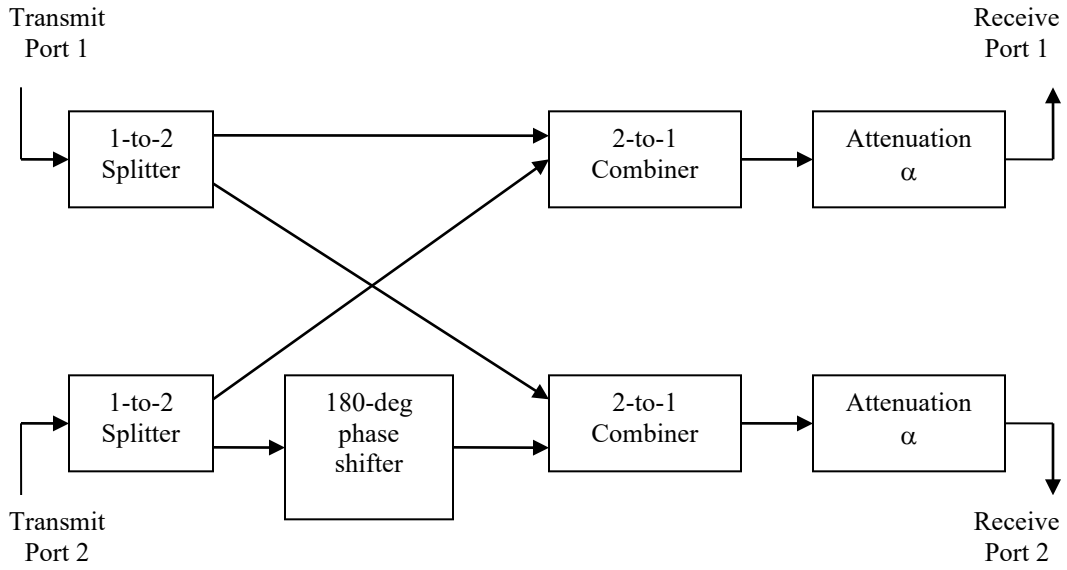


**Figure 026 –EVM test setup**

The 180 degree phase shifter shall be 180 +/- 10 degrees. The relative amplitudes of the connections $h_{ij}$ shall be within +/-1 dB of the relative values specified in the H matrices above.

The sampled signals shall be processed in a manner similar to an actual receiver, according to the following steps, or an equivalent procedure:

a) Start of frame shall be detected.
b) Transition from short sequences to channel estimation sequences shall be detected, and fine timing (with one sample resolution) shall be established.
c) Coarse and fine frequency offsets shall be estimated.
d) The packet shall be derotated according to estimated frequency offset.
e) The complex channel response coefficients shall be estimated for each of the subcarriers.
f) For each of the data OFDM symbols: transform the symbol into subcarrier received values, estimate the phase from the pilot subcarriers, derotate the subcarrier values according to estimated phase, and apply an MMSE channel equalizer to each vector of received subcarrier values based on complex estimated channel response coefficients found in (e).
g) For each data-carrying subcarrier of each transmitted stream, find the closest constellation point and compute the Euclidean distance from it.
h) Compute the RMS average of all errors in a packet. It is given by:

$$Error_{RMS} = \frac{\sum_{i=1}^{N_f} \sqrt{\frac{\sum_{l=1}^{N_{SS}} \sum_{j=1}^{L_P} \sum_{k=1}^{N_{ST}} \{(I(i,j,k,l) - I_0(i,j,k,l))^2 + (Q(i,j,k,l) - Q_0(i,j,k,l))^2\}}{N_{ST} L_P P_0 N_{SS}}}}{N_f} \quad (26)$$

where

$L_P$ is the length of the packet;
$N_{SS}$ is the number of spatial streams;
$N_f$ is the number of frames for the measurement;
$N_{ST}$ is the total number of subcarriers (data and pilots) per OFDM symbol;
$(I_0(i,j,k,l), Q_0(i,j,k,l))$ denotes the ideal symbol point of the $i^{th}$ frame, $j^{th}$ OFDM symbol of the frame, $k^{th}$ subcarrier, and $l^{th}$ spatial stream of the OFDM symbol in the complex plane;
$(I(i,j,k,l), Q(i,j,k,l))$ denotes the observed point of the $i^{th}$ frame, $j^{th}$ OFDM symbol of the frame, $k^{th}$ subcarrier, and $l^{th}$ spatial stream of the OFDM symbol in the complex plane;
$P_0$ is the average power of the constellation.

The vector error on a phase plane is shown in Figure 121 in IEEE 802.11a-1999 subclause 17.3.9.7.

The test shall be performed over at least 20 frames ($N_f$), and the RMS average shall be taken. The packets under test shall be at least 16 OFDM symbols long. Random data shall be used for the symbols.

### 20.3.10 PMD RX specifications

Subclauses 20.3.10.1 through 20.3.10.5 describe the receive specifications associated with the PMD sublayer.

#### 20.3.10.1 RX minimum input level sensitivity

The packet error rate (PER) shall be less than 10% at a PSDU length of 1000 bytes for rate-dependent input levels shall be the numbers listed in Table 018 or less. The minimum input levels are measured at the antenna connectors and are referenced as the average power per receive antenna.

**Table 018—Receiver minimum input level sensitivity**

| Constellation size | Code Rate | Minimum sensitivity (dBm) |
|---|---|---|
| BPSK | ½ | -82 |
| BPSK | ¾ | -81 |
| QPSK | ½ | -79 |
| QPSK | ¾ | -77 |
| 16-QAM | ½ | -74 |
| 16-QAM | ¾ | -70 |
| 64-QAM | 2/3 | -66 |
| 64-QAM | ¾ | -65 |
| 64-QAM | 5/6 | -64 |

### 20.3.10.2 RX maximum input level

The RX maximum input level shall be defined as the maximum at any or all antennas, and shall follow IEEE 802.11a-1999 subclause 17.3.10.4 for the 4920-5805 MHz band, and follow IEEE 802.11g-2003 subclause 19.5.3 for the 2400-2497 MHz band.

### 20.3.10.3 CCA sensitivity

The CCA sensitivity of all Clause 20 compliant devices shall conform to IEEE 802.11a-2003 subclause 17.3.10.5.

## 20.3.11 PLCP TX procedure

The transmit PLCP is shown in Figure 029. In order to transmit data, PHY-TXSTART.request shall be enabled so that the PHY entity shall be in the transmit state. Further, the PHY shall be set to operate at the appropriate frequency through station management via the PLME. Other transmit parameters, such as DATARATE, TRANSMISSION_MODE, NUM_STREAMS, and TXPWR_LEVEL, are set via the PHY-SAP with the PHY-TXSTART.request(TXVECTOR), as described in 20.2.

A clear channel shall be indicated by PHY-CCA.indicate(IDLE). The MAC considers this indication before issuing the PHY-TXSTART.request. Transmission of the PPDU or A-PPDU shall be initiated after receiving the PHYTXSTART. request(TXVECTOR) primitive. The TXVECTOR elements for the PHY-TXSTART.request are the PLCP header parameters LENGTH, DATARATE, TRANSMISSION_MODE, NUM_STREAMS, CODE_TYPE, SERVICE, LPI, and BURST_DURATION, and the PMD parameter TXPWR_LEVEL.

The PLCP shall issue PMD_TXPWRLVL, PMD_RATE, PMD_NUM_STREAMS, and PMD_TRANSMISSION_MODE, primitives to configure the PHY. The PLCP shall then issue a PMD_TXSTART.request, and transmission of the PLCP preamble and PLCP header, based on the parameters passed in the PHY-TXSTART.request primitive will begin. Once PLCP preamble transmission is started, the PHY entity shall immediately initiate data scrambling and data encoding. The scrambled and encoded data shall then be exchanged between the MAC and the PHY through a series of PHYDATA.request(DATA) primitives issued by the MAC, and PHY-DATA.confirm primitives issued by the PHY. The modulation rate change, if any, shall be initiated from the SERVICE field data of the PLCP header, as described in 20.3.2. The PHY proceeds with PSDU transmission through a series of data octet transfers from the MAC. The PLCP header parameter, SERVICE, and PSDU are encoded by the convolutional encoder with the bit-stealing function described in 20.3.5.5. At the PMD layer, the data octets are sent in bit 0–7 order and presented to the PHY through PMD_DATA.request primitives. In the PMD, the GI shall be inserted in every OFDM symbol as a countermeasure against severe delay spread.

Transmission of a PSDU can be prematurely terminated by the MAC through the primitive PHY-TXEND.request. PHY-TXSTART shall be disabled by the issuance of the PHY-TXEND.request. Normal transmission of a PSDU occurs after the transmission of the final bit of the last PSDU octet, according to the number of bytes supplied in the PLCP header LENGTH.

Each PHY-TXEND.request is acknowledged with a PHY-TXEND.confirm primitive from the PHY. If the coded PSDU (C-PSDU) is not multiples of the OFDM symbol, bits shall be stuffed to make the C-PSDU length multiples of the OFDM symbol.

If an aggregated PPDU (A-PPDU) is being transmitted as indicated by the TXVECTOR LPI parameter, the PHY will wait for the next PHY_TXSTART.request from the MAC. The process of transmitting the subsequent MPDUs as part of the A-PPDU is identical to the first MPDU except that the PLCP will not issue PMD primitives to configure the PHY.

Normal termination of the A-PPDU occurs at the termination of the transmission of the last PSDU, indicated by the PHY PLCP header LPI field. A permaturely terminated PSDU transmission from the MAC will prematurely terminate the transmission of the A-PPDU.

The A-PPDU transmission shall be completed and the PHY entity shall enter the receive state (i.e., PHY-TXSTART shall be disabled).

A typical state machine implementation of the transmit PLCP is provided in Figure 027. Requests (.req) and confirmations(.confirm) are issued once with designated states.

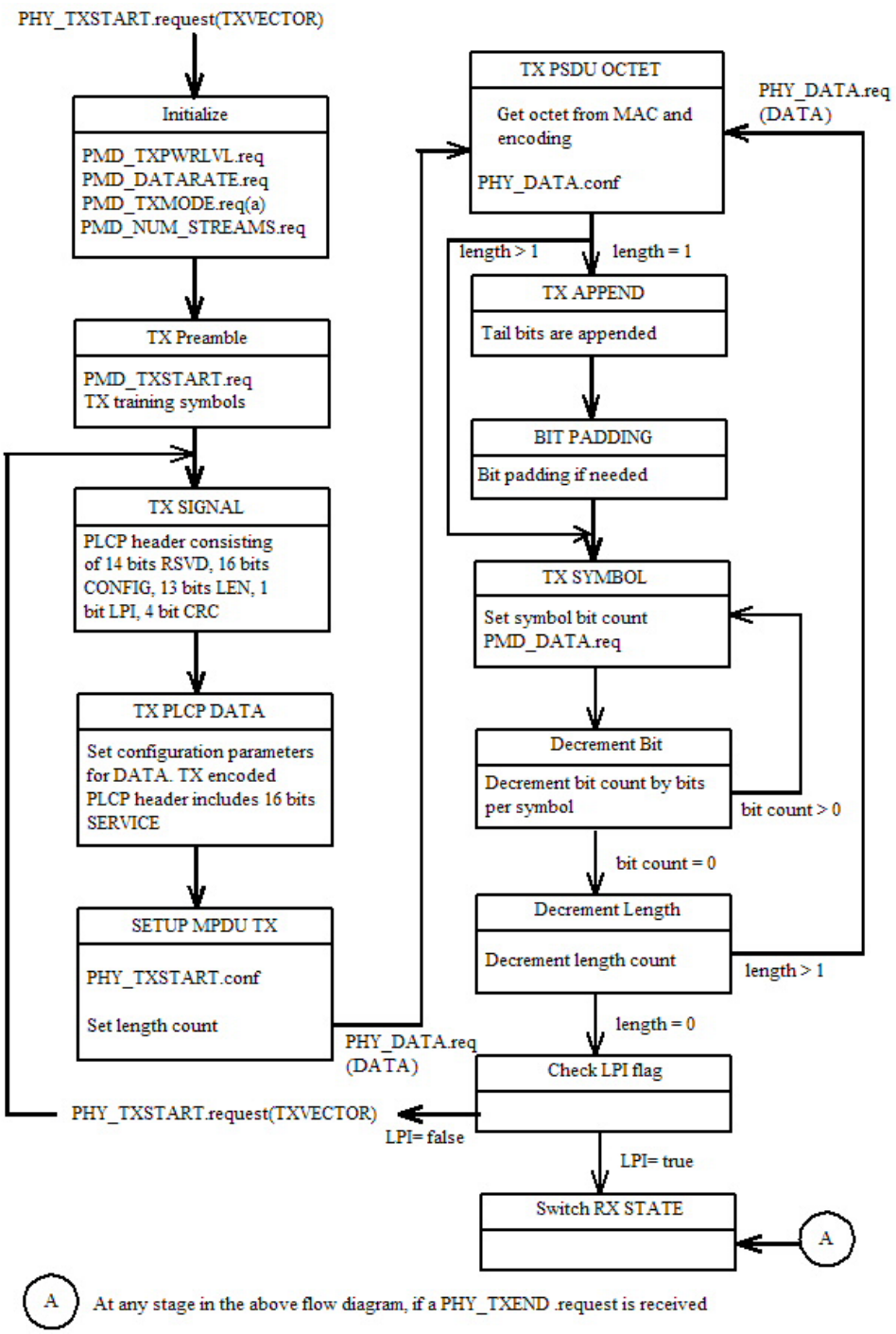



**Figure 027 –PLCP transmit state machine**

## 20.3.12 PLCP RX procedure

The receive PLCP is shown in Figure 030. In order to receive data, PHY-TXSTART.request shall be disabled so that the PHY entity is in the receive state. Further, through station management (via the PLME) the PHY is set to the appropriate frequency. Other receive parameters, such as RSSI and indicated DATARATE, TRANSMISSION_MODE, NUM_STREAMS, CODE_TYPE, LPI, and BURST_DURATION may be accessed via the PHY-SAP.

Upon receiving the transmitted PLCP preamble, PMD_RSSI.indicate shall report a significant received signal strength level to the PLCP. This indicates activity to the MAC via PHY_CCA.indicate. PHY_CCA.indicate(BUSY) shall be issued for

reception of a signal prior to correct reception of the PLCP frame. The PMD primitive PMD_RSSI is issued to update the RSSI and parameter reported to the MAC.

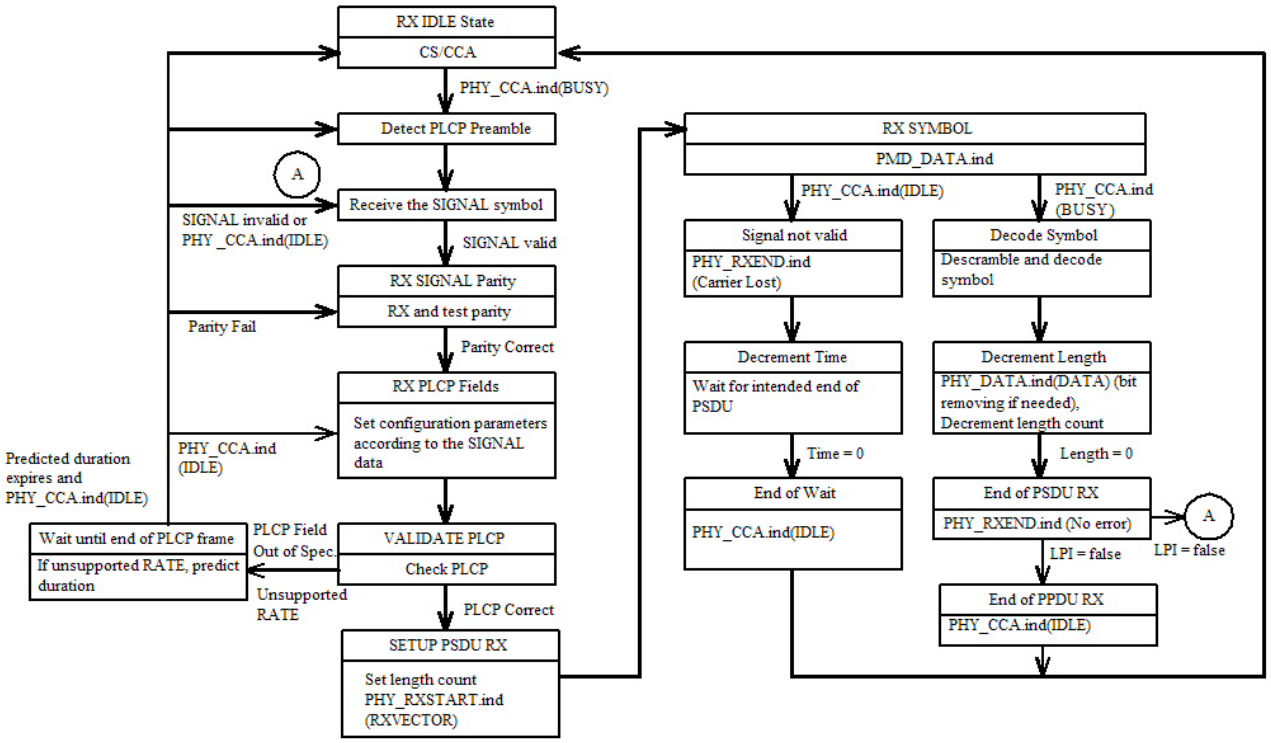



**Figure 028 – PLCP receive state machine**

After PHY-CCA.indicate is issued, the PHY entity shall begin receiving the training symbols and searching for the SIGNAL in order to set the length of the data stream, the demodulation type, and the decoding rate. Once the SIGNAL is detected without any errors detected by the CRC checker, FEC decode shall be initiated and the PLCP SERVICE fields and data shall be received, and decoded. Should the status of CCA return to the IDLE state during reception prior to completion of the full PLCP processing, the PHY receiver shall return to the RX IDLE state.

If the PLCP header reception is successful (and the SIGNAL field is completely recognizable and supported), a PHY-RXSTART.indicate(RXVECTOR) shall be issued. The RXVECTOR associated with this primitive includes the SIGNAL fields, the SERVICE field, the PSDU length in bytes, and the RSSI. Also, in this case, the HT PHY will ensure that the CCA shall indicate a busy medium for the intended duration of the transmitted frame, as indicated by the LENGTH field. The received PSDU bits are assembled into octets, decoded, and presented to the MAC using a series of PHY-DATA.indicate(DATA) primitive exchanges. The rate change indicated in the SIGNAL field shall be initiated from the SERVICE field data of the PLCP header, as described in 20.3.2. The PHY shall proceed with PSDU reception. After the reception of the final bit of the last PSDU octet indicated by the PLCP header LENGTH field, the receiver shall transition to the RX IDLE state if LPI is 1 or to the RX SIGNAL state if LPI is 0 in the RXVECTOR associated with this primitive, as shown in Figure 030. If the LPI is 1 in the RXVECTOR, a PHY-RXEND.indicate(NoError) primitive shall also be issued.

In the event that a change in the RSSI causes the status of the CCA to return to the IDLE state before the complete reception of the PSDU, as indicated by the PLCP LENGTH field, the error condition PHYRXEND.indicate(CarrierLost) shall be reported to the MAC. The HT PHY will ensure that the CCA indicates a busy medium for the intended duration of the transmitted packet. If the indicated rate in the SIGNAL field is not receivable, a PHY-RXSTART.indicate will not be issued. The PHY shall issue the error condition PHY-RXEND.indicate(UnsupportedRate). If the PLCP header is receivable, but the FCS check of the PLCP header is not valid, a PHY-RXSTART.indicate will not be issued. The PHY shall issue the error condition PHY-RXEND.indicate(FormatViolation). Any data received after the indicated data length are considered pad bits (to fill out an OFDM symbol) and should be discarded. A typical state machine implementation of the receive PLCP is given in Figure 028.

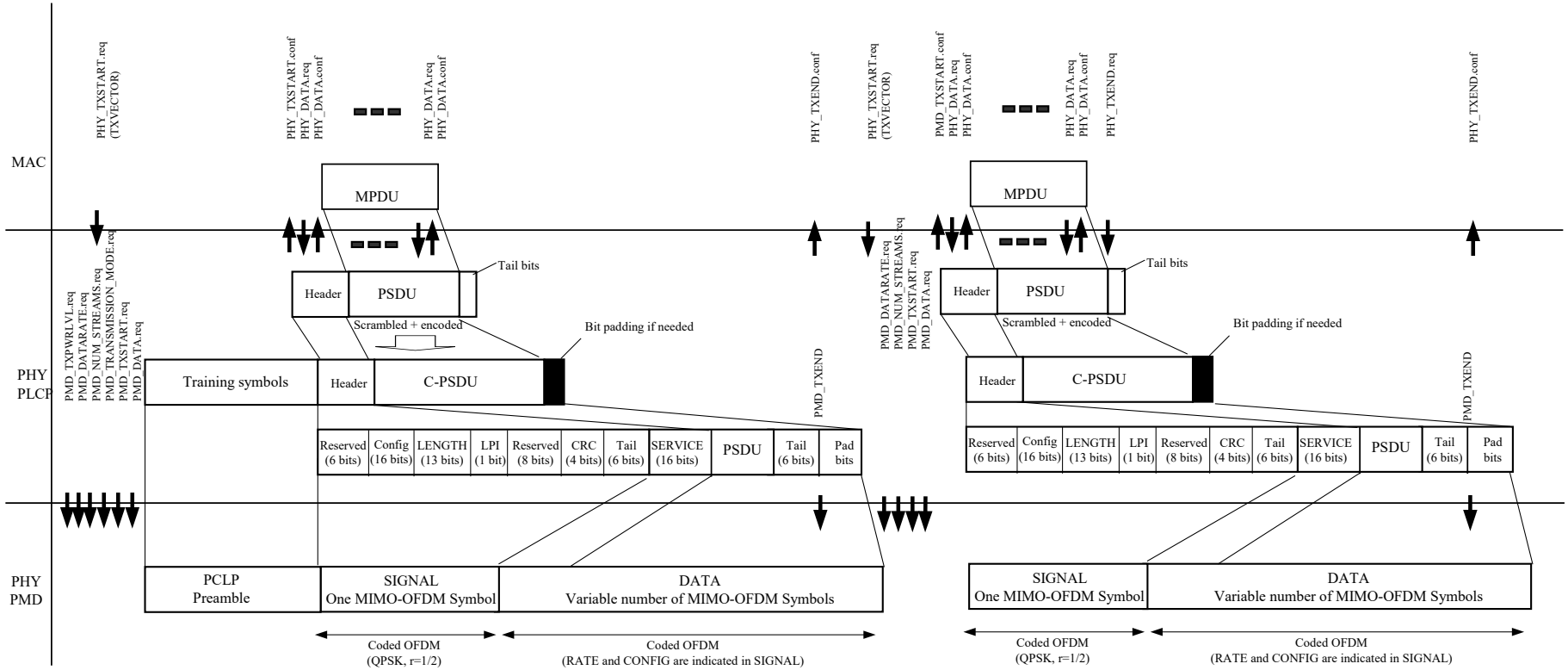



**Fig. 029 PLCP transmit procedure for A-PPDU transmission in greenfield 20 MHz modes**

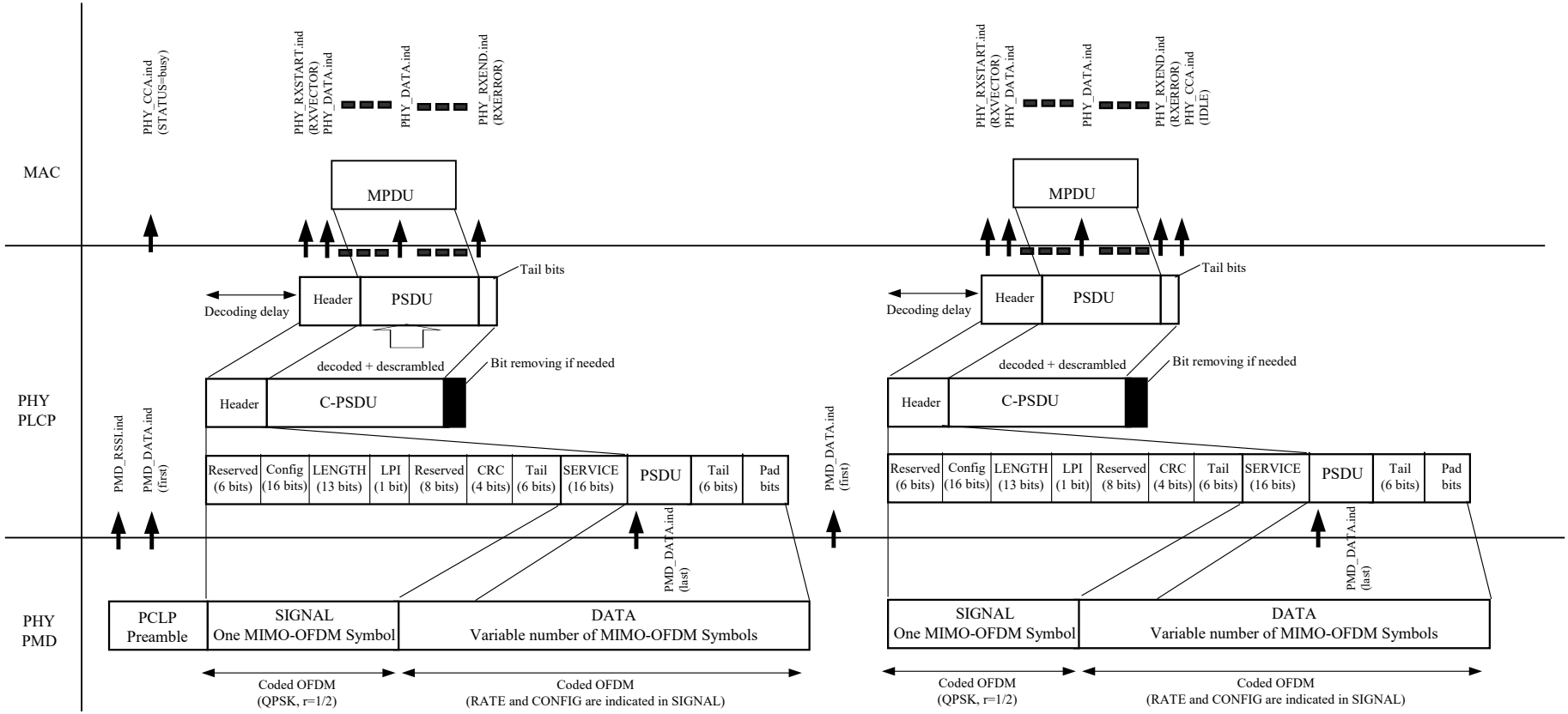



**Fig. 030 PLCP receive procedure for A-PPDU reception in greenfield 20 MHz modes**

# 20.4 MIMO-OFDM PMD operating specifications

## 20.4.1 PLME_SAP sublayer management primitives

Table 20.4.2T1 lists the MIB attributes that may be accessed by the PHY entities and the intralayer of higher level LMEs. These attributes are accessed via the PLME-GET, PLME-SET, PLME-RESET, and PLME-CHARACTERISTICS primitives defined in 10.4.

## 20.4.2 MIMO-OFDM management information base

All MIMO-OFDM PHY MIB attributes are defined in Clause 13, with specific values defined in Table 20.4.2.T1. The column titled “Operational semantics” in Table 20.4.2.T1 contains two types: static and dynamic. Static MIB attributes are fixed and cannot be modified for a given PHY implementation. Dynamic MIB attributes can be modified by some management entity.

**Table 20.4.2T1 MIB attribute default values/ranges**

| Managed Object | Default Value / Range | Operational Semantics |
|---|---|---|
| dot11 PHY Operation Table | | |
| dot11PHYtype | HTP (Value to be assigned) | Static |
| dot11CurrentRegDomain | Implementation dependent | Static |
| dot11TempType | Implementation dependent | Static |
| **dot11 PHY Antenna Table** | | |
| dot11CurrentTxAntenna | Implementation dependent | Dynamic |
| dot11DiversitySupport | Implementation dependent | Static |
| dot11CurrentRxAntenna | Implementation dependent | Dynamic |
| **Dot11 PHY Tx Power Table** | | |
| dot11NumberSupportedPowerLevels | Implementation dependent | Static |
| dot11TxPowerLevel1 | Implementation dependent | Static |
| dot11TxPowerLevel2 | Implementation dependent | Static |
| dot11TxPowerLevel3 | Implementation dependent | Static |
| dot11TxPowerLevel4 | Implementation dependent | Static |
| dot11TxPowerLevel5 | Implementation dependent | Static |
| dot11TxPowerLevel6 | Implementation dependent | Static |
| dot11TxPowerLevel7 | Implementation dependent | Static |
| dot11TxPowerLevel8 | Implementation dependent | Static |
| dot11CurrentTxPowerLevel | Implementation dependent | Dynamic |
| **dot11 Phy DSSS Table** | | |
| dot11CurrentChannel | Implementation dependent | Dynamic |
| **dot11 Reg Domains Supported Table** | | |
| dot11RegDomainsSupportedValue(s) | Implementation dependent | Static |
| **dot11 PHY Antennas List Table** | | |
| dot11SupportedTxAntenna | Implementation dependent | Static |
| dot11SupportedRxAntenna | Implementation dependent | Static |
| dot11DiversitySelectionRx | Implementation dependent | Dynamic |
| **dot11 Supported Data Rates Tx Table** | | |
| dot11SupportedDataratesTxValue | See Clause 10.4.4.2 rate code columns of Tables 003-009 and Table 016 | Static |
| **dot11 Supported Data Rates Rx Table** | | |
| dot11SupportedDataRatesRxValue | See Clause 10.4.4.2 rate code columns of Tables 003-009 and Table 016 | Static |
| **dot11 PHY HTP Table** | | |

| | | |
|---|---|---|
| dot11CurrentFrequency | Implementation dependent | Dynamic |
| dot11SupportedTransmissionModes | Assign optional types in TRANSMISSION_MODE of Table 001 to bits in bit mask | Static |
| dot11SupportedNumStreams | X'0' = Support 1 and 2 streams<br>X'1' = Support 1, 2, and 3 streams<br>X'2' = Support 1, 2, and 4 streams<br>X'3' = Support 1, 2, 3, and 4 streams | Static |
| dot11SupportedCodeTypes | X'0' = convolutional only<br>X'1' = convolutional and LDPC | Static |

### 20.4.3 MIMO-OFDM TXTIME calculation

The value of the TXTIME parameter returned by the PLME-TXTIME.confirm primitive shall be calculated according to the following equation:

$TXTIME = TXTIME_{CONV}$ if CODE_TYPE is convolutional and $TXTIME_{LDPC}$ if CODE_TYPE is LDPC

where

$$TXTIME_{CONV} = T_{MIXED} + T_{PREAMBLE} + T_{SIGNAL} + T_{SYM} \cdot \text{Ceiling}((16 + 8 \cdot LENGTH + 6)/N_{DBPS})$$

$$TXTIME_{LDPC} = T_{MIXED} + T_{PREAMBLE} + T_{SIGNAL} + T_{SYM} \cdot N_{S1}$$

$T_{MIXED}$ is 20μs if TRANSMISSION_MODE is a mixed mode and 0μs if it is a greenfield mode

$T_{PREAMBLE}$ is 16μs if TRANSMISSION_MODE specifies $N_{TX} = 2$ and 28μs if TRANSMISSION_MODE specifies $N_{TX} = 3$ or 4

$T_{SIGNAL}$ is 4μs

$N_{DBPS}$ is derived from the DATARATE parameter (Ceiling is a function that returns the smallest integer value greater than or equal to its argument value)

$N_{S1}$ is defined in subclause 20.3.5.7.3.

### 20.4.4 MIMO-OFDM PHY characteristics

**Table 20.4.4.1—MIMO-OFDM PHY characteristics**

| Characteristic | Value |
|---|---|
| aSlotTime | 9 μs |
| aSIFSTime | 16 μs |
| aRIFSTime | 2 μs |
| aCCATime | <4 μs |
| aRxTxTurnaroundTime | Implementation dependent as long as the requirements of aSIFSTime are met. |
| aTxRxTurnaroundTime | Implementation dependent as long as the requirements of aSIFSTime are met. |
| aTxPLCPDelay | Implementation dependent as long as the requirements of aRxTxTurnaroundTime are met. |
| aRxPLCPDelay | Implementation dependent as long as the requirements of |

| | |
|---|---|
| | aSIFSTime and aCCATime are met |
| aRxTxSwitchTime | Implementation dependent |
| aTxRampOnTime | Implementation dependent as long as the requirements of aRxTxTurnaroundTime are met |
| aTxRampOffTime | Implementation dependent as long as the requirements of aSIFSTime are met |
| ATxRFDelay | Implementation dependent as long as the requirements of aRxTxTurnaroundTime are met |
| ARxRFDelay | Implementation dependent as long as the requirements of aSIFSTime and aCCATime are met |
| aAirPropagationTime | <<1 μs |
| aMACProcessingDelay | <2 μs |
| aPreambleLength | 16 μs |
| aPLCPHeaderLength | 4 μs |
| aMPDUMaxLength | 8191 |
| aCWmin | 15 |
| aCWmax | 1023 |

## 20.5 MIMO-OFDM operating specifications

### 20.5.1 Scope and field of application

This subclause describes the PMD services provided to the PLCP for the MIMO-OFDM PHY.

### 20.5.2 Overview of service

The MIMO-OFDM sublayer accepts PLCP sublayer service primitives and provides the actual means by which data is transmitted or received from the medium. The combined functions of the MIMO-OFDM PMD sublayer primitives and parameters for the receive function result in a data stream, timing information, and associated received signal parameters being delivered to the PLCP sublayer. A similar functionality is provided for data transmission.

### 20.5.3 Overview of interactions

The primitives associated with the PLCP sublayer to the MIMO-OFDM fall into two basic categories

a) Service primitives that support PLCP peer-to-peer interactions;
b) Service primitives that have local significance and that support sublayer-to-sublayer interactions.

### 20.5.4 Basic services and options

All of the service primitives described in this subclause are considered mandatory, unless otherwise specified.

#### 20.5.4.1 PMD_SAP peer-to-peer service primitives

Table 20.5.4.1 indicates the primitives for peer-to-peer interactions.

**Table 20.5.4.1 PMD_SAP peer-to-peer services**

| Primitive | Request | Indicate | Confirm | Response |
|---|---|---|---|---|
| PMD_Data | X | X | | |

#### 20.5.4.2 PMD_SAP sublayer-to-sublayer service primitives

Table 19.9.4.2 indicates the primitives for sublayer-to-sublayer interactions.

**Table 19.9.4.2 PMD_SAP sublayer-to-sublayer services**

| Primitive | Request | Indicate | Confirm | Response |
|---|---|---|---|---|
| PMD_TXSTART | X | | | |
| PMD_TXEND | X | | | |
| PMD_ANTSEL | X | | | |
| PMD_TXPWRLVL | X | | | |
| PMD_TRANSMISSION_MODE | X | | | |
| PMD_NUM_STREAMS | X | | | |
| PMD_DATARATE | X | | | |
| PMD_RSSI | | X | | |

## 20.5.4.3 PMD_SAP service primitive parameters

Table 19.9.4.3 shows the parameters used by one or more of the PMD_SAP service primitives.

**Table 20.5.4.3 List of parameters for the PMD primitives**

| Parameter | Associated primitive | Value | Description |
|---|---|---|---|
| TXD_UNIT | PMD_DATA.request | 0 to (2^n)-1, where n is the number of bits per symbol for the transmission mode, number of streams, and data rate specified in PMD_TRANSMISSION_MODE.request, PMD_NUM_STREAMS.request, and PMD_DATARATE.request primitives. | This parameter represents a single block of data, which, in turn, is used by the PMD to be encoded into a transmitted symbol. |
| RXD_UNIT | PMD_DATA.indicate | 0 to (2^n)-1, where n is the number of bits per symbol for the transmission mode, number of streams, and data rate specified in PMD_TRANSMISSION_MODE.request, PMD_NUM_STREAMS.request, and PMD_DATARATE.request primitives. | This parameter represents a single symbol that has been demodulated by the PMD entity. |
| TRANSMISSION_MODE | PMD_TRANSMISSION_MODE.request | See Table 001 in 20.2 | This parameter specifies to the PMD layer, which transmission mode is used. |
| ANT_STATE | PMD_ANTSEL.request | 1 to 256 | ANT_STATE selects which of the available antennas is used for transmission. The number of available antennas is determined from the MIB table parameters. |
| TXPWR_LEVEL | PMD_TXPWRLVL.request | 1-8 | TXPWR_LEVEL selects which of the optional transmit power levels should be |

| | | | |
|---|---|---|---|
| | | | used for the current PPDU transmission. The number of available power levels is determined from the MIB table parameters. |
| DATARATE | PMD_DATARATE.request | See Clause 10.4.4.2 rate code columns of Tables 003-009 and Table 016 | DATARATE selects which of the data rates is used for PSDU transmission. |
| RSSI | PMD_RSSI.indicate | 8 bits of RSSI (256 levels) | The RSSI is a measure of the RF energy received. Mapping of the RSSI values to actual received power is implementation dependent. |

## 20.5.5 PMD_SAP detailed service specification

The following subclauses describe the services provided by each PMD primitive.

### 20.5.5.1 PMD_DATA.request

This primitive is the same as that defined in 17.5.5.1 and 18.4.5.1 except that the parameter TXD_UNIT is expanded in scope to reflect the supported transmission formats defined in 20.5.4.3.

### 20.5.5.2 PMD_DATA.indicate

This primitive is the same as that defined in 17.5.5.2 and 18.4.5.2 except that the parameter RXD_UNIT is expanded in scope to reflect the supported transmission formats defined in 20.5.4.3.

### 20.5.5.3 PMD_TRANSMISSION_MODE.request

This primitive is the same as that defined in 18.4.5.3 except that the parameter MODULATION of that section is expanded in scope to reflect the supported transmission formats defined in 20.5.4.3.

### 20.5.5.4 PMD_TXSTART.request

This primitive is the same as that defined in 17.5.5.3 and 18.4.5.6.

### 20.5.5.5 PMD_TXEND.request

This primitive is the same as that defined in 17.5.5.4 and 18.4.5.7.

### 20.5.5.6 PMD_ANTSEL.request

This primitive is the same as that defined in 18.4.5.8, including the definition of the parameter ANT_STATE.

### 20.5.5.7 PMD_TXPRWLVL.request

This primitive is the same as that defined in 17.5.5.5, including the definition of the parameter TXPWR_LEVEL.

### 20.5.5.8 PMD_DATARATE.request

This primitive is the same as that defined in 17.5.5.6 and 18.4.5.10, except that the parameter DATARATE is expanded in scope to reflect the supported MIMO-OFDM transmission modes as defined in 20.5.4.3.

### 20.5.5.9 PMD_RSSI.indicate

This primitive is the same as that defined in 17.5.5.7 and 18.4.5.11, including the parameter RSSI. This primitive is used to aid in link optimization algorithms such as roaming decisions.

# Annex A – LDPC matrix definitions

(normative)

**Table A.1 – Description of the matrix prototype of the rate 1/2 parity check matrix**

| Row | Col | Shift |
|---|---|---|
| 0 | 3 | 9 |
| 0 | 7 | 15 |
| 0 | 16 | 5 |
| 0 | 22 | 23 |
| 0 | 32 | 6 |
| 0 | 35 | 12 |
| 0 | 36 | 23 |
| 1 | 2 | 12 |
| 1 | 6 | 16 |
| 1 | 10 | 19 |
| 1 | 26 | 12 |
| 1 | 31 | 23 |
| 1 | 36 | 5 |
| 1 | 37 | 24 |
| 2 | 2 | 9 |
| 2 | 9 | 15 |
| 2 | 16 | 2 |
| 2 | 29 | 15 |
| 2 | 37 | 8 |
| 2 | 37 | 9 |
| 2 | 38 | 2 |
| 3 | 1 | 11 |
| 3 | 5 | 15 |
| 3 | 14 | 17 |
| 3 | 22 | 7 |
| 3 | 36 | 12 |
| 3 | 38 | 19 |
| 3 | 39 | 25 |
| 4 | 4 | 15 |
| 4 | 8 | 3 |
| 4 | 10 | 15 |
| 4 | 26 | 16 |
| 4 | 34 | 6 |
| 4 | 39 | 6 |
| 4 | 40 | 10 |
| 5 | 4 | 20 |
| 5 | 10 | 24 |
| 5 | 11 | 17 |
| 5 | 23 | 4 |
| 5 | 33 | 25 |
| 5 | 40 | 24 |
| 5 | 41 | 15 |
| 6 | 1 | 14 |
| 6 | 5 | 17 |
| 6 | 13 | 0 |
| 6 | 28 | 14 |
| 6 | 35 | 16 |
| 6 | 41 | 24 |
| 6 | 42 | 5 |
| 7 | 1 | 7 |
| 7 | 9 | 7 |
| 7 | 11 | 3 |
| 7 | 21 | 12 |
| 7 | 30 | 18 |
| 7 | 42 | 15 |
| 7 | 43 | 21 |
| 8 | 2 | 9 |
| 8 | 7 | 25 |
| 8 | 10 | 4 |
| 8 | 18 | 15 |
| 8 | 34 | 15 |
| 8 | 43 | 18 |
| 8 | 44 | 18 |
| 9 | 4 | 13 |
| 9 | 9 | 5 |
| 9 | 18 | 6 |
| 9 | 20 | 3 |
| 9 | 39 | 8 |
| 9 | 44 | 14 |
| 9 | 45 | 15 |
| 10 | 0 | 3 |
| 10 | 7 | 11 |
| 10 | 11 | 10 |
| 10 | 23 | 21 |
| 10 | 33 | 17 |
| 10 | 45 | 13 |
| 10 | 46 | 12 |
| 11 | 1 | 11 |
| 11 | 9 | 9 |
| 11 | 11 | 15 |
| 11 | 29 | 6 |
| 11 | 38 | 11 |
| 11 | 46 | 9 |
| 11 | 47 | 5 |
| 12 | 5 | 16 |
| 12 | 5 | 22 |

| | | |
|---|---|---|
| 12 | 10 | 9 |
| 12 | 24 | 0 |
| 12 | 45 | 5 |
| 12 | 47 | 7 |
| 12 | 48 | 10 |
| 13 | 3 | 13 |
| 13 | 10 | 0 |
| 13 | 13 | 20 |
| 13 | 20 | 23 |
| 13 | 42 | 7 |
| 13 | 48 | 21 |
| 13 | 49 | 14 |
| 14 | 3 | 8 |
| 14 | 7 | 1 |
| 14 | 11 | 3 |
| 14 | 25 | 24 |
| 14 | 46 | 3 |
| 14 | 49 | 3 |
| 14 | 50 | 7 |
| 15 | 0 | 8 |
| 15 | 9 | 0 |
| 15 | 11 | 5 |
| 15 | 19 | 26 |
| 15 | 31 | 8 |
| 15 | 50 | 5 |
| 15 | 51 | 2 |
| 16 | 4 | 4 |
| 16 | 8 | 6 |
| 16 | 15 | 4 |
| 16 | 19 | 11 |
| 16 | 43 | 20 |

| | | |
|---|---|---|
| 16 | 51 | 5 |
| 16 | 52 | 16 |
| 17 | 1 | 10 |
| 17 | 5 | 24 |
| 17 | 10 | 13 |
| 17 | 27 | 3 |
| 17 | 32 | 26 |
| 17 | 52 | 7 |
| 17 | 53 | 24 |
| 18 | 4 | 10 |
| 18 | 8 | 8 |
| 18 | 12 | 10 |
| 18 | 30 | 21 |
| 18 | 48 | 7 |
| 18 | 53 | 16 |
| 18 | 54 | 17 |
| 19 | 4 | 23 |
| 19 | 6 | 15 |
| 19 | 14 | 14 |
| 19 | 28 | 4 |
| 19 | 50 | 5 |
| 19 | 54 | 13 |
| 19 | 55 | 11 |
| 20 | 3 | 9 |
| 20 | 6 | 18 |
| 20 | 15 | 16 |
| 20 | 25 | 5 |
| 20 | 40 | 0 |
| 20 | 55 | 12 |
| 20 | 56 | 8 |
| 21 | 0 | 4 |

| | | |
|---|---|---|
| 21 | 6 | 20 |
| 21 | 11 | 6 |
| 21 | 24 | 9 |
| 21 | 55 | 20 |
| 21 | 56 | 24 |
| 21 | 57 | 12 |
| 22 | 2 | 10 |
| 22 | 8 | 12 |
| 22 | 12 | 12 |
| 22 | 27 | 4 |
| 22 | 53 | 3 |
| 22 | 57 | 0 |
| 22 | 58 | 19 |
| 23 | 0 | 2 |
| 23 | 9 | 17 |
| 23 | 17 | 17 |
| 23 | 21 | 9 |
| 23 | 49 | 14 |
| 23 | 58 | 22 |
| 23 | 59 | 23 |
| 24 | 1 | 16 |
| 24 | 7 | 5 |
| 24 | 17 | 7 |
| 24 | 29 | 12 |
| 24 | 56 | 19 |
| 24 | 59 | 23 |
| 24 | 60 | 4 |
| 25 | 0 | 8 |
| 25 | 8 | 13 |
| 25 | 18 | 1 |
| 25 | 28 | 25 |

| | | |
|---|---|---|
| 25 | 44 | 1 |
| 25 | 60 | 26 |
| 25 | 61 | 13 |
| 26 | 4 | 1 |
| 26 | 9 | 1 |
| 26 | 21 | 10 |
| 26 | 26 | 12 |
| 26 | 52 | 3 |
| 26 | 61 | 6 |
| 26 | 62 | 18 |
| 27 | 3 | 21 |
| 27 | 5 | 8 |
| 27 | 22 | 13 |
| 27 | 27 | 17 |
| 27 | 59 | 21 |
| 27 | 62 | 21 |
| 27 | 63 | 12 |
| 28 | 1 | 13 |
| 28 | 8 | 26 |
| 28 | 20 | 18 |
| 28 | 32 | 11 |
| 28 | 58 | 21 |
| 28 | 63 | 23 |
| 28 | 64 | 3 |
| 29 | 2 | 16 |
| 29 | 5 | 6 |
| 29 | 19 | 10 |
| 29 | 25 | 17 |
| 29 | 54 | 20 |
| 29 | 64 | 16 |
| 29 | 65 | 8 |

| | | |
|---|---|---|
| 30 | 3 | 16 |
| 30 | 7 | 15 |
| 30 | 16 | 1 |
| 30 | 31 | 0 |
| 30 | 41 | 13 |
| 30 | 65 | 15 |
| 30 | 66 | 17 |
| 31 | 0 | 20 |
| 31 | 6 | 8 |
| 31 | 15 | 4 |
| 31 | 34 | 1 |
| 31 | 51 | 22 |
| 31 | 66 | 4 |
| 31 | 67 | 8 |
| 32 | 2 | 11 |
| 32 | 7 | 17 |
| 32 | 13 | 3 |
| 32 | 33 | 12 |
| 32 | 57 | 20 |
| 32 | 67 | 7 |
| 32 | 68 | 3 |
| 33 | 0 | 19 |
| 33 | 6 | 22 |
| 33 | 14 | 8 |
| 33 | 30 | 14 |
| 33 | 35 | 18 |
| 33 | 68 | 16 |
| 33 | 69 | 0 |
| 34 | 3 | 6 |
| 34 | 6 | 0 |
| 34 | 17 | 16 |

| | | |
|---|---|---|
| 34 | 24 | 19 |
| 34 | 47 | 12 |
| 34 | 69 | 1 |
| 34 | 70 | 21 |
| 35 | 2 | 22 |
| 35 | 8 | 22 |
| 35 | 12 | 26 |
| 35 | 23 | 1 |
| 35 | 70 | 5 |
| 35 | 71 | st |

**Table A.2 – Description of the matrix prototype of the rate 2/3 parity check matrix**

| Row | Col | Shift |
|---|---|---|
| 0 | 5 | 16 |
| 0 | 5 | 22 |
| 0 | 10 | 9 |
| 0 | 24 | 0 |
| 0 | 45 | 5 |
| 0 | 47 | 7 |
| 0 | 48 | 10 |
| 1 | 3 | 13 |
| 1 | 10 | 0 |
| 1 | 13 | 20 |
| 1 | 20 | 23 |
| 1 | 42 | 7 |
| 1 | 48 | 21 |
| 1 | 49 | 14 |

| | | |
|---|---|---|
| 2 | 3 | 8 |
| 2 | 7 | 1 |
| 2 | 11 | 3 |
| 2 | 25 | 24 |
| 2 | 46 | 3 |
| 2 | 49 | 3 |
| 2 | 50 | 7 |
| 3 | 0 | 8 |
| 3 | 9 | 0 |
| 3 | 11 | 5 |
| 3 | 19 | 26 |
| 3 | 31 | 8 |
| 3 | 50 | 5 |
| 3 | 51 | 2 |
| 4 | 4 | 4 |
| 4 | 8 | 6 |
| 4 | 15 | 4 |
| 4 | 19 | 11 |
| 4 | 43 | 20 |
| 4 | 51 | 5 |
| 4 | 52 | 16 |
| 5 | 1 | 10 |
| 5 | 5 | 24 |
| 5 | 10 | 13 |
| 5 | 27 | 3 |
| 5 | 32 | 26 |
| 5 | 52 | 7 |
| 5 | 53 | 24 |

| | | |
|---|---|---|
| 6 | 3 | 9 |
| 6 | 4 | 10 |
| 6 | 7 | 15 |
| 6 | 8 | 8 |
| 6 | 12 | 10 |
| 6 | 16 | 5 |
| 6 | 22 | 23 |
| 6 | 30 | 21 |
| 6 | 32 | 6 |
| 6 | 35 | 12 |
| 6 | 36 | 23 |
| 6 | 48 | 7 |
| 6 | 53 | 16 |
| 6 | 54 | 17 |
| 7 | 2 | 12 |
| 7 | 4 | 23 |
| 7 | 6 | 15 |
| 7 | 6 | 16 |
| 7 | 10 | 19 |
| 7 | 14 | 14 |
| 7 | 26 | 12 |
| 7 | 28 | 4 |
| 7 | 31 | 23 |
| 7 | 36 | 5 |
| 7 | 37 | 24 |
| 7 | 50 | 5 |
| 7 | 54 | 13 |
| 7 | 55 | 11 |

| | | |
|---|---|---|
| 8 | 2 | 9 |
| 8 | 3 | 9 |
| 8 | 6 | 18 |
| 8 | 9 | 15 |
| 8 | 15 | 16 |
| 8 | 16 | 2 |
| 8 | 25 | 5 |
| 8 | 29 | 15 |
| 8 | 37 | 8 |
| 8 | 37 | 9 |
| 8 | 38 | 2 |
| 8 | 40 | 0 |
| 8 | 55 | 12 |
| 8 | 56 | 8 |
| 9 | 0 | 4 |
| 9 | 1 | 11 |
| 9 | 5 | 15 |
| 9 | 6 | 20 |
| 9 | 11 | 6 |
| 9 | 14 | 17 |
| 9 | 22 | 7 |
| 9 | 24 | 9 |
| 9 | 36 | 12 |
| 9 | 38 | 19 |
| 9 | 39 | 25 |
| 9 | 55 | 20 |
| 9 | 56 | 24 |
| 9 | 57 | 12 |

| | | |
|---|---|---|
| 10 | 2 | 10 |
| 10 | 4 | 15 |
| 10 | 8 | 3 |
| 10 | 8 | 12 |
| 10 | 10 | 15 |
| 10 | 12 | 12 |
| 10 | 26 | 16 |
| 10 | 27 | 4 |
| 10 | 34 | 6 |
| 10 | 39 | 6 |
| 10 | 40 | 10 |
| 10 | 53 | 3 |
| 10 | 57 | 0 |
| 10 | 58 | 19 |
| 11 | 0 | 2 |
| 11 | 4 | 20 |
| 11 | 9 | 17 |
| 11 | 10 | 24 |
| 11 | 11 | 17 |
| 11 | 17 | 17 |
| 11 | 21 | 9 |
| 11 | 23 | 4 |
| 11 | 33 | 25 |
| 11 | 40 | 24 |
| 11 | 41 | 15 |
| 11 | 49 | 14 |
| 11 | 58 | 22 |
| 11 | 59 | 23 |

| | | |
|---|---|---|
| 12 | 1 | 14 |
| 12 | 1 | 16 |
| 12 | 5 | 17 |
| 12 | 7 | 5 |
| 12 | 13 | 0 |
| 12 | 17 | 7 |
| 12 | 28 | 14 |
| 12 | 29 | 12 |
| 12 | 35 | 16 |
| 12 | 41 | 24 |
| 12 | 42 | 5 |
| 12 | 56 | 19 |
| 12 | 59 | 23 |
| 12 | 60 | 4 |
| 13 | 0 | 8 |
| 13 | 1 | 7 |
| 13 | 8 | 13 |
| 13 | 9 | 7 |
| 13 | 11 | 3 |
| 13 | 18 | 1 |
| 13 | 21 | 12 |
| 13 | 28 | 25 |
| 13 | 30 | 18 |
| 13 | 42 | 15 |
| 13 | 43 | 21 |
| 13 | 44 | 1 |
| 13 | 60 | 26 |
| 13 | 61 | 13 |

| | | |
|---|---|---|
| 14 | 2 | 9 |
| 14 | 4 | 1 |
| 14 | 7 | 25 |
| 14 | 9 | 1 |
| 14 | 10 | 4 |
| 14 | 18 | 15 |
| 14 | 21 | 10 |
| 14 | 26 | 12 |
| 14 | 34 | 15 |
| 14 | 43 | 18 |
| 14 | 44 | 18 |
| 14 | 52 | 3 |
| 14 | 61 | 6 |
| 14 | 62 | 18 |
| 15 | 3 | 21 |
| 15 | 4 | 13 |
| 15 | 5 | 8 |
| 15 | 9 | 5 |
| 15 | 18 | 6 |
| 15 | 20 | 3 |
| 15 | 22 | 13 |
| 15 | 27 | 17 |
| 15 | 39 | 8 |
| 15 | 44 | 14 |
| 15 | 45 | 15 |
| 15 | 59 | 21 |
| 15 | 62 | 21 |
| 15 | 63 | 12 |

| | | |
|---|---|---|
| 16 | 0 | 3 |
| 16 | 1 | 13 |
| 16 | 7 | 11 |
| 16 | 8 | 26 |
| 16 | 11 | 10 |
| 16 | 20 | 18 |
| 16 | 23 | 21 |
| 16 | 32 | 11 |
| 16 | 33 | 17 |
| 16 | 45 | 13 |
| 16 | 46 | 12 |
| 16 | 58 | 21 |
| 16 | 63 | 23 |
| 16 | 64 | 3 |
| 17 | 1 | 11 |
| 17 | 2 | 16 |
| 17 | 5 | 6 |
| 17 | 9 | 9 |
| 17 | 11 | 15 |
| 17 | 19 | 10 |
| 17 | 25 | 17 |
| 17 | 29 | 6 |
| 17 | 38 | 11 |
| 17 | 46 | 9 |
| 17 | 47 | 5 |
| 17 | 54 | 20 |
| 17 | 64 | 16 |
| 17 | 65 | 8 |

| | | |
|---|---|---|
| 18 | 3 | 16 |
| 18 | 7 | 15 |
| 18 | 16 | 1 |
| 18 | 31 | 0 |
| 18 | 41 | 13 |
| 18 | 65 | 15 |
| 18 | 66 | 17 |
| 19 | 0 | 20 |
| 19 | 6 | 8 |
| 19 | 15 | 4 |
| 19 | 34 | 1 |
| 19 | 51 | 22 |
| 19 | 66 | 4 |
| 19 | 67 | 8 |
| 20 | 2 | 11 |
| 20 | 7 | 17 |
| 20 | 13 | 3 |
| 20 | 33 | 12 |
| 20 | 57 | 20 |
| 20 | 67 | 7 |
| 20 | 68 | 3 |
| 21 | 0 | 19 |
| 21 | 6 | 22 |
| 21 | 14 | 8 |
| 21 | 30 | 14 |
| 21 | 35 | 18 |
| 21 | 68 | 16 |
| 21 | 69 | 0 |

| | | |
|---|---|---|
| 22 | 3 | 6 |
| 22 | 6 | 0 |
| 22 | 17 | 16 |
| 22 | 24 | 19 |
| 22 | 47 | 12 |
| 22 | 69 | 1 |
| 22 | 70 | 21 |
| 23 | 2 | 22 |
| 23 | 8 | 22 |
| 23 | 12 | 26 |
| 23 | 23 | 1 |
| 23 | 70 | 5 |
| 23 | 71 | st |

**Table A.3 – Description of the matrix prototype of the rate 3/4 parity check matrix**

| Row | Col | Shift |
|---|---|---|
| 0 | 3 | 9 |
| 0 | 4 | 10 |
| 0 | 7 | 15 |
| 0 | 8 | 8 |
| 0 | 12 | 10 |
| 0 | 16 | 5 |
| 0 | 22 | 23 |
| 0 | 30 | 21 |
| 0 | 32 | 6 |
| 0 | 35 | 12 |

| | | |
|---|---|---|
| 0 | 36 | 23 |
| 0 | 48 | 7 |
| 0 | 53 | 16 |
| 0 | 54 | 17 |
| 1 | 2 | 12 |
| 1 | 4 | 23 |
| 1 | 6 | 15 |
| 1 | 6 | 16 |
| 1 | 10 | 19 |
| 1 | 14 | 14 |
| 1 | 26 | 12 |
| 1 | 28 | 4 |
| 1 | 31 | 23 |
| 1 | 36 | 5 |
| 1 | 37 | 24 |
| 1 | 50 | 5 |
| 1 | 54 | 13 |
| 1 | 55 | 11 |
| 2 | 2 | 9 |
| 2 | 3 | 9 |
| 2 | 6 | 18 |
| 2 | 9 | 15 |
| 2 | 15 | 16 |
| 2 | 16 | 2 |
| 2 | 25 | 5 |
| 2 | 29 | 15 |
| 2 | 37 | 8 |
| 2 | 37 | 9 |

| | | |
|---|---|---|
| 2 | 38 | 2 |
| 2 | 40 | 0 |
| 2 | 55 | 12 |
| 2 | 56 | 8 |
| 3 | 0 | 4 |
| 3 | 1 | 11 |
| 3 | 5 | 15 |
| 3 | 6 | 20 |
| 3 | 11 | 6 |
| 3 | 14 | 17 |
| 3 | 22 | 7 |
| 3 | 24 | 9 |
| 3 | 36 | 12 |
| 3 | 38 | 19 |
| 3 | 39 | 25 |
| 3 | 55 | 20 |
| 3 | 56 | 24 |
| 3 | 57 | 12 |
| 4 | 2 | 10 |
| 4 | 4 | 15 |
| 4 | 8 | 3 |
| 4 | 8 | 12 |
| 4 | 10 | 15 |
| 4 | 12 | 12 |
| 4 | 26 | 16 |
| 4 | 27 | 4 |
| 4 | 34 | 6 |
| 4 | 39 | 6 |

| | | |
|---|---|---|
| 4 | 40 | 10 |
| 4 | 53 | 3 |
| 4 | 57 | 0 |
| 4 | 58 | 19 |
| 5 | 0 | 2 |
| 5 | 4 | 20 |
| 5 | 9 | 17 |
| 5 | 10 | 24 |
| 5 | 11 | 17 |
| 5 | 17 | 17 |
| 5 | 21 | 9 |
| 5 | 23 | 4 |
| 5 | 33 | 25 |
| 5 | 40 | 24 |
| 5 | 41 | 15 |
| 5 | 49 | 14 |
| 5 | 58 | 22 |
| 5 | 59 | 23 |
| 6 | 1 | 14 |
| 6 | 1 | 16 |
| 6 | 5 | 17 |
| 6 | 7 | 5 |
| 6 | 13 | 0 |
| 6 | 17 | 7 |
| 6 | 28 | 14 |
| 6 | 29 | 12 |
| 6 | 35 | 16 |
| 6 | 41 | 24 |

| | | |
|---|---|---|
| 6 | 42 | 5 |
| 6 | 56 | 19 |
| 6 | 59 | 23 |
| 6 | 60 | 4 |
| 7 | 0 | 8 |
| 7 | 1 | 7 |
| 7 | 8 | 13 |
| 7 | 9 | 7 |
| 7 | 11 | 3 |
| 7 | 18 | 1 |
| 7 | 21 | 12 |
| 7 | 28 | 25 |
| 7 | 30 | 18 |
| 7 | 42 | 15 |
| 7 | 43 | 21 |
| 7 | 44 | 1 |
| 7 | 60 | 26 |
| 7 | 61 | 13 |
| 8 | 2 | 9 |
| 8 | 4 | 1 |
| 8 | 7 | 25 |
| 8 | 9 | 1 |
| 8 | 10 | 4 |
| 8 | 18 | 15 |
| 8 | 21 | 10 |
| 8 | 26 | 12 |
| 8 | 34 | 15 |
| 8 | 43 | 18 |

| | | |
|---|---|---|
| 8 | 44 | 18 |
| 8 | 52 | 3 |
| 8 | 61 | 6 |
| 8 | 62 | 18 |
| 9 | 3 | 21 |
| 9 | 4 | 13 |
| 9 | 5 | 8 |
| 9 | 9 | 5 |
| 9 | 18 | 6 |
| 9 | 20 | 3 |
| 9 | 22 | 13 |
| 9 | 27 | 17 |
| 9 | 39 | 8 |
| 9 | 44 | 14 |
| 9 | 45 | 15 |
| 9 | 59 | 21 |
| 9 | 62 | 21 |
| 9 | 63 | 12 |
| 10 | 0 | 3 |
| 10 | 1 | 13 |
| 10 | 7 | 11 |
| 10 | 8 | 26 |
| 10 | 11 | 10 |
| 10 | 20 | 18 |
| 10 | 23 | 21 |
| 10 | 32 | 11 |
| 10 | 33 | 17 |
| 10 | 45 | 13 |

| | | |
|---|---|---|
| 10 | 46 | 12 |
| 10 | 58 | 21 |
| 10 | 63 | 23 |
| 10 | 64 | 3 |
| 11 | 1 | 11 |
| 11 | 2 | 16 |
| 11 | 5 | 6 |
| 11 | 9 | 9 |
| 11 | 11 | 15 |
| 11 | 19 | 10 |
| 11 | 25 | 17 |
| 11 | 29 | 6 |
| 11 | 38 | 11 |
| 11 | 46 | 9 |
| 11 | 47 | 5 |
| 11 | 54 | 20 |
| 11 | 64 | 16 |
| 11 | 65 | 8 |
| 12 | 3 | 16 |
| 12 | 5 | 16 |
| 12 | 5 | 22 |
| 12 | 7 | 15 |
| 12 | 10 | 9 |
| 12 | 16 | 1 |
| 12 | 24 | 0 |
| 12 | 31 | 0 |
| 12 | 41 | 13 |
| 12 | 45 | 5 |

| | | |
|---|---|---|
| 12 | 47 | 7 |
| 12 | 48 | 10 |
| 12 | 65 | 15 |
| 12 | 66 | 17 |
| 13 | 0 | 20 |
| 13 | 3 | 13 |
| 13 | 6 | 8 |
| 13 | 10 | 0 |
| 13 | 13 | 20 |
| 13 | 15 | 4 |
| 13 | 20 | 23 |
| 13 | 34 | 1 |
| 13 | 42 | 7 |
| 13 | 48 | 21 |
| 13 | 49 | 14 |
| 13 | 51 | 22 |
| 13 | 66 | 4 |
| 13 | 67 | 8 |
| 14 | 2 | 11 |
| 14 | 3 | 8 |
| 14 | 7 | 1 |
| 14 | 7 | 17 |
| 14 | 11 | 3 |
| 14 | 13 | 3 |
| 14 | 25 | 24 |
| 14 | 33 | 12 |
| 14 | 46 | 3 |
| 14 | 49 | 3 |

| | | |
|---|---|---|
| 14 | 50 | 7 |
| 14 | 57 | 20 |
| 14 | 67 | 7 |
| 14 | 68 | 3 |
| 15 | 0 | 8 |
| 15 | 0 | 19 |
| 15 | 6 | 22 |
| 15 | 9 | 0 |
| 15 | 11 | 5 |
| 15 | 14 | 8 |
| 15 | 19 | 26 |
| 15 | 30 | 14 |
| 15 | 31 | 8 |
| 15 | 35 | 18 |
| 15 | 50 | 5 |
| 15 | 51 | 2 |
| 15 | 68 | 16 |
| 15 | 69 | 0 |
| 16 | 3 | 6 |
| 16 | 4 | 4 |
| 16 | 6 | 0 |
| 16 | 8 | 6 |
| 16 | 15 | 4 |
| 16 | 17 | 16 |
| 16 | 19 | 11 |
| 16 | 24 | 19 |
| 16 | 43 | 20 |
| 16 | 47 | 12 |

| | | |
|---|---|---|
| 16 | 51 | 5 |
| 16 | 52 | 16 |
| 16 | 69 | 1 |
| 16 | 70 | 21 |
| 17 | 1 | 10 |
| 17 | 2 | 22 |
| 17 | 5 | 24 |
| 17 | 8 | 22 |
| 17 | 10 | 13 |
| 17 | 12 | 26 |
| 17 | 23 | 1 |
| 17 | 27 | 3 |
| 17 | 32 | 26 |
| 17 | 52 | 7 |
| 17 | 53 | 24 |
| 17 | 70 | 5 |
| 17 | 71 | st |

**Table A.4 – Description of the matrix prototype of the rate 5/6 parity check matrix**

| Row | Col | Shift |
|---|---|---|
| 0 | 1 | 16 |
| 0 | 3 | 9 |
| 0 | 5 | 16 |
| 0 | 5 | 22 |
| 0 | 7 | 5 |
| 0 | 7 | 15 |

| | | |
|---|---|---|
| 0 | 10 | 9 |
| 0 | 16 | 5 |
| 0 | 17 | 7 |
| 0 | 22 | 23 |
| 0 | 24 | 0 |
| 0 | 29 | 12 |
| 0 | 32 | 6 |
| 0 | 35 | 12 |
| 0 | 36 | 23 |
| 0 | 45 | 5 |
| 0 | 47 | 7 |
| 0 | 48 | 10 |
| 0 | 56 | 19 |
| 0 | 59 | 23 |
| 0 | 60 | 4 |
| 1 | 0 | 8 |
| 1 | 2 | 12 |
| 1 | 3 | 13 |
| 1 | 6 | 16 |
| 1 | 8 | 13 |
| 1 | 10 | 0 |
| 1 | 10 | 19 |
| 1 | 13 | 20 |
| 1 | 18 | 1 |
| 1 | 20 | 23 |
| 1 | 26 | 12 |
| 1 | 28 | 25 |
| 1 | 31 | 23 |

| | | |
|---|---|---|
| 1 | 36 | 5 |
| 1 | 37 | 24 |
| 1 | 42 | 7 |
| 1 | 44 | 1 |
| 1 | 48 | 21 |
| 1 | 49 | 14 |
| 1 | 60 | 26 |
| 1 | 61 | 13 |
| 2 | 2 | 9 |
| 2 | 3 | 8 |
| 2 | 4 | 1 |
| 2 | 7 | 1 |
| 2 | 9 | 1 |
| 2 | 9 | 15 |
| 2 | 11 | 3 |
| 2 | 16 | 2 |
| 2 | 21 | 10 |
| 2 | 25 | 24 |
| 2 | 26 | 12 |
| 2 | 29 | 15 |
| 2 | 37 | 8 |
| 2 | 37 | 9 |
| 2 | 38 | 2 |
| 2 | 46 | 3 |
| 2 | 49 | 3 |
| 2 | 50 | 7 |
| 2 | 52 | 3 |
| 2 | 61 | 6 |

| | | |
|---|---|---|
| 2 | 62 | 18 |
| 3 | 0 | 8 |
| 3 | 1 | 11 |
| 3 | 3 | 21 |
| 3 | 5 | 8 |
| 3 | 5 | 15 |
| 3 | 9 | 0 |
| 3 | 11 | 5 |
| 3 | 14 | 17 |
| 3 | 19 | 26 |
| 3 | 22 | 7 |
| 3 | 22 | 13 |
| 3 | 27 | 17 |
| 3 | 31 | 8 |
| 3 | 36 | 12 |
| 3 | 38 | 19 |
| 3 | 39 | 25 |
| 3 | 50 | 5 |
| 3 | 51 | 2 |
| 3 | 59 | 21 |
| 3 | 62 | 21 |
| 3 | 63 | 12 |
| 4 | 1 | 13 |
| 4 | 4 | 4 |
| 4 | 4 | 15 |
| 4 | 8 | 3 |
| 4 | 8 | 6 |
| 4 | 8 | 26 |

| | | |
|---|---|---|
| 4 | 10 | 15 |
| 4 | 15 | 4 |
| 4 | 19 | 11 |
| 4 | 20 | 18 |
| 4 | 26 | 16 |
| 4 | 32 | 11 |
| 4 | 34 | 6 |
| 4 | 39 | 6 |
| 4 | 40 | 10 |
| 4 | 43 | 20 |
| 4 | 51 | 5 |
| 4 | 52 | 16 |
| 4 | 58 | 21 |
| 4 | 63 | 23 |
| 4 | 64 | 3 |
| 5 | 1 | 10 |
| 5 | 2 | 16 |
| 5 | 4 | 20 |
| 5 | 5 | 6 |
| 5 | 5 | 24 |
| 5 | 10 | 13 |
| 5 | 10 | 24 |
| 5 | 11 | 17 |
| 5 | 19 | 10 |
| 5 | 23 | 4 |
| 5 | 25 | 17 |
| 5 | 27 | 3 |
| 5 | 32 | 26 |

| | | |
|---|---|---|
| 5 | 33 | 25 |
| 5 | 40 | 24 |
| 5 | 41 | 15 |
| 5 | 52 | 7 |
| 5 | 53 | 24 |
| 5 | 54 | 20 |
| 5 | 64 | 16 |
| 5 | 65 | 8 |
| 6 | 1 | 14 |
| 6 | 3 | 16 |
| 6 | 4 | 10 |
| 6 | 5 | 17 |
| 6 | 7 | 15 |
| 6 | 8 | 8 |
| 6 | 12 | 10 |
| 6 | 13 | 0 |
| 6 | 16 | 1 |
| 6 | 28 | 14 |
| 6 | 30 | 21 |
| 6 | 31 | 0 |
| 6 | 35 | 16 |
| 6 | 41 | 13 |
| 6 | 41 | 24 |
| 6 | 42 | 5 |
| 6 | 48 | 7 |
| 6 | 53 | 16 |
| 6 | 54 | 17 |
| 6 | 65 | 15 |

| | | |
|---|---|---|
| 6 | 66 | 17 |
| 7 | 0 | 20 |
| 7 | 1 | 7 |
| 7 | 4 | 23 |
| 7 | 6 | 8 |
| 7 | 6 | 15 |
| 7 | 9 | 7 |
| 7 | 11 | 3 |
| 7 | 14 | 14 |
| 7 | 15 | 4 |
| 7 | 21 | 12 |
| 7 | 28 | 4 |
| 7 | 30 | 18 |
| 7 | 34 | 1 |
| 7 | 42 | 15 |
| 7 | 43 | 21 |
| 7 | 50 | 5 |
| 7 | 51 | 22 |
| 7 | 54 | 13 |
| 7 | 55 | 11 |
| 7 | 66 | 4 |
| 7 | 67 | 8 |
| 8 | 2 | 9 |
| 8 | 2 | 11 |
| 8 | 3 | 9 |
| 8 | 6 | 18 |
| 8 | 7 | 17 |
| 8 | 7 | 25 |

| | | |
|---|---|---|
| 8 | 10 | 4 |
| 8 | 13 | 3 |
| 8 | 15 | 16 |
| 8 | 18 | 15 |
| 8 | 25 | 5 |
| 8 | 33 | 12 |
| 8 | 34 | 15 |
| 8 | 40 | 0 |
| 8 | 43 | 18 |
| 8 | 44 | 18 |
| 8 | 55 | 12 |
| 8 | 56 | 8 |
| 8 | 57 | 20 |
| 8 | 67 | 7 |
| 8 | 68 | 3 |
| 9 | 0 | 4 |
| 9 | 0 | 19 |
| 9 | 4 | 13 |
| 9 | 6 | 20 |
| 9 | 6 | 22 |
| 9 | 9 | 5 |
| 9 | 11 | 6 |
| 9 | 14 | 8 |
| 9 | 18 | 6 |
| 9 | 20 | 3 |
| 9 | 24 | 9 |
| 9 | 30 | 14 |
| 9 | 35 | 18 |

| | | |
|---|---|---|
| 9 | 39 | 8 |
| 9 | 44 | 14 |
| 9 | 45 | 15 |
| 9 | 55 | 20 |
| 9 | 56 | 24 |
| 9 | 57 | 12 |
| 9 | 68 | 16 |
| 9 | 69 | 0 |
| 10 | 0 | 3 |
| 10 | 2 | 10 |
| 10 | 3 | 6 |
| 10 | 6 | 0 |
| 10 | 7 | 11 |
| 10 | 8 | 12 |
| 10 | 11 | 10 |
| 10 | 12 | 12 |
| 10 | 17 | 16 |
| 10 | 23 | 21 |
| 10 | 24 | 19 |
| 10 | 27 | 4 |
| 10 | 33 | 17 |
| 10 | 45 | 13 |
| 10 | 46 | 12 |
| 10 | 47 | 12 |
| 10 | 53 | 3 |
| 10 | 57 | 0 |
| 10 | 58 | 19 |
| 10 | 69 | 1 |

| | | |
|---|---|---|
| 10 | 70 | 21 |
| 11 | 0 | 2 |
| 11 | 1 | 11 |
| 11 | 2 | 22 |
| 11 | 8 | 22 |
| 11 | 9 | 9 |
| 11 | 9 | 17 |
| 11 | 11 | 15 |
| 11 | 12 | 26 |
| 11 | 17 | 17 |
| 11 | 21 | 9 |
| 11 | 23 | 1 |
| 11 | 29 | 6 |
| 11 | 38 | 11 |
| 11 | 46 | 9 |
| 11 | 47 | 5 |
| 11 | 49 | 14 |
| 11 | 58 | 22 |
| 11 | 59 | 23 |
| 11 | 70 | 5 |
| 11 | 71 | st |

1

# APPENDIX J

# IEEE P802.11
# Wireless LANs

## WWiSE Proposal: High throughput extension to the 802.11 Standard

**Date:** 2005-01-06


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## Abstract

Changes and additions to IEEE Std. 802.11-1999 (Reaff 2003), as amended by published amendments IEEE802.11a, IEEE802.11g, IEEE802.11h and IEEE802.11i and by IEEE draft standard 802.11e/D9.0 are provided to support a new high throughput physical layer (PHY) for operation in the 2.4 and 5 GHz bands.

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# Draft Amendment to IEEE Standard for Information technology-
# Telecommunications and information exchange between systems -
# Local and metropolitan area networks -
# Specific Requirements -

# Part 20: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications:

# High throughput extension for the 2.4 GHz and 5 GHz Bands

[This amendment is based on IEEE Std 802.11™, 1999 Edition (Reaff 2003), as amended by IEEE Std 802.11a™-1999 and IEEE Std 802.11g™-2003, and Draft Amendment IEEE P802.11e/D9.0]

## 3. Definitions

***Insert the following new definitions in alphabetical order, renumbering as necessary:***

**20 MHz transmission:** A frame transmission in which the modulation spans only one of the 20 MHz channels of a 40 MHz Channel Pair.

**40 MHz channel pair:** A pair of 20 MHz channels whose centre frequencies are separated by 20 MHz and which can be treated as a single channel for 40 MHz transmissions by a BSS, and where one of the 20 MHz channels will also be used for (non-overlapping) 20 MHz transmissions by the BSS.

**40 MHz transmission:** A frame transmission in which the modulation spans both 20 MHz channels of a 40 MHz channel pair.

**aggregated MSDU (A-MSDU):** A MSDU that encapsulates one or more MSDUs to be transmitted to the same destination.

**aggregated PPDU (A-PPDU):** A PPDU that contains one or more pairs of PLCP headers and PSDUs.

**HTP burst transmission:** A sequence of frames transmitted by a single high-throughput station in a single medium access. The frames may be transmitted as part of an A-PPDU, or with reduced or zero interfame spacing to enhance medium efficiency.

**primary channel:** The channel in a 40 MHz channel pair that will be used for 20 MHz transmissions as well as being part of the 40 MHz channel for 40 MHz transmissions.

**secondary channel:** The channel in a 40 MHz channel pair that is used only as part of the 40 MHz channel for 40 MHz transmissions, and which is not used for 20 MHz transmissions.

**HTP rate group:** A group of rates supported by an HTP STA that use the same transmit bandwidth, the same number of transmit antennas, and the number of spatial streams.

**HTP STA:** A STA which conforms to the minimum mandatory requirements set forth in clause 20.

**40MHz HTP rate:** Any rate supported by an HTP STA that uses 40MHz of transmit bandwidth.

**20MHz HTP STA:** An HTP STA which does not support any 40MHz HTP rate.

**40MHz HTP STA:** An HTP STA which supports the ability to receive at least one 40MHz HTP rate.

**MIMO-OFDM:** Multiple input multiple output orthogonal frequency division multiplexing

# 4. Abbreviations and acronyms

***Insert the following acronyms alphabetically in the list in Clause 4:***

| | |
|---|---|
| A-MSDU | aggregated MSDU |
| A-PPDU | aggregated PPDU |
| ECC | error correction code |
| HT | high throughput |
| HTP | high-throughput PHY conforming to Clause 20 |
| LDPCC | low density parity check code |
| MIMO | multiple input multiple output |
| nHTP | non HTP PHY conforming to Clause 15 or Clause 17 or Clause 18 or Clause 19, but not to Clause 20 |
| RIFS | reduced interframe space |
| STBC | space time block code |

# 6. MAC Service Definition

# 6.1 Overview of MAC services

## 6.1.4 Data service architecture (informative)

***Change the paragraph in 6.1.4 (.11e) as shown:***

The MAC data plane architecture (i.e., processes that involve transport of all or part of an MSDU) is shown in Figure 11g. During transmission, an MSDU goes through some or all of the following processes: frame delivery deferral during power save mode, aggregation, sequence number assignment, fragmentation, encryption, integrity protection, and frame formatting. IEEE 802.1X may block the MSDU at the Controlled Port. At some point the Data frames that contain all or part of the MSDU are queued per access category/TS. This queuing may be at any of the three points indicated in Figure 11g.

During reception, a received data frame goes through processes of MPDU header + cyclic redundancy codecheck (CRC) validation, duplicate removal, possible reordering if the Block Ack mechanism is used, decryption, defragmentation, integrity checking, de-aggregation, and replay detection. After replay detection (or defragmentation if security is used), the MSDU is delivered to the MAC_SAP or to the DS. The IEEE 802.1X Controlled/ Uncontrolled Ports discard the MSDU if the Controlled Port is not enabled or if the MSDU does not represent an IEEE 802.1X frame. TKIP and CCMP MPDU frame order enforcement occurs after decryption, but prior to MSDU defragmentation; therefore, defragmentation will fail if MPDUs arrive out of order.

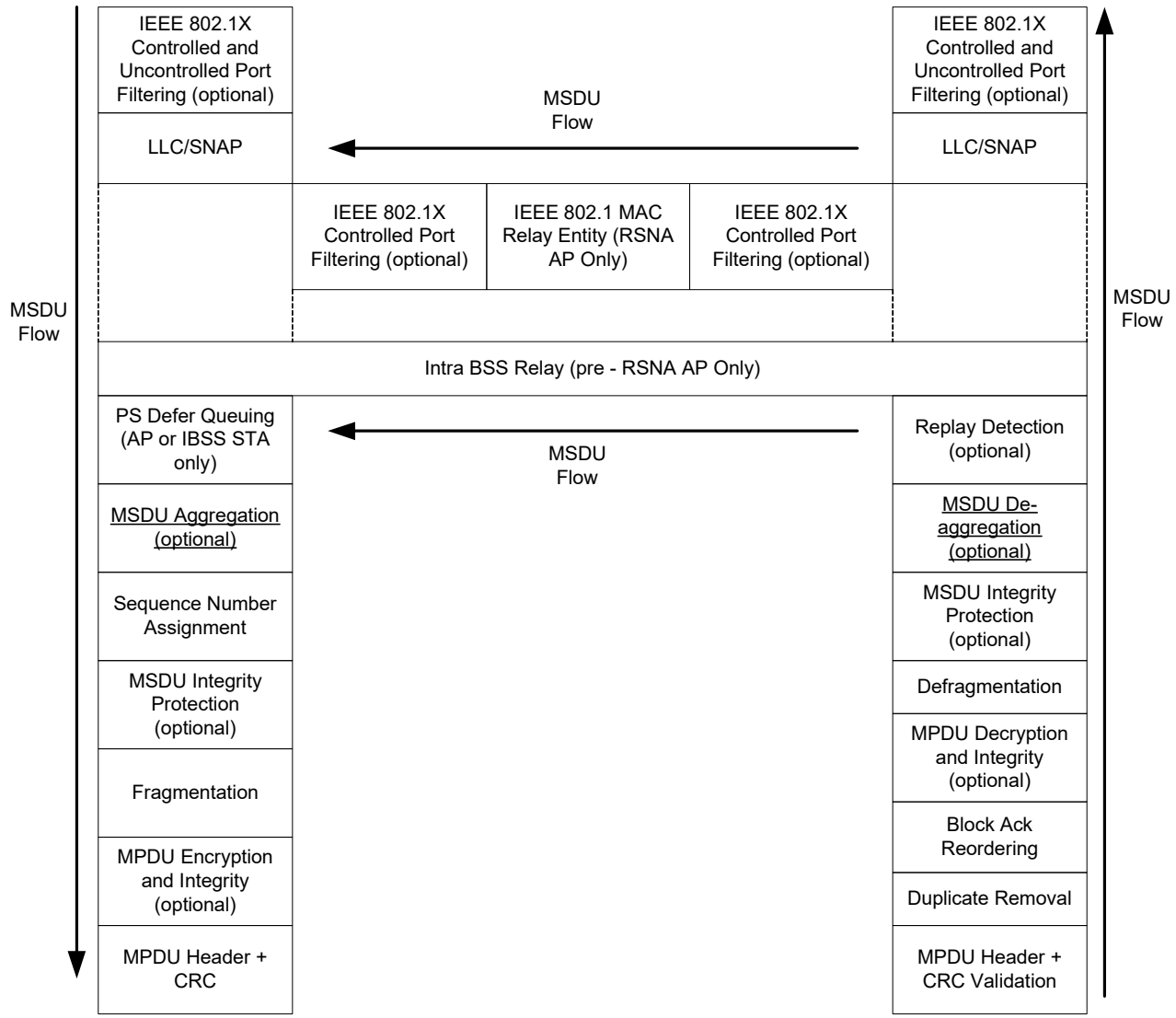



**Figure 11g – MAC data plane architecture**

# 6.2 Detailed service specification

## 6.2.1 MAC data services

## 6.2.1.1 MA-UNITDATA.request

### 6.2.1.1.2 Semantics of the service primitive

***Change the third from the last paragraph as follows:***

The data parameter specifies the MSDU to be transmitted by the MAC sublayer entity. For IEEE 802.11, the length of the MSDU ~~must~~shall be less than or equal to ~~2304~~ 8100 octets when a PHY defined in Clause 20 is employed or 4000 when a PHY defined in Clause 17 is employed.

# 7. Frame Formats

## 7.1 MAC frame formats

### 7.1.2 General frame format

***Change Figure 12(.11e) as follows:***

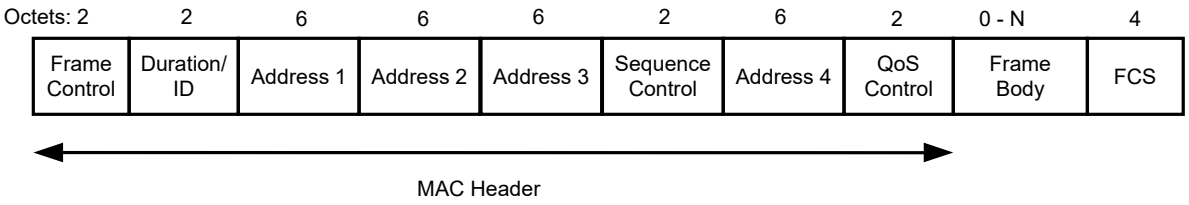



**Figure 12 – MAC frame format**

The maximum frame body length, N, is 8100 when a Clause 20 PHY is employed, and 4000 when a Clause 17 PHY is employed.

### 7.1.3 Frame fields

### 7.1.3.5 QoS Control field

***Change Table 3.1 in 7.1.3.5 (.11e) to appear as follows:***

**Table 3.1 – QoS Control field**

| Applicable Frame (sub) Types | Bits 0-3 | Bit 4 | Bit 5-6 | Bit 7 | Bits 8-15 |
|---|---|---|---|---|---|
| QoS (+)CF-Poll frames sent by HC | TID | EOSP | Ack Policy | Reserved | TXOP limit |
| QoS Data and QoS Data+CF-Ack frames sent by HC | TID | EOSP | Ack Policy | Aggregated MSDU Present | QAP PS Buffer State |
| QoS Null, QoS CFAck frames sent by HC | TID | EOSP | Ack Policy | Reserved | QAP PS Buffer State |
| QoS data type frames sent by non-AP QSTAs | TID | 0 | Ack Policy | Aggregated MSDU Present | TXOP duration requested |
| | TID | 1 | Ack Policy | Aggregated MSDU Present | Queue size |

## 7.2 Format of individual frame types

## 7.2.1 Control Frames

### 7.2.1.7 Block Acknowledgement Request (BlockAckReq) frame format

***Change the diagram of the BAR control field of 7.2.1.7 to appear as follows:***




**Figure 21.2– BAR Control Field**

***Insert the following text and table immediately after Figure 21.2 within clause 7.2.1.7:***

The ACK Policy subfield of the BAR Control field contains the ACK policy for the BlockAckReq frame. The ACK policy subfield bits shall have the meaning indicated in table 3.3:

| **Bits in BAR Control field** | **Meaning** |
|---|---|
| **Bit 0 Bit 1** | |
| 0 0 | Normal acknowledgement.<br>The addressed recipient returns an ACK as defined in 9.2.8 or a Block Acknowledgement frame after a SIFS period, according to the previously negotiated block ack policy as described in 11.5. The Ack Policy field is set to this value in all directed Block Ack Request frames in which the sender requires immediate acknowledgement, including those requiring an immediate Block Acknowledgement. |
| 1 0 | No Acknowledgement<br>The addressed recipient performs no immediate response action upon receipt of the frame. More details are provided in 9.11. The Ack Policy is set to this value in all BlockAckReq frames in which the sender does not require immediate, explicit acknowledgement. |
| 0 1 | Reserved |
| 1 1 | Reserved |

**Table 3.3**

### 7.2.1.8 Block Acknowledgement (BlockAck) frame format

***Change the diagram of the BA control field of 7.2.1.8 to appear as follows:***

The BA control field defined in Figure 21.5 consists of the TID and Ack Policy subfields as shown in figure 21.5.

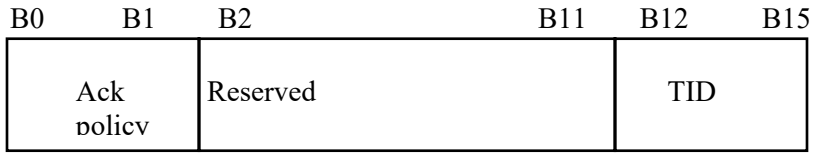



**Figure 21.5 – BA Control Field**

***Insert the following text and table immediately after Figure 21.5 within clause 7.2.1.8:***

The ACK Policy subfield of the BA Control field contains the ACK policy for the Block Acknowledgement frame. The ACK policy subfield bits shall have the meaning indicated in table 3.4:

| **Bits in BAR Control field** | **Meaning** |
|---|---|
| **Bit 0 Bit 1** | |
| 0 0 | Normal acknowledgement.<br>The addressed recipient returns an ACK as defined in 9.2.8 after a SIFS period. The Ack Policy field is set to this value in all directed Block Acknowledgement frames in which the sender requires immediate acknowledgement. |
| 1 0 | No Acknowledgement<br>The addressed recipient performs no immediate response action upon receipt of the frame. More details are provided in 9.11. The Ack Policy is set to this value in all Block Acknowledgement frames in which the sender does not require immediate, explicit acknowledgement. |
| 0 1 | Reserved |
| 1 1 | Reserved |

**Table 3.4**

## 7.2.2 Data Frames

***Change the text, figures and tables in 7.2.2 (.11e) as shown:***

The frame format for a Data frame is dependent on the QoS subfield of the subtype field and is as defined in Figure 22.

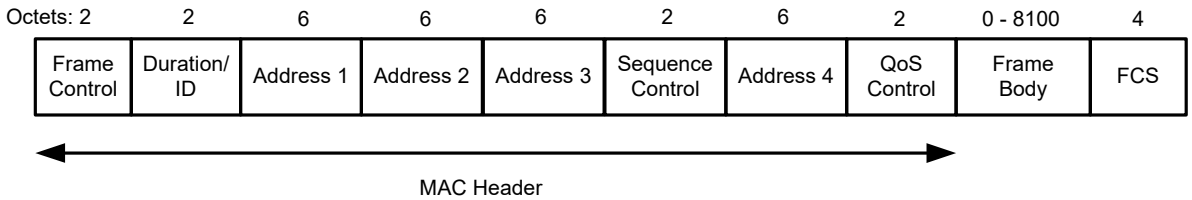



**Figure 22 – Data frame**

***Change the definitions as follows:***

The DA is the destination of the A-MSDU or MSDU (or fragment thereof) in the frame body field.

The SA is the address of the MAC entity which initiated the A-MSDU or MSDU (or fragment thereof) in the frame body field.

## 7.2.3 Management frames

## 7.2.3.1 Beacon frame format

***Insert the Channel Set entry and change the notes in Table 5(.11g) to read as follows:***

| Order | Information | Notes |
|---|---|---|
| 7 | DS Parameter Set | The DS Parameter Set information element is present within Beacon frames generated by STAs using Clause 15, Clause 18 and Clause 19 PHYs and by STAs using Clause 20 PHYs while operating in the 2.4GHz band. |
| 15 | Channel Set | The Channel Set information element is present within Beacon frames generated by APs using a Clause 20 PHY operating on a 40 MHz channel pair |
| 19 | ERP Information | The ERP Information element is present within Beacon frames generated by STAs using ERP PHYs and HTP PHYs and is optionally present in other cases. |

***Add a new clause 7.2.3.1.1 immediately after the existing clause 7.2.3.1 "Beacon Frame Format"***

## 7.2.3.1.1 Secondary Channel Beacon Format

An AP with a Clause 20 PHY operating on a 40 MHz channel pair may send a Beacon frame on the secondary channel as described in clause 9.13.2.1. In contrast to the normal sending of Beacon frames, the aim of sending a Beacon frame on the secondary channel is to discourage use of that channel (other than as the secondary channel of the 40 MHz channel pair) and as a result, the required frame body is substantially different.

The contents of the fields of the Beacon frame sent on the secondary channel shall be the same as those of the Beacon frame sent on the primary channel, with the exceptions noted below.

The Supported Rate Set Information Element shall consist of a single Clause 20 rate, marked as a basic rate.

**Table 7.2.3.1.1T1 – Beacon Frame Body when used as a Secondary Channel Beacon**

| Order | Information | Notes |
|---|---|---|
| 1 | Timestamp | |

| | | |
|---|---|---|
| 2 | Beacon Interval | |
| 3 | Capability | |
| 4 | Service Set Identifier (SSID) | |
| 5 | Supported Rate Set | |
| 6 | CF Parameter Set | May optionally be included to further discourage use of this channel. |
| 5 | Channel Set | |

### 7.2.3.9 Probe Response frame format

***Insert the Channel Set entry and change the notes in Table 12(.11g) to read as follows:***

| Order | Information | Notes |
|---|---|---|
| 7 | DS Parameter Set | The DS Parameter Set information element is present within Probe Response frames generated by STAs using Clause 15, Clause 18 and Clause 19 PHYs and by STAs using Clause 20 PHYs while operating in the 2.4GHz band. |
| 11 | Channel Set | The Channel Set information element is present within Probe Response frames generated by APs using a Clause 20 PHY operating on a 40 MHz Channel Pair |
| 18 | ERP Information | The ERP Information element is present within Probe Response frames generated by STAs using ERP PHYs and HTP PHYs and is optionally present in other cases. |

## 7.3 Management frame body components

### 7.3.1 Fixed fields

### 7.3.1.4 Capability Information field

***Change the second paragraph in 7.3.1.4(.11e) as shown:***

The length of the Capability Information field is 2 octets. The format of the Capability Information field is defined as illustrated in Figure 27. No subfield is supplied for ERP as a STA supports ERP operation if it includes all the clause 19 mandatory rates in its supported rate set. No subfield is supplied for HTP (STAs employing a

Clause 20 PHY), as a STA supports HTP operation if it includes all of the Clause 20 mandatory rates in its supported rate set.

### 7.3.1.11 Action Field

***Add the following rows to Table 19A to:***

| Name | Value | See Subclause |
|---|---|---|
| High Throughput | 4 | 7.4.5 |

## 7.3.2 Information Elements

***Add a new row to Table 20 "Element IDs" as follows, and adjust reserved ids appropriately***

| | |
|---|---|
| Channel Set | XXX-To be assigned by ANA before letter ballot |

***Add the following text to the end of clause 7.3.2 after the table of Element IDs***

Individual information elements may be extended in length by future versions of this standard by adding new fields to the end of an existing information element. STAs shall ignore any additional information beyond the expected end of an Information Element, and shall treat any such information element as legal.

### 7.3.2.13 ERP Information element

***Change the text of clause 7.3.2.13(.11g) as follows:***

~~The ERP Information element contains information on the presence of Clause 15 or Clause 18 stations in the BSS that are not capable of Clause 19 (ERP-OFDM) data rates. It also contains the requirement of the ERP Information element sender (AP in a BSS or STA in an IBSS) as to the use of protection mechanisms to optimize BSS performance and as to the use of long or short Barker preambles. See Figure 42E for a definition of the frame element.~~

The ERP Information element contains information on:

a) the presence of Clause 15 or Clause 18 stations in the BSS that are not capable of Clause 19 (ERP-OFDM) data rates
b) the directive from the ERP Information element sender (the AP, or in an IBSS a STA) as to the use of protection mechanisms to optimize BSS performance in the presence of STA which have implemented a PHY from Clause 15 or Clause 18 and not including Clause 19 capability
c) the directive from the ERP Information element sender (AP in a BSS or STA in an IBSS) as to the use of long or short Barker preambles
d) the presence of Clause 19 stations in the BSS, when the ERP Information element sender is an HTP STA
e) the directive from the ERP Information element sender (AP in a BSS or STA in an IBSS) as to the use of OFDM-protection mechanisms to optimize BSS performance
f) the presence of Clause 17 stations in the BSS, when the ERP Information element sender is a HTP STA
g) the presence of Clause 17 stations in the secondary 20 MHz channel which potentially limits the ability of the HTP STA to utilize a 40 MHz wide channel, when the ERP Information element sender is a HTP STA

h) the presence of HTP STA in the BSS which are not capable of receiving 40 MHz channel transmissions (20MHz HTP STA), when the ERP Information element sender is an HTP STA

i) the directive from the ERP Information element sender (AP in a BSS or STA in an IBSS) as to the use of 20MHz-protection mechanisms to optimize BSS performance

See Figure 42E for a definition of the ERP Information element.

In an infrastructure BSS, if one or more NonERP STAs are associated in the BSS, the Use_Protection bit shall be set to 1 in transmitted ERP Information Elements.

In an infrastructure BSS, if one or more Clause 19 or Clause 17 STAs are associated in the BSS, then the Use_OFDM_Protection bit shall be set to 1 in ERP Information Elements transmitted by HTP STAs and may be set to 1 in ERP Information Elements transmitted by nHTP STAs.

In an infrastructure BSS, if one or more 20MHz HTP STAs are associated in the BSS, then the Use_20MHz_Protection bit shall be set to 1 in ERP Information Elements transmitted by HTP STAs and may be set to 1 in ERP Information Elements transmitted by nHTP STAs.

In an IBSS, the setting of the Use_Protection and Use_OFDM_Protection and Use_20MHz_Protection bits is left to the STA. In an IBSS, there is no uniform concept of association; therefore, a typical algorithm for setting the Use_Protection and Use_OFDM_Protection and Use_20MHz_Protection bits will take into account the traffic pattern and history on the network. If a member of an IBSS which is not an HTP STA detects one or more NonERP STAs that are members of the same IBSS, then the Use_Protection bit should be set to 1 in the ERP Information Element of transmitted Beacon and Probe Response frames. If a member of an IBSS which is a HTP STA detects one or more Clause 19 STAs or one or more Clause 17 STAs that are members of the same IBSS, then the Use_OFDM_Protection bit should be set to 1 in the ERP Information Element of transmitted Beacon and Probe Response frames. If a member of an IBSS which is an HTP STA detects one or more 20MHz HTP STAs that are members of the same IBSS, then the Use_20MHz_Protection bit should be set to 1 in the ERP Information Element of transmitted Beacon and Probe Response frames.

In an infrastructure BSS, the NonERP_Present bit shall be set to 1 when a NonERP STA is associated with the BSS. Examples of when the NonERP present bit may additionally be set to 1 include, but are not limited to, when:

a) A NonERP infrastructure or independent BSS is overlapping (a NonERP BSS may be detected by the reception of a Beacon where the supported rates contain only Clause 15 or Clause 18 rates).

b) In an IBSS, if a Beacon frame is received from one of the IBSS participants where the supported rate set contains only Clause 15 or Clause 18 rates.

c) A management frame (excluding a Probe Request) is received where the supported rate set includes only Clause 15 or Clause 18 rates.

In an infrastructure BSS, the OFDM_PRESENT bit shall be set to 1 in ERP Information Elements transmitted by HTP STA when a Clause 17 or Clause 19 STA is associated with the BSS. Examples of when the OFDM_PRESENT bit may additionally be set to 1 in an ERP Information Element transmitted by a HTP STA include, but are not limited to, when

a) A Clause 17 or Clause 19 infrastructure or independent BSS is overlapping. (A Clause 17 BSS may be detected by the reception of a Beacon where the supported rates element and extended supported rates element contain only Clause 17 rates. A Clause 19 BSS may be detected by the reception of a Beacon where the supported rates and extended supported rates elements contain at least one rate from the set of Clause 19 rates and no HTP rates.)

b) In an IBSS, if a Beacon frame is received from one of the IBSS participants where the supported rate set contains:

1) only Clause 17 rates
OR
2) at least one rate from the set of Clause 19 rates and no HTP rates.

c) A management frame (excluding a Probe Request) is received where the supported rate set includes:

1) only Clause 17 rates
OR
2) at least one rate from the set of Clause 19 rates and no HTP rates.

The OFDM_PRESENT bit may optionally be set to 1 in ERP Information Elements transmitted by nHTP STA.

In an infrastructure BSS, the 20MHz_HTP_PRESENT bit shall be set to 1 in ERP Information Elements transmitted by HTP STA when one or more 20MHz HTP STAs are associated in the BSS. Examples of when the 20MHz_HTP_PRESENT bit may additionally be set to 1 in an ERP Information Element transmitted by a HTP STA include, but are not limited to, when

a) An infrastructure or independent BSS which is overlapping and which has signalled the presence of 20MHz HTP STA as indicated by the 20MHz_HTP_PRESENT bit.

b) In an IBSS, if a Beacon frame is received from one of the IBSS participants where the supported rate set contains at least one rate from the set of Clause 20 rates, but no 40MHz HTP rates.

c) A management frame (excluding a Probe Request) is received where the supported rate set contains at least one rate from the set of Clause 20 rates, but no 40MHz HTP rates.

The 20MHz_HTP_PRESENT bit may optionally be set to 1 in ERP Information Elements transmitted by nHTP STA.

~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs shall invoke the use of a protection mechanism as described in clause 9.13 after transmission or reception of the Use_Protection bit with a value of 1 in an MMPDU to or from the BSS that the ~~ERP AP or ERP STA~~ ERP AP, ERP STA, HTP AP or HTP STA has joined or started. ~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs may additionally invoke clause 9.13 protection mechanism use at other times.

~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs may disable clause 9.13 protection mechanism use after transmission or reception of the Use_Protection bit with a value of 0 in an MMPDU to or from the BSS that the ~~ERP APs or ERP STAs~~ ERP AP, ERP STA, HTP AP or HTP STA has joined or started.

HTP APs and HTP STAs shall invoke the use of an OFDM protection mechanism after transmission or reception of the Use_OFDM_Protection bit with a value of 1 in an MMPDU to or from the BSS that the HTP AP or HTP STA has joined or started unless a protection mechanism as defined in clause 9.13 is being concurrently employed, in which case, the use of an OFDM protection mechanism is optional. HTP APs and HTP STAs may optionally invoke OFDM protection mechanism use at other times.

HTP APs and HTP STAs may disable OFDM protection mechanism use after transmission or reception of the Use_OFDM_Protection bit with a value of 0 in an MMPDU to or from the BSS that the HTP AP or HTP STA has joined or started.

40MHz HTP APs and 40MHz HTP STAs shall invoke the use of a 20MHz protection mechanism after transmission or reception of the Use_20MHz_Protection bit with a value of 1 in an MMPDU to or from the BSS that the 40MHz HTP AP or 40MHz HTP STA has joined or started unless a protection mechanism as defined in clause 9.13, or an OFDM protection mechanism is being concurrently employed, in which case, the use of a 20MHz protection mechanism is optional. 40MHz HTP APs and 40 MHz HTP STAs may optionally invoke 20MHz protection mechanism use at other times.

40MHz HTP APs and 40MHz HTP STAs may disable 20MHz protection mechanism use after transmission or reception of the Use_20MHz_Protection bit with a value of 0 in an MMPDU to or from the BSS that the 40MHz HTP AP or 40MHz HTP STA has joined or started.

When there are no NonERP STAs associated with the BSS and the ERP Information Element sender's dot11ShortPreambleOptionImplemented MIB variable is set to true, then the Barker_Preamble_Mode bit may be set to 0. The Barker_Preamble_Mode bit shall be set to 1 by the ERP Information Element sender if one or more associated NonERP STAs are not short preamble capable as indicated in their Capability Information field, or if the ERP Information Element senders dot11ShortPreambleOptionImplemented MIB variable is set to false.

If a member of an IBSS detects one or more non-short preamble-capable STAs that are members of the same IBSS, then the Barker_Preamble_Mode bit should be set to 1 in the transmitted ERP Information Element.

~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs shall use long preambles when transmitting Clause 15, Clause 18, and Clause 19 frames after transmission or reception of an ERP Information Element with a Barker_Preamble_Mode value of 1 in an MMPDU to or from the BSS that the ~~ERP APs or ERP STAs~~ ERP AP, ERP STA, HTP AP or HTP STA has joined or started, regardless of the value of the short preamble capability bit from the same received or transmitted MMPDU that contained the ERP Information Element. ~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs may additionally use long preambles when transmitting Clause 15, Clause 18, and Clause 19 frames at other times. ~~ERP APs and ERP STAs~~ ERP APs, ERP STAs, HTP APs and HTP STAs may use short preambles when transmitting Clause 15, Clause 18, and Clause 19 frames after transmission or reception of an ERP Information Element with a Barker_Preamble_Mode value of 0 in an MMPDU to or from the BSS that the ~~ERP APs or ERP STAs~~ ERP AP, ERP STA, HTP AP or HTP STA has joined or started, regardless of the value of the short preamble capability bit from the same received or transmitted MMPDU. ~~NonERP STAs and NonERP APs~~STAs which are neither ERP nor HTP and APs which are neither ERP nor HTP may also follow the rules given in this paragraph.

The Secondary_Channel_Used bit may be set to 0 in ERP Information Elements transmitted by HTP STAs or HTP APs if no frames with a Clause 17 BSSID have been received within the last two seconds on the secondary 20 MHz channel of the BSS that the HTP AP or HTP STA has joined or started, otherwise, the Secondary_Channel_Used bit shall be set to 1. nHTP STAs and nHTP APs shall always set the Secondary_Channel_Used bit to 0 if they transmit ERP Information elements.

Recommended behavior for setting the Use_Protection bit is contained in 9.10.

The ERP Information element shall have the form shown in Figure 42E.

| B0-B7 | B0-B7 | B0 | B1 | B2 | B3 | B4 | B5 | B6 | B7 |
|---|---|---|---|---|---|---|---|---|---|
| ElementID | Length(1) | NonERP Present | Use_protection | Barker preamble mode | OFDM_present | Use_OFDM_Protection | Secondary_Channel_Used | 20MHz_HTP_PRESENT | USE_20MHz_PROTECTION |

**Figure 42E**

~~Bits r3 through r7 are reserved, set to 0, and are ignored on reception. Note that the length of this element is flexible and may be expanded in the future.~~

Note that the length of this element is flexible and may be expanded in the future.

### 7.3.2.22.1 Basic Report

***Change one of the reserved bits in figure 46o "Map Field Format" to be "Secondary Channel"***

***Add the following after the definition of the "Unmeasured bit"***

— Secondary Channel bit, which shall be set to 1 when at least one valid Secondary Channel Beacon (as described in clause 9.13.2.1) was received during the measurement period from another BSS. Otherwise the Secondary Channel bit shall be set to zero.

***Add the following new clauses as the last sub-clauses of 7.3.2 "Information Elements"***

### 7.3.2.25 Channel Set

The Channel Set information element is used to convey information about the channels from which a 40 MHz Channel Pair are formed. The Primary Channel field shall contain the channel number of the primary channel. The Secondary Channel shall contain the channel number of the secondary channel.

This information element may be extended in later versions of this standard.

See Figure 000n:

| | Element ID | Length | Primary Channel | Secondary Channel |
|---|---|---|---|---|
| Octets: | 1 | 1 | 1 | 1 |

**Figure 000n- Channel Set element format**

### 7.4.5 High Throughput action details

Four Action frame formats are defined for High Throughput. An action field, in the octet field immediatedly after the Category field, differentiates the four formats. The Action field values associated with each format are defined in Table 20.22.

## Table 20.22 – High Throughput Action field values

| Action field value | Description |
|---|---|
| 0 | Mode Request |
| 1 | Mode Report |
| 2 | MIMO Channel Request |

| | |
|---|---|
| 3 | MIMO Channel Report |
| 4-255 | Reserved |

### 7.4.5.1 Mode Request frame format

The Mode Request frame uses the Action frame body format and is transmitted by a STA requesting the receiving STA to indicate the best transmission mode to employ for high throughput communication. The format of the Mode Request frame is shown in Figure 000n1.

The Category field shall be set to 4 (representing High Throughput).

The Actions field shall be set to 0 (representing a Mode Request Frame).

The Dialog Token field shall be set to a nonzero value chosen by the STA sending the Mode Request to identify the request/report transaction.

The Mode Request field shall be set to 1. All other values for this field are reserved.

| | Category | Action | Dialog Token | Mode Request |
|---|---|---|---|---|
| Octets: | 1 | 1 | 1 | 1 |

**Figure 000n1- Mode Request frame format**

Upon reception of a Mode Request frame, an STA must respond with a Mode Response, as described in 7.4.5.2. A null response may be used.

### 7.4.5.2 Mode Response frame format

The Mode Response frame uses the Action frame body format and is transmitted by a STA in response to a Mode Request frame. It may also be used as an unsolicited request to use a certain PHY mode. The format of the Mode Response frame is shown in Figure 000n2.

The Category field shall be set to 4 (representing High Throughput).

The Actions field shall be set to 1 (representing a Mode Response Frame).

The Dialog Token field shall be set to the value in any corresponding Mode Request Frame. If the Mode Response is not being transmitted in response to a Measurement Request frame, the Dialog token shall be set to zero.

The Mode Response field shall contain the mode that the STA would prefer the requesting station to employ. The specific mechanism for determining this mode is implementation dependent. A null response of all ones (i.e. 0xFFFF) is used if the station is unable to determine a mode. Otherwise, the mode is indicating using bits b6:b21 as shown in Figure 017 (SIG-N field). All other bits are reserved and set to zero.

| Category | Action | Dialog Token | Mode Response |
|---|---|---|---|

| Octets: | 1 | 1 | 1 | 4 |
|---|---|---|---|---|

**Figure 000n2- Mode Response frame format**

### 7.4.5.3 MIMO Channel Request frame format

The MIMO Channel Request frame uses the Action frame body format and is transmitted by a STA requesting the receiving STA to provide its estimate of the MIMO channel matrix seen on receiving this frame. The format of the MIMO Channel Request frame is shown in Figure 000n3.

The Category field shall be set to 4 (representing High Throughput).

The Actions field shall be set to 2 (representing a MIMO Channel Request Frame).

The Dialog Token field shall be set to a nonzero value chosen by the STA sending the MIMO Channel Request to identify the request/report transaction.

The MIMO Channel Request field shall be set to 1. All other values for this field are reserved.

| Category | Action | Dialog Token | MIMO Channel Request |
|---|---|---|---|
| Octets: 1 | 1 | 1 | 1 |

**Figure 000n3- MIMO Channel Request frame format**

### 7.4.5.4 MIMO Channel Response frame format

The MIMO Channel Response frame uses the Action frame body format and is transmitted by a STA in response to a MIMO Channel Request frame. It may also be used as an unsolicited indication of the observed MIMO channel matrix. The format of the MIMO Channel Response frame is shown in Figure 000n4.

The Category field shall be set to 4 (representing High Throughput).

The Actions field shall be set to 3 (representing a MIMO Channel Response Frame).

The Dialog Token field shall be set to the value in any corresponding MIMO Channel Request Frame. If the MIMO Channel Response is not being transmitted in response to a MIMO Channel Request frame, the Dialog token shall be set to zero.

| Category | Action | Dialog Token | Mode Response |
|---|---|---|---|
| Octets: 1 | 1 | 1 | N |

**Figure 000n4- MIMO Channel Response frame format**

The Mode Response field is of varying length depending on the actual channel matrix being encoded. The octects of the Mode Response field are set according to the table below.

**Table XYZ – Mode Response Encoding**

| Octet | Contents |
|---|---|
| 1-2 | Length of Mode Response field in octets (16 bit unsigned integer) |
| 3 | Response type<br><br>0 for Null<br><br>1 for MIMO channel estimate<br><br>2-255 Reserved |
| 4 | Number of Rows in Channel Matrix (i.e. NRx antennas) |
| 5 | Number of Columns in Channel Matrix (i.e. NTx antennas) |
| 6 to (5+Nst*Nrows*Ncols*4) | Channel matrix elements row by row starting with element (1,1) from lowest to highest subcarrier. Each element is encoded as two 16 bit signed integers (I and Q). |

For the MIMO channel estimate, the station sends the actual channel estimate it computes during preamble processing of a MIMO Channel Request Frame.

# 9. MAC sublayer functional description

## 9.1 MAC architecture

***Insert the following subclause after clause 9.1.3(.11e) and renumber existing subclauses 9.1.4(.11e) through 9.1.5(.11e) to be subclauses 9.1.5 through 9.1.6***

### 9.1.4 MSDU aggregation

One or more MSDUs being sent to the same receiver can be aggregated into a single A-MSDU. Aggregation of more than one frame can improve system efficiency as seen at the MAC sub-layer due to the fact that the overheads associated with channel access (e.g. PLCP preamble, MAC header, IFS spacing, etc.) can be amortized over two or more MSDUs. Frames with address types of Broadcast ,Multicast, or Unicast frames can be aggregated with other frames of the same address type, but not with frames of different address type due to the requirement to share the receiver address. Aggregation is optional and the process is considered a “sub-process” between MSDU queuing and sequence number assignment in Figure 11g of Clause 6.1.4.

A STA shall only use MSDU aggregation where it knows that the receiver supports MSDU aggregation. A STA shall not aggregate MSDUs that have different values of priority as indicated by the MA-UNITDATA.request

primitive. A STA may aggregate MSDUs with different values of destination address as long as they would have the same value in the Address 1 field had they been sent as individual MPDUs.

To form an A-MSDU, two or more MSDUs are aggregated together, separated by a sub-frame header. This is shown in Figure 001n. The resulting A-MSDU is therefore the combination of all MSDUs in the A-MSDU along with a sub-frame header for each constituent MSDU.

The destination address of the A-MSDU is the address of the STA that is the next immediate intended receiver of the aggregated frame. The source address of the A-MSDU is the MAC address of the STA that created the A-MSDU.

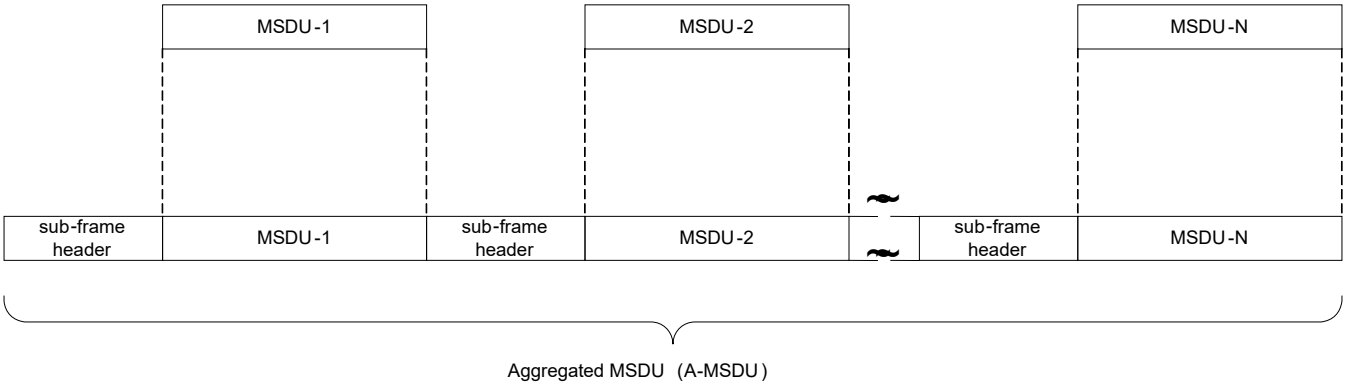



**Figure 001n – Formation of an A-MSDU**

The format for the sub-frame header is given in Figure 002n. The sub-frame header is 14 octets in length and consists of a 16-bit MSDU length field, a 6-octet source address of the constituent MSDU, and a 6-octet destination address of the constituent MSDU. The MSDU length field indicates the length, in octets, of the constituent MSDU.

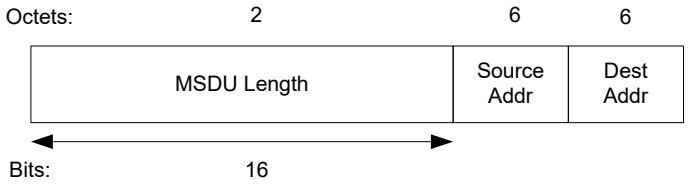



**Figure 002n – Sub-Frame Header**

A data frame bearing an A-MSDU within its frame body is identified by a '1' in the Aggregated MSDU bit of the QoS Control Field (Clause 7.1.3.5). For data frames containing a non-aggregated MSDU, this bit will be zero.

After aggregation, the procedures for handling an A-MSDU are no different from an MSDU including sequence number assignment, optional MSDU integrity protection, and fragmentation, with the single exception of the Aggregated MSDU bit described above. Once formed, A-MSDUs shall not be un-aggregated by the transmitter, as there are no facilities for individual sequencing or retransmission of the constituent MSDUs.

A method for determining when to engage optional MSDU aggregation is out of scope for this standard.

***Insert the following subclause after clause 9.1.3(.11e) and renumber existing subclauses 9.1.6(.11e) to be subclauses 9.1.7***

### 9.1.6 HTP Burst Transmission overview

The high-throughput PHY defines burst transmission formats that permit more efficient usage of the medium. A HTP burst transmission is performed in a single medium access, and permits frames to be sent to different destination addresses. These formats shall only be used to transmit frames to other HTP STAs, and may be used as part of any kind of TXOP. The medium spacing before and after a HTP burst transmission shall be governed by the rules covering the spacing before and after a non-burst transmission in the TXOP.

A HTP burst transmission consists of a sequence of frames transmitted by a single HTP STA without intervening frames by any other STA. The frames of the HTP burst transmission shall be transmitted using a single HTP rate group as defined in 20.3.2.2. During a HTP burst transmission, the MAC may utilise RIFS and/or instruct the PHY to aggregate multiple frames into a single A-PPDU. These formats are illustrated in Figure 003n.

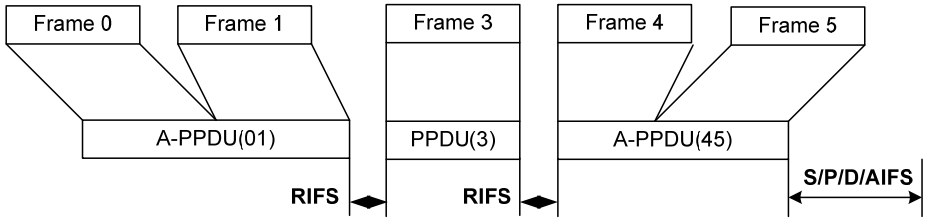



**Figure 003n – HTP Burst transmission**

Frames may be aggregated into a single A-PPDU if they are being transmitted at the same TXPWR_LEVEL. A frame that uses a different TXPWR_LEVEL as the previous frame in the HTP burst transmission may use RIFS.

# 9.2 DCF

### 9.2.3 Interframe Space (IFS)

***Change the text in clause 9.2.3(.11e) as follows***

The time interval between frames is called the IFS. A STA shall determine that the medium is idle through the use of the carrier sense function for the interval specified. An interframe space, RIFS, is defined for use between frames in a HTP burst transmission, and another five IFSs are defined to provide priority levels for access to the wireless media. To obtain access to the medium, a STA shall determine that the medium is idle through the use of the carrier sense function for the interval specified. ~~Five different IFSs are defined to provide priority levels for access to the wireless media; they~~ The interframe spaces are listed in order, from the shortest to the longest except for AIFS. Figure 49 shows some of these relationships.

a) RIFS Reduced Interframe Space
b) Short Interframe Space
c) PIFS Point Coordination Function (PCF) Interframe Space
d) DIFS Distributed Coordination Function (DCF) Interframe Space
e) AIFS Arbitration Interframe Space (used by the QoS facility)
f) EIFS Extended Interframe Space

***Insert the following subclause after clause 9.2.3(.11e) and renumber existing subclauses 9.2.3.1(.11e) through 9.2.3.5(.11e) to be subclauses 9.2.3.2 through 9.2.3.6.***

### 9.2.3.1 RIFS

The RIFS may be used for the second or subsequent frame of a HTP burst transmission if the frame will be transmitted at a different power than the immediately previous frame.

### 9.2.12 Determination of PLME aCWmin characteristics

***Modify the first paragraph of clause 9.2.12 as follows:***

In the case of the Clause 19 Extended Rate PHY and Clause 20 High Throughput PHY, the aCWmin value is dependent on the requestor's characteristic rate set. The characteristic rate set is equal to the IBSS's supported rate set when the STA is operating as a member of an IBSS. It is equal to the AP's supported rate set when the STA is associated with an AP. At all other times, it is equal to the STA's mandatory rate set. The MAC variable aCWmin is set to aCWmin(0) if the characteristic rate set includes only rates in the set 1, 2, 5.5, 11 otherwise, aCWmin is set to aCWmin(1). If the returned value for aCWmin is a scalar, then the MAC always sets the variable aCWmin to the returned scalar value of aCWmin.

## 9.6 Multirate support

***Make the following changes to paragraph 7 of clause 9.6(.11g) "Multirate Support":***

To allow the transmitting STA to calculate the contents of the Duration/ID field, a STA responding to a received frame shall transmit its Control Response (either CTS or ACK) frames at the highest rate in the BSSBasicRateSet that is less than or equal to the rate of the immediately previous frame in the frame exchange sequence (as defined in 9.7) and that is of the same modulation ~~type~~ class (see Clause 9.6.1) as the received frame. If no rate in the basic rate set meets these conditions, then the control frame sent in response to a received frame shall be transmitted at the highest mandatory rate of the PHY that is less than or equal to the rate of the received frame, and that is of the same modulation ~~type~~ class as the received frame. In addition, the Control Response frame shall be sent using the same PHY options as the received frame, unless they conflict with the requirement to use the BSSBasicRateSet.

***Add new clause 9.6.1 immediately following the existing clause 9.6***

### 9.6.1 Modulation Classes

In order to determine the rules for response frames given in clause 9.6, the following modulation classes are defined. Each row defines a modulation class. Modulation types within the same row have the same modulation class, while modulation types in different rows have different modulation classes.

**Table 9.6.1T Modulation Classes**

| Modulation Class | Description |
|---|---|
| 1 | Clause 16 Infrared PHY |
| 2 | Clause 14 Frequency Hopping Spread Spectrum PHY |

| | |
|---|---|
| 3 | Clause 15 DSSS PHY, and Clause 18 High Rate DSSS PHY |
| 4 | Clause 19.6 ERP-PBCC PHY |
| 5 | Clause 19.7 DSSS-OFDM |
| 6 | Clause 19.5 ERP-OFDM PHY |
| 7 | Clause 17 Orthogonal Frequency Division Multiplexing PHY in the 5GHz band |
| 8 | Clause 20 High Throughput PHY (20 MHz transmissions) |
| 9 | Clause 20 High Throughput PHY (40 MHz transmissions) |

# 9.9 HCF

## 9.9.1 HCF contention-based channel access (EDCA)

### 9.9.1.4 Multiple frame transmission in an EDCA TXOP

***Change the first paragraph of subclause 9.9.1.4(.11e) as follows:***

Multiple frames may be transmitted in an acquired EDCA TXOP following the rules in 9.9.1.3. if there are more than one frame pending in the AC for which the channel has been acquired. However, those frames that are pending in other ACs shall not be transmitted in this EDCA TXOP. If a QSTA has in its transmit queue an additional frame of the same AC as the one just transmitted, and the duration of transmission of that frame plus any expected acknowledgement for that frame is less than the remaining medium occupancy timer value, then the QSTA may commence transmission of that frame ~~at SIFS after the completion of the immediately preceding frame exchange sequence~~ after the completion of the appropriate interframe space from the end of the immediately preceding frame exchange sequence. The intention of using the multiple frame transmission shall be indicated by the QSTA through the setting of the duration/ID values in one of the following two ways (see 7.1.4):

## 9.9.2 HCF controlled channel access

### 9.9.2.1 HCF controlled channel access procedure

### 9.9.2.1.2 CAP generation

***Change the second paragraph of subclause 9.9.2.1.2(.11e) as follows***

~~During a CFP or a TXOP in CP, after each data, QoS data or management type frame with a group address in the Address1 field, the HC shall wait for at least one PIFS period, and shall only continue to transmit if the WM is idle.~~ After the last frame of all ~~other non-final~~ frame exchange sequences ~~(e.g., sequences that convey unicast QoS data or management type frames)~~ during a TXOP, the holder of the current TXOP shall wait for one SIFS period before transmitting the first frame of the next frame exchange sequence, unless the frame exchange is part of a HTP burst transmission when the rules identified in clause 9.1.6 apply. The HC may sense the channel and reclaim the channel after a duration of PIFS after the TXOP, if the channel remains idle. A CAP ends when the HC does not reclaim the channel after a duration of PIFS after the end of a TXOP.

### 9.9.2.2 TXOP structure and timing

***Change the first paragraph of subclause 9.9.2.2(.11e) as follows***

Any QoS data type frame of a subclass that includes CF-Poll contains a TXOP limit in its QoS control field. The ensuing polled TXOP is protected by the NAV set by the Duration field of the frame that contained the QoS (+) CF-Poll function, as shown in Figure 62.4. Within a polled TXOP a QSTA may initiate the transmission of one or more frame exchange sequences, with all such sequences being part of a HTP burst transmission, or being nominally separated by a SIFS interval. The QSTA shall not initiate transmission of a frame unless the transmission, and any acknowledgement or other immediate response expected from the peer MAC entity, are able to complete prior to the end of the remaining TXOP duration. All transmissions, including the response frames, within the polled TXOP are considered to be the part of the TXOP and the HC shall account for these when setting the TXOP limit. If the TXOP Limit subfield in the QoS Control field of the QoS data type frame that includes CF-Poll is set to 0, then the QSTA to which the frame is directed to shall respond with either one MPDU or one QoS Null frame.

## 9.10 Block acknowledgment

### 9.10.1 Introduction (Informative)

***Change the first paragraph of subclause 9.9.10.1(.11e) as follows***

The Block Acknowledgement (Block Ack) mechanism allows a block of QoS Data MPDUs to be transmitted between two QSTAs without intervening ACK frames ~~each separated by a SIFS period, between two QSTAs~~. The mechanism is for improving the channel efficiency by aggregating several acknowledgements into one frame. There are two types of Block Ack mechanisms: immediate and delayed. Immediate Block Ack is suitable for high-bandwidth, low latency traffic while the delayed Block Ack is suitable for applications that tolerate moderate latency. In this clause, the QSTA with data to send using the Block Ack mechanism is referred to as the originator and the receiver of that data as the recipient.

### 9.10.3 Data and acknowledgement transfer

***Change the first paragraph of subclause 9.9.10.1(.11e) as follows***

After setting up for the Block exchange following the procedure in 9.10.2, the originator may transmit a Block of QoS data type frames ~~separated by SIFS period,~~ with the total number of frames not exceeding the Buffer Size subfield in the associated ADDBA response frame. Each of the frames shall have the Ack policy subfield in the QoS Control set to "Block Acknowledgement". The RA field of the frames shall be the recipient's *unicast* address. The originator requests acknowledgement of outstanding QoS Data type frames by sending a BlockAckReq frame. The recipient shall maintain a Block Ack record for the block.

## 9.12 Frame exchange sequences

***Edit Table 22.1(.11e) <HCF sequence> and replace all "=" with"-".***

***Remove definiton 36 from end of Table 22.4(.11e) (no PIFS spacing defined anymore).***

***Replace the last sentence of the text in subclause 9.12 as follows(.11e) with:***

Individual frames within each of these sequences ~~are separated by a SIFS~~ may be send as part of a HTP burst transmission if the frames meet the rules identified in clause 9.16., otherwise a SIFS separation is used unless an "=" sign appears between frames in the table, in which case, PIFS is used.

# 9.13 Protection mechanism

***Delete two paragraphs from the text of clause 9.13 as follows:***

If a protection mechanism is being used, a fragment sequence may only employ ERP-OFDM modulation for the final fragment and control response.

The rules for calculating RTS/CTS NAV fields are unchanged when using RTS/CTS as a protection mechanism.

***Insert the following two new subclauses after clause 9.13:***

## 9.13.1 OFDM Protection

The intent of an OFDM protection mechanism is to ensure that an HTP STA does not transmit an MPDU of type Data or an MMPDU, using a Clause 20 rate which is not also a Clause 17 or Clause 19 rate unless it has attempted to update the NAV or cause a PHY-CCA.indicate(status=BUSY) to be elicited by receiving Clause 17 or Clause 19 STAs.

The updated NAV period shall be longer than or equal to the total time required to send the data and any required response frames.

The PHY-CCA.indicate(status=BUSY) shall be longer than or equal to the total time required to send the data and any required response frames.

HTP STAs shall use OFDM protection mechanisms (such as RTS/CTS or CTS-to-self employing a Clause 19 or Clause 17 rate) for Clause 20-only rate MPDUs of type Data or MMPDUs when the Use_OFDM_Protection field of transmitted or received ERP Information elements is set to 1 and the BSSID of the frame which contained the ERP Information element is the same as the BSS which the HTP STA has joined or started. Clause 19 rates shall be employed when the BSS is operating in a Clause 19 channel. Clause 17 rates shall be employed when the BSS is operating in a Clause 17 channel.

OFDM Protection mechanism frames shall conform to at least one of the following conditions:
a) The frame shall be sent using one of the mandatory Clause 19 or Clause 17 rates and using one of the mandatory Clause 17 or Clause 19 waveforms, so that all known ERP or Clause 17 STAs in the BSA will know the duration of the exchange even if they cannot detect the Clause 20 frames using their CCA function
b) The frame shall be sent using a Clause 17 preamble and signal field (additional, non-clause 17 preamble and signal field may be present following the Clause 17 preamble and signal field)
c) The frame shall be sent using a Clause 19 preamble and signal field (additional, non-clause 19 preamble and signal field may be present following the Clause 19 preamble and signal field)

In the case of a BSS composed of only HTP STAs, but with knowledge of a neighboring co-channel BSS having nHTP traffic, the AP may require either or both of protection mechanisms and OFDM protection mechanisms to protect the BSSs traffic from interference. This will provide propagation of NAV of PHY-CCA.indicate(status=BUSY) to all associated STAs and all STAs in a neighboring co-channel BSS within range through BSS basic rate set modulated messages. Frames that propagate the NAV throughout the BSS include RTS/CTS/ACK frames, all data frames with the "more fragments" field set to 1, all data frames sent in response to PS-Poll that are not preceded in the frame sequence by a data frame with the "more fragments" field set to 1,

Beacon frames with nonzero CF time, +CF-POLL frames, various QOS frames, and CF-End frames. Frames that propagate PHY-CCA.indicate(status=BUSY) throughout the BSS include any frames which commence with an appropriately chosen preamble and signal field.

If any of the rates in the BSSBasicRateSet of the OFDM protection mechanism frame transmitting STAs BSS are Clause 17 or Clause 19 rates, then the OFDM protection mechanism frames shall be sent at one of those Clause 17 or Clause 19 basic rates, unless either condition b) or condition c) from above has been met, in which case, no rate restrictions apply.

OFDM Protection Mechanisms shall not be used where the frame transmission will be protected by the Protection Mechanism defined in clause 9.13

### 9.13.2 20MHz Protection

The intent of a 20MHz protection mechanism is to ensure that a 40MHz HTP STA does not transmit an MPDU of type Data or an MMPDU as a 40MHz transmission unless it has attempted to update the NAV or cause a PHY-CCA.indicate(status=BUSY) to be elicited by receiving 20MHz HTP STAs which may be present.

The updated NAV period shall be longer than or equal to the total time required to send the data and any required response frames.

The PHY-CCA.indicate(status=BUSY) shall be longer than or equal to the total time required to send the data and any required response frames.

40MHz HTP STAs shall use 20MHz protection mechanisms (such as RTS/CTS or CTS-to-self employing a 20MHz HTP rate) for 40MHz transmissions of MPDUs of type Data or MMPDUs when the Use_20MHz_Protection field of transmitted or received ERP Information elements is set to 1 and the BSSID of the frame which contained the ERP Information element is the same as the BSS which the 40MHz HTP STA has joined or started.

20MHz Protection mechanism frames shall conform to at least one of the following conditions:
a) The frame shall be sent using one of the mandatory 20MHz HTP rates, so that all known 20MHz HTP STAs in the BSA will know the duration of the exchange even if they cannot detect 40MHz transmissions using their CCA function.
b) The frame shall be sent using a 20MHz preamble and signal field (additional, non-20MHz preamble and signal field may be present following the 20MHz preamble and signal field)

In the case of a BSS composed of only 40MHz HTP STAs, but with knowledge of a neighboring co-channel BSS having nHTP traffic, the AP may require any of clause 9.13 protection mechanisms, OFDM protection mechanisms and 20MHz protection mechanisms to protect the BSSs traffic from interference. This will provide propagation of NAV of PHY-CCA.indicate(status=BUSY) to all associated STAs and all STAs in a neighboring co-channel BSS within range through BSS basic rate set modulated messages. Frames that propagate the NAV throughout the BSS include RTS/CTS/ACK frames, all data frames with the “more fragments” field set to 1, all data frames sent in response to PS-Poll that are not preceded in the frame sequence by a data frame with the “more fragments” field set to 1, Beacon frames with nonzero CF time, +CF-POLL frames, various QOS frames, and CF-End frames. Frames that propagate PHY-CCA.indicate(status=BUSY) throughout the BSS include any frames which commence with an appropriately chosen preamble and signal field.

If any of the rates in the BSSBasicRateSet of the 20MHz protection mechanism frame transmitting STAs BSS are 20MHz rates, then the 20MHz protection mechanism frames shall be sent at one of those 20MHz basic rates, unless condition b) from above has been met, in which case, no rate restrictions apply.

OFDM Protection Mechanisms shall not be used where the frame transmission will be protected by the Protection Mechanism defined in clause 9.13

***Insert new clause 9.14 and sub-clauses as follows:***

## 9.14 40 MHz Channel Pairs

Clause 20 defines a mode in which High Throughput PHYs can transmit a frame utilising a 40 MHz channel pair in order to achieve lower frame durations than if a single 20 MHz channel was used. This clause describes the MAC support for this feature in an infrastructure BSS. 40 MHz transmissions shall only be used when the STA has joined or started an Infrastructure BSS.

A 40 MHz channel pair consists of two 20 MHz channels, and a BSS operating on a 40 MHz Channel Pair will make use of one of these channels (called the primary channel) for 20 MHz transmissions. The other channel (called the secondary channel) will not be used by the BSS for 20 MHz transmissions.

### 9.14.1 40 MHz Fundamentals of Operation

A 40 MHz channel pair consists of two 20 MHz channels, on each of which there could be 20 MHz transmissions (from an overlapping BSS on either channel, or from 20 MHz transmissions on the primary channel), and on each of which the Carrier Sense mechanism described in clause 9.2.1 could be run. However, it is not possible to combine two Carrier Sense mechanisms without degrading the effective priority of 40 MHz transmissions to such an extent that they would provide no benefit.

For this reason the MAC models a 40 MHz channel pair as a single 20 MHz channel (the primary channel) in which some transmissions happen to “overflow” into the Secondary Channel.

A STA that wishes to transmit on both channels of a 40MHz channel shall conduct CCA on the primary channel, with the following extension. For any frame transmission that requires the CCA function to indicate a clear channel before transmission, the secondary channel CCA state shall also be checked. If the secondary channel CCA indicates a busy channel, the STA shall not transmit on the secondary channel. It shall either fall back to 20MHz operation (for only the current transmission), or shall consider the frame transmission to have failed (including all incrementing of retry counters and contention windows etc where required).

An AP shall indicate that it is operating on a 40 MHz channel pair by including the Channel Set information element in its Beacon frames. An AP shall not change the information contained in the Channel Set information element without invoking the channel move procedure described in clause 11.6.7. A STA that has joined a BSS and that wishes to use 40 MHz transmissions shall check the setting of the Secondary_Channel_Used bit in the ERP Information Element in the last valid Beacon frame received from the BSS, and shall not use 40 MHz transmissions where the Secondary_Channel_Used bit is set to 1.

A STA shall not send a 20 MHz transmission to a member STA of a BSS on the secondary channel of that BSS. A STA that has joined or started a BSS operating on a 40 MHz channel pair shall discard all 20 MHz transmissions received on the secondary channel. A STA shall not join a BSS on its secondary channel.

An AP that detects significant evidence of collisions on the secondary channel may invoke the channel move procedure described in clause 11.6.7.

#### 9.14.2.1 Secondary Channel Beacon

In order to reduce the chance of the secondary channel being used by an overlapping BSS, an AP may send a Beacon frame using the secondary channel with contents chosen to discourage use of the secondary channel by other BSSes.

The frame body of such a beacon is shown in Clause 7.2.3.1.1. These beacons contain a rate set consisting of a single clause 20 basic rate, and so should not cause non-clause 20 STAs to attempt to associate with the AP on the secondary channel.

When transmitting a beacon on the secondary channel, the AP may observe the channel access mechanisms described elsewhere in clause 9 for the transmission of Beacon frames, or it may transmit the Beacon frame without consideration of the state of the secondary channel.

### 9.14.3 Beacon Transmission

An AP operating on a 40 MHz channel pair shall send Beacon frames (with the exception of Secondary Channel Beacon frames) on the primary channel using a 20 MHz transmission.

### 9.14.4 Limits on Channel Numbering

Both the primary and secondary Channels shall be legal 20 MHz channels in the 5GHz band. For a primary channel number “n”, the secondary channel number shall be either “n+4” or “n-4”.

# 10. Layer management

## 10.4 PLME SAP interface

### 10.4.3 PLME_CHARACTERISTICS.confirm

#### 10.4.3.2 Semantics of the service primitive

***Change the primitive description as follows:***

The primitive provides the following parameters:

PLME-CHARACTERISTICS.confirm(
aSlotTime,
aSIFSTime,
aRIFSTime,
aCCATime,
aRxTxTurnaroundTime,
aTxPLCPDelay,
aRxPLCPDelay,
aRxTxSwitchTime,
aTxRampOnTime,
aTxRampOffTime,
aTxRFDelay,
aRxRFDelay,

aAirPropagationTime,
aMACProcessingDelay,
aPreambleLength,
aPLCPHeaderLength,
aMPDUDurationFactor,
aMPDUMaxLength,
aCWmin,
aCWmax
)

***Add the following entry to the table:***

| | | |
|---|---|---|
| aRIFSTime | integer | The minimum time (in microseconds) that the PHY requires between PSDUs that are transmitted with differing TXPWR_LEVELs within a HTP burst transmission. |

## 10.4.4 PLME-DSSSTESTMODE.request

## 10.4.4.2 Semantics of the service primitive

***Change the sixth row in the table in 10.4.4.2 as shown:***

| | | | |
|---|---|---|---|
| DATA_RATE | Integer | 2, 4, 11, 12,<br>18, 22, 24,<br>36, 44, 48,<br>66, 72, 73-92, 96,<br>97-106, 108, 109-121 | Selects among rates and transmission modes<br>02 = 1 Mbit/s<br>04 = 2 Mbit/s<br>11 = 5.5 Mbit/s<br>12 = 6 Mbit/s<br>18 = 9 Mbit/s<br>22 = 11 Mbit/s<br>24 = 12 Mbit/s<br>36 = 18 Mbit/s<br>44 = 22 Mbit/s<br>48 = 24 Mbit/s<br>66 = 33 Mbit/s<br>72 = 36 Mbit/s<br>96 = 48 Mbit/s<br>108 = 54 Mbit/s<br>73-95, 97-107, 109-122 = See Tables 003-009 and Table 017 in subclause 20.3.2.2 and 20.3.5.10 respectively |

# 20. High throughput PHY specification for the 2.4 and 5 GHz bands

## 20.1 Overview

This clause specifies the PHY entity for a multiple input multiple output orthogonal frequency division multiplexing (MIMO-OFDM) system and the additions that have to be made to the base standard to accommodate the MIMO-OFDM PHY. The radio frequency LAN system is aimed for both the 2.4 GHz band and the 5 GHz bands, as specified in subclause 20.3.8.3

### 20.1.1 Introduction

The MIMO-OFDM system provides a wireless LAN with mandatory data payload communication capabilities of up to 135 Mbit/s and with optional modes capable of supporting data rates up to 540 Mbit/s. The MIMO-OFDM PHY draws from the basic OFDM PHY defined in Clause 17, and builds its extensions to two, three, and four transmit antenna modes (hereafter known as 2TX, 3TX, and 4TX, respectively), operating in 20 MHz bandwidth. Additionally, 1TX, 2TX, 3TX, and 4TX modes are also defined for operation in 40 MHz bandwidth.

### 20.1.2 Operational Modes

The radio portion of all Clause 20 compliant MIMO-OFDM PHY systems shall implement all mandatory and optional data rates defined in Clause 17, all mandatory data rates defined in Clause 19, and all optional data rates of the OFDM-based ERP defined in Clause 19, in their respective bands of operation. In addition, support for transmitting and receiving data using the MIMO-OFDM PHY defined in this Clause is mandatory for all rates specified for the 2TX, 20 MHz mode in subclause 20.3.2.2. Support for 3TX and 4TX modes in 20 MHz; 1TX, 2TX, 3TX, and 4TX modes in 40 MHz; and all modes defined in subclause 20.3.5.10 shall be optional.

Furthermore, the amendment extends the optional ‘half-clocked’ operation with 10 MHz channel spacings described in Section 17 and Annex J to high throughput modes. For each mode offered at 20 MHz channel spacing, a corresponding mode with half the data rate is offered with 10 MHz channel spacing. Support of the 27, 40.5, 54, 60.75, and 67.5 Mbps modes corresponding to the modes in Table 003 is mandatory when using 10 MHz channel spacing.

### 20.1.3 Scope

This subclause describes the PHY services provided to the IEEE 802.11 wireless LAN MAC by the MIMO-OFDM system. The MIMO-OFDM PHY layer consists of two protocol functions, defined as follows:

a) A PHY convergence function, which adapts the capabilities of the physical medium dependent (PMD) system to the PHY service. This function is supported by the physical layer convergence procedure (PLCP), which defines a method of mapping the IEEE 802.11 PHY sublayer service data units (PSDU) into a framing format suitable for sending and receiving user data and management information between two or more stations using the associated PMD system.

b) A PMD system whose function defines the characteristics and method of transmitting and receiving data through a wireless medium between two or more stations, each using the MIMO-OFDM PHY.

### 20.1.4 MIMO-OFDM PHY functions

The architecture of the MIMO-OFDM PHY is depicted in the ISO/IEC basic reference model shown in Figure 141 of 18.4.1. The MIMO-OFDM PHY contains three functional entities: the PMD function, the PHY convergence function (PLCP), and the layer management function.

The MIMO-OFDM PHY service is provided to the MAC through the PHY service primitives defined in Clause 12. Interoperability is addressed by use of the carrier sense mechanism specified in 9.2.1 and the protection mechanism in 9.10. This mechanism allows non-MIMO-OFDM stations to know of MIMO-OFDM traffic that they cannot demodulate so they may defer the medium to that traffic.

## 20.2 PHY-specific service parameter list

The architecture of the IEEE 802.11 MAC is intended to be PHY independent. Some PHY implementations require PHY-dependent MAC state machines running in the MAC sublayer in order to meet certain PMD requirements. The PHY-dependent MAC state machine resides in a sublayer defined as the MAC sublayer management entity (MLME). In certain PMD implementations, the MLME may need to interact with the PLME as part of the normal PHY SAP primitives. These interactions are defined by the PLME parameter list currently defined in the PHY service primitives as TXVECTOR and RXVECTOR. The list of these parameters, and the values they may represent, are defined in the specific PHY specifications for each PMD. This subclause addresses the TXVECTOR and RXVECTOR for the MIMO-OFDM PHY.

The parameters in Table 001 are defined as part of the TXVECTOR parameter list in the PHY-TXSTART.request service and PLME-TXTIME.request primitives.

**Table 001—TXVECTOR parameters**

| Parameter | Value |
|---|---|
| DATARATE | The rate used to transmit the PSDU in Mbit/s. Allowed value depends on the values of TRANSMISSION_MODE and NUM_STREAMS parameters<br><br>Values: 6.75, 10.125, 13.5, 20.25, 27, 40.5, 54, 60.75, 67.5, 81, 108, 121.5, 135, 162, 182.25, 202.5, 216, 243, 270, 324, 364.5, 405, 432, 486, 540 |
| LENGTH | The length of the PSDU in octets<br><br>Range: 1-8191 |
| TRANSMISSION_MODE | The mode used for transmission of the PPDU. Determines the preamble type used.<br><br>Enumerated type: 2TX20GF, 3TX20GF, 4TX20GF, 2TX20MM, 3TX20MM, 4TX20MM, 1TX40GF, 2TX40GF, 3TX40GF, 4TX40GF, 1TX40MM, 2TX40MM, 3TX40MM, 4TX40MM. |
| NUM_STREAMS | The number of independent spatial streams transmitted. |

| | |
|---|---|
| | Values: 1, 2, 3, 4. |
| CODE_TYPE | Convolutional or LDPC<br><br>Values: 0 (convolutional), 1 (LDPC) |
| SERVICE | The scrambler initialization vector.<br><br>16 null bits |
| TXPWR_LEVEL | The transmit power level. The definition of these levels is up to the implementer.<br><br>Range: 1-8 |
| LPI | Indicates that this is the last PSDU to be aggregated into the current PPDU<br><br>Values: true, false |
| BURST_ DURATION | The length in microseconds of the BURST_DURATION field in the mixed mode preamble. Only used when a mixed mode TRANSMISSION_MODE is selected.<br><br>Range: 0-4095 |

The parameters in Table 002 are defined as part of the RXVECTOR parameter list in the PHY-RXSTART.indicate service primitive. When implementations require the use of these vectors, some or all of these parameters may be used in the vectors.

**Table 002—RXVECTOR parameters**

| Parameter | Value |
|---|---|
| DATARATE | The rate at which the PSDU was received in Mbit/s. Allowed value depends on the values of TRANSMISSION_MODE and NUM_STREAMS parameters<br><br>Values: 6.75, 10.125, 13.5, 20.25, 27, 40.5, 54, 60.75, 67.5, 81, 108, 121.5, 135, 162, 182.25, 202.5, 216, 243, 270, 324, 364.5, 405, 432, 486, 540 |
| LENGTH | The length of the PSDU in octets.<br><br>Range: 1-8191 |
| TRANSMISSIO N_MODE | The transmission type detected during reception of the PPDU<br><br>Enumerated type: 2TX20GF, 3TX20GF, 4TX20GF, 2TX20MM, 3TX20MM, 4TX20MM, 1TX40GF, 2TX40GF, 3TX40GF, 4TX40GF, 1TX40MM, 2TX40MM, 3TX40MM, 4TX40MM. |
| NUM_STREAM S | The number of independent spatial streams transmitted.<br><br>Values: 1,2,3,4. |
| CODE_TYPE | Convolutional or LDPC<br><br>Values: 0 (convolutional), 1 (LDPC) |
| SERVICE | Null |
| RSSI | The RSSI is a measure of the RF energy received by the MIMO-OFDM PHY, averaged across all RX antennas. The 8-bit value is in the range of 0 to RSSI maximum as described in 17.2.3.2. |
| LPI | Indicates that this is the last PSDU to be aggregated into the current PPDU |

| | |
|---|---|
| | Values: true, false |
| BURST_ DURATION | The length in microseconds of the BURST_DURATION field in the mixed mode preamble. Only valid when a mixed mode TRANSMISSION_MODE is used.<br><br>Range: 0-4095 |

# 20.3 MIMO-OFDM PLCP sublayer

## 20.3.1 Introduction

This subclause provides a convergence procedure by which PSDUs are converted to and from PPDUs at the transmitter and receiver. During transmission, the PSDU shall be appended with a PLCP preamble and header to create the PPDU. At the receiver, the PLCP preamble and header are processed to aid in the demodulation and delivery of the PSDU.

Stations implementing the MIMO-OFDM PHY shall use one of two methods of access to the medium. The medium may be reserved solely via a MAC mechanism, as defined in subclause 9.13. Alternatively, a special PLCP frame format may be used to cause non-MIMO-OFDM stations to defer the medium to MIMO-OFDM traffic. Hereafter, these two methods of access shall be known as greenfield and mixed-mode, respectively.

## 20.3.2 PLCP frame format

Figure 001 shows the format of the PPDU used with greenfield access in the 1TX mode of operation in 40 MHz and the 2TX modes of operation in both 20 and 40 MHz. The PPDU consists of a MIMO-OFDM PLCP preamble, MIMO-OFDM PLCP header, PSDU, and may consist of appended tail bits and pad bits.

The MIMO-OFDM PLCP preamble is composed of a sequence of short and long training symbols. The format of the PLCP preamble is defined in subclause 20.3.3 for each mode of operation in the MIMO-OFDM PHY.

The MIMO-OFDM PLCP header is composed of the SIGNAL-N field and the SERVICE field. The SIGNAL-N field is defined in 20.3.4 and consists of 54 bits that specify all configuration and length-related parameters associated with PPDU transmission. The SERVICE field is composed of 16 bits and is defined in subclause 20.3.5.1.

The SERVICE field of the PLCP header and the PSDU (with tail and pad bits appended, if necessary) are denoted as DATA and may constitute multiple MIMO-OFDM symbols. These symbols are transmitted according to the configuration parameters specified in the SIGNAL-N field.

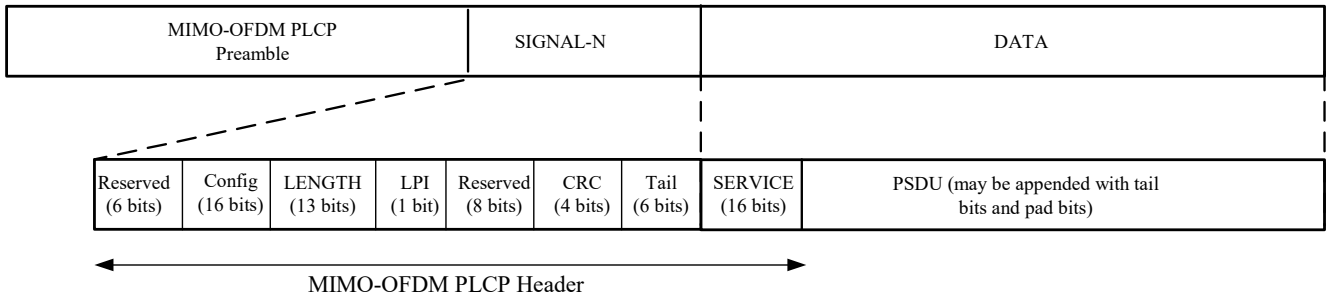



**Figure 001 – PPDU frame format: Greenfield access in the 1TX (40 MHz) and 2TX (20 and 40 MHz) modes**

Figure 002 shows the format of the PPDU used with greenfield access in the 3TX and 4TX modes of operation in both 20 and 40 MHz. In these modes the MIMO-OFDM PLCP preamble field is extended according to subclause 20.3.3 in order to provide training from the additional transmit antennas.

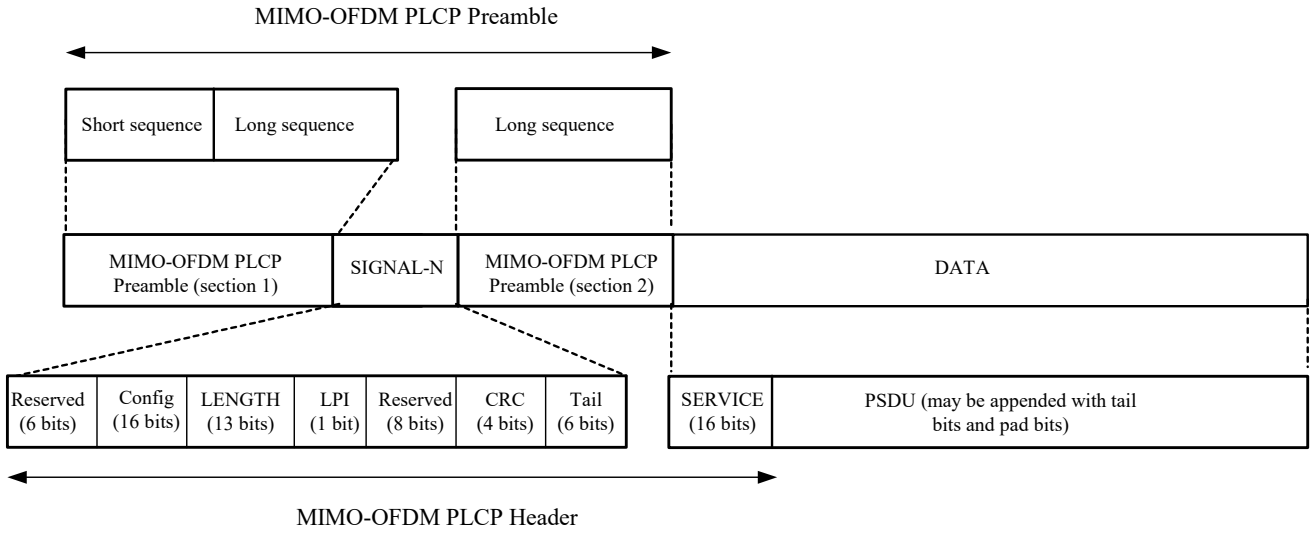



**Figure 002 – PPDU frame format: Greenfield access in the 3TX and 4TX modes (20 and 40 MHz)**

Figure 003 shows the format of the PPDU used with mixed-mode access in the 1TX mode of operation in 40 MHz and the 2TX modes of operation in both 20 and 40 MHz. The PLCP header in these modes consists of an additional SIGNAL-MM field that conveys information about the MIMO-OFDM PPDU transmission to non-MIMO-OFDM stations, causing them to defer the medium for the duration of the MIMO-OFDM transmission. The SIGNAL-MM field is defined in subclause 20.3.4.

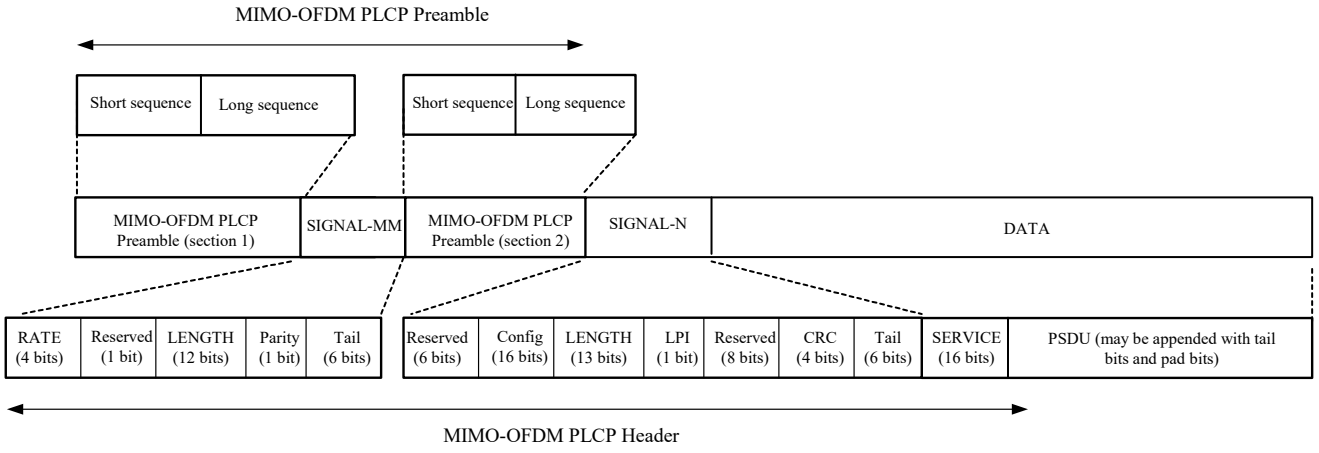



**Figure 003 – PPDU frame format: Mixed mode access in the 1TX (40 MHz) and 2TX (20 and 40 MHz) modes**

Figures 004 and 005 shows the format of the PPDU used with mixed mode access in the 3TX and 4TX modes, operating in 20 MHz and 40 MHz, respectively.

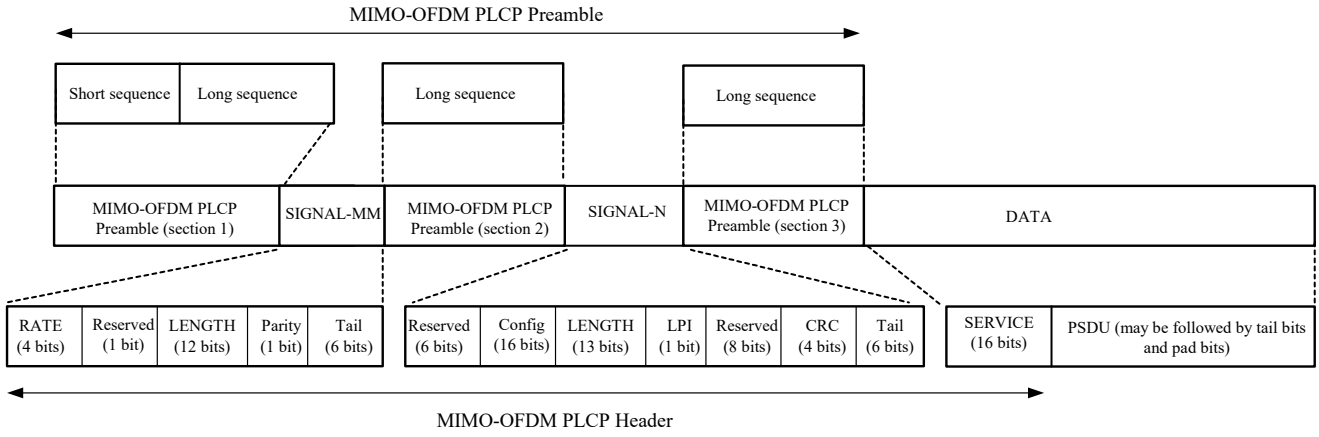



**Figure 004– PPDU frame format: Mixed mode access in the 3TX and 4TX modes (20 MHz)**

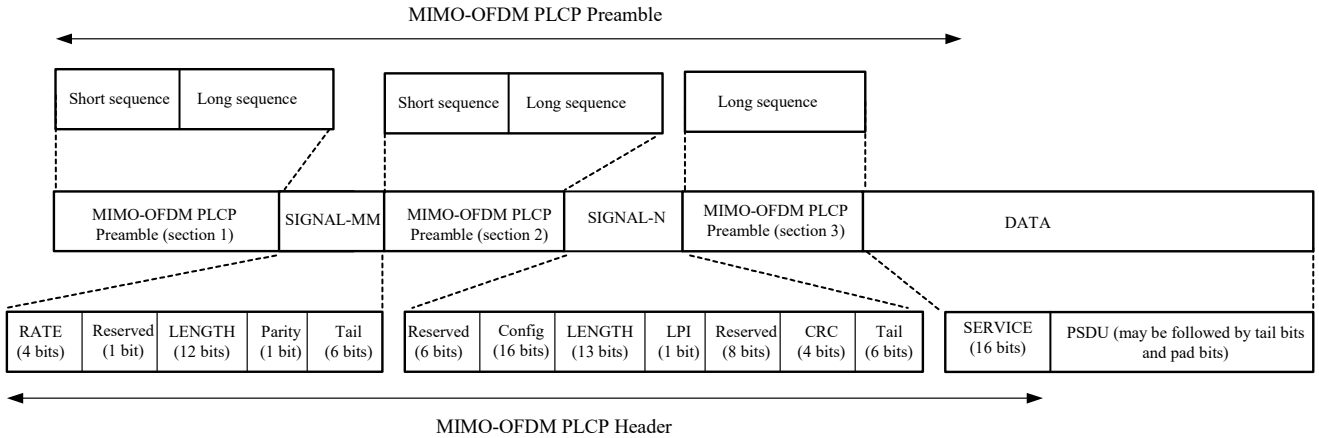



**Figure 005– PPDU frame format: Mixed mode access in the 3TX and 4TX modes (40 MHz)**

#### 20.3.2.1 Overview of the PPDU encoding process

The encoding process is composed of many detailed steps, which are described fully in later subclauses, as noted below. The following overview intends to facilitate understanding the details described in these subclauses:

a) Produce the PLCP preamble fields for each transmit antenna based on the TRANSMISSION_MODE field of the TXVECTOR. Refer to 20.3.3 for details.

b) Produce the PLCP header field from the LENGTH, DATARATE, TRANSMISSION_MODE, NUM_STREAMS, CODE_TYPE, and SERVICE fields of the TXVECTOR by filling the appropriate bit fields, as described in subclause 20.3.4 and subclause 20.3.5.1.

c) Calculate from the DATARATE, TRANSMISSION_MODE, and NUM_STREAMS fields of the TXVECTOR, the number of data bits per MIMO-OFDM symbol ($N_{DBPS}$), the code rate (R), the number of bits in each OFDM subcarrier per antenna ($N_{BPSC}$), the number of coded bits per MIMO-OFDM symbol ($N_{CBPS}$), the number of spatial streams ($N_{SS}$), and the number of encoding streams ($N_{ES}$).

d) Extend the data bit string with "zero" bits (at least 6 bits for each encoding stream) so that the resulting length will be a multiple of the number of data bits per OFDM symbol ($N_{DBPS}$).

e) Initiate the scrambler with a pseudorandom non-zero state; generate a sequence of scrambled data bits as defined in subclause 20.3.5.4.

f) Demultiplex every other bit of the "data" to the $N_{ES}$ encoding streams, with bit 0 directed to the first encoder.

g) Replace the six scrambled "zero" bits following the "data" of each parallel encoding stream with six nonscrambled "zero" bits (These bits return the convolutional encoder to the "zero state" and are denoted as "tail bits.").

h) Encode each extended, scrambled parallel encoding stream data string with a convolutional encoder (R = 1/2). Omit (puncture) some of the encoder output string (chosen according to "puncturing pattern") to reach the desired "code rate", as defined in subclause 20.3.5.5.

i) Divide the parallel encoded bit strings into groups of $N_{CBPS} / N_{ES}$ bits and multiplex them alternately between the $N_{ES}$ encoders' outputs to obtain a single aggregated bit string.

j) Divide the aggregated bit string into groups of $N_{CBPS}$ bits. Within each group, perform an "interleaving" (reordering) of the bits according to the rule specified in subclause 20.3.5.6. The interleaving parameters are independent of $N_{ES}$.

k) Divide the resulting coded and interleaved data string into groups of $N_{BPSC}$ bits. For each of the bit groups, convert the bit group into a complex number according to the modulation encoding tables.

l) Divide the complex number string into groups of $N_{SD} \times N_{SS}$ complex numbers, where $N_{SD}$ is the number of data subcarriers per OFDM symbol, and $N_{SS}$ is the number of spatial streams to be transmitted. Map the complex numbers to antennas and subcarriers, as specified in subclause 20.3.5.8. The first $N_{SD}$ complex numbers are modulated on the subcarriers of the first transmit antenna.

m) Insert $N_{SP}$ subcarriers as pilots on each transmit antenna, according to subclause 20.3.5.9.

n) For each group of subcarriers, and on each TX antenna, convert the subcarriers to time domain using inverse Fourier transform. Prepend to the Fourier-transformed waveform a circular extension of itself thus forming a

guard interval (GI), and truncate the resulting periodic waveform to a single OFDM symbol length by applying time domain windowing. Refer to 20.3.2.4 for details.

o) Append the OFDM symbols for each antenna one after another, starting with the SIGNAL symbols defined in subclause 20.3.4, and with fields of the PLCP preamble inserted in between if necessary. Refer to 20.3.3 for details.

p) Up-convert the resulting "complex baseband" waveform on each antenna to an RF frequency according to the center frequency of the desired channel and transmit. Refer to 20.3.2.4 and 20.3.8.1 for details.

#### 20.3.2.2 RATE-dependent parameters

When the number of transmitted spatial streams $N_{SS}$ is equal to the number of transmit antennas $N_{TX}$, the RATE-dependent modulation parameters shall be set according to the values defined in Tables 003, 004, and 005 respectively for the 2TX, 3TX, and 4TX modes in 20 MHz. The RATE-dependent parameters for the 1TX, 2TX, 3TX, and 4TX modes in 40 MHz shall be set according to the values defined in Tables 006, 007, 008, and 009, respectively.

The number of parallel encoding streams $N_{ES}$ shall be 2 for all modes in 40 MHz in which the number of spatial streams $N_{SS}$ is greater than two. $N_{ES}$ shall be 1 for all other modes.

**Table 003—Rate-dependent parameters for 20 MHz, $N_{SS}$ = 2 ($N_{ES}$ = 1)**

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data subcarriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 54 | 16-QAM | 1/2 | 4 | 54 | 2 | 432 | 216 | 73 |
| 81 | 16-QAM | 3/4 | 4 | 54 | 2 | 432 | 324 | 74 |
| 108 | 64-QAM | 2/3 | 6 | 54 | 2 | 648 | 432 | 75 |
| 121.5 | 64-QAM | 3/4 | 6 | 54 | 2 | 648 | 486 | 76 |
| 135 | 64-QAM | 5/6 | 6 | 54 | 2 | 648 | 540 | 77 |

**Table 004—Rate-dependent parameters for 20 MHz, $N_{SS}$ = 3 ($N_{ES}$ = 1)**

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data subcarriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 81 | 16-QAM | 1/2 | 4 | 54 | 2 | 648 | 324 | 78 |
| 121.5 | 16-QAM | 3/4 | 4 | 54 | 2 | 648 | 486 | 79 |
| 162 | 64-QAM | 2/3 | 6 | 54 | 2 | 972 | 648 | 80 |
| 182.25 | 64-QAM | 3/4 | 6 | 54 | 2 | 972 | 729 | 81 |
| 202.5 | 64-QAM | 5/6 | 6 | 54 | 2 | 972 | 810 | 82 |

**Table 005—Rate-dependent parameters for 20 MHz, $N_{SS}$ = 4 ($N_{ES}$ = 1)**

| Data rate (Mbits/s | Modulation | Code rate (R) | Coded bits per subcarrier | Number of data subcarrier | Number of pilots | Coded bits per MIMO- | Data bits per MIMO- | Clause 10.4.4.2 rate |
|---|---|---|---|---|---|---|---|---|

| ) | | | per antenna ($N_{BPSC}$ ) | s ($N_{SD}$ ) | ($N_{SP}$ ) | OFDM symbol ($N_{CBPS}$ ) | OFDM symbol ($N_{DBPS}$ ) | code |
|---|---|---|---|---|---|---|---|---|
| 108 | 16-QAM | 1/2 | 4 | 54 | 2 | 864 | 432 | 83 |
| 162 | 16-QAM | 3/4 | 4 | 54 | 2 | 864 | 648 | 84 |
| 216 | 64-QAM | 2/3 | 6 | 54 | 2 | 1296 | 864 | 85 |
| 243 | 64-QAM | 3/4 | 6 | 54 | 2 | 1296 | 972 | 86 |
| 270 | 64-QAM | 5/6 | 6 | 54 | 2 | 1296 | 1080 | 87 |

**Table 006—Rate-dependent parameters for 40 MHz, $N_{SS}$ = 1 ($N_{ES}$ = 1)**

| Data rate (Mbits/s ) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$ ) | Number of data subcarriers ($N_{SD}$ ) | Number of pilots ($N_{SP}$ ) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$ ) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$ ) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 13.5 | BPSK | 1/2 | 1 | 108 | 4 | 108 | 54 | 88 |
| 20.25 | BPSK | 3/4 | 1 | 108 | 4 | 108 | 81 | 89 |
| 27 | QPSK | 1/2 | 2 | 108 | 4 | 216 | 108 | 90 |
| 40.5 | QPSK | 3/4 | 2 | 108 | 4 | 216 | 162 | 91 |
| 54 | 16-QAM | 1/2 | 4 | 108 | 4 | 432 | 216 | 92 |
| 81 | 16-QAM | 3/4 | 4 | 108 | 4 | 432 | 324 | 93 |
| 108 | 64-QAM | 2/3 | 6 | 108 | 4 | 648 | 432 | 94 |
| 121.5 | 64-QAM | 3/4 | 6 | 108 | 4 | 648 | 486 | 95 |
| 135 | 64-QAM | 5/6 | 6 | 108 | 4 | 648 | 540 | 97 |

**Table 007—Rate-dependent parameters for 40 MHz, $N_{SS}$ = 2 ($N_{ES}$ = 1)**

| Data rate (Mbits/s ) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$ ) | Number of data subcarriers ($N_{SD}$ ) | Number of pilots ($N_{SP}$ ) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$ ) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$ ) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 108 | 16-QAM | 1/2 | 4 | 108 | 4 | 864 | 432 | 98 |
| 162 | 16-QAM | 3/4 | 4 | 108 | 4 | 864 | 648 | 99 |
| 216 | 64-QAM | 2/3 | 6 | 108 | 4 | 1296 | 864 | 100 |
| 243 | 64-QAM | 3/4 | 6 | 108 | 4 | 1296 | 972 | 101 |
| 270 | 64-QAM | 5/6 | 6 | 108 | 4 | 1296 | 1080 | 102 |

**Table 008—Rate-dependent parameters for 40 MHz, $N_{SS}$ = 3 ($N_{ES}$ = 2)**

| Data rate (Mbits/s ) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$ ) | Number of data subcarriers ($N_{SD}$ ) | Number of pilots ($N_{SP}$ ) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$ ) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$ ) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 162 | 16-QAM | 1/2 | 4 | 108 | 4 | 1296 | 648 | 103 |
| 243 | 16-QAM | 3/4 | 4 | 108 | 4 | 1296 | 972 | 104 |
| 324 | 64-QAM | 2/3 | 6 | 108 | 4 | 1944 | 1296 | 105 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 364.5 | 64-QAM | 3/4 | 6 | 108 | 4 | 1944 | 1458 | 106 |
| 405 | 64-QAM | 5/6 | 6 | 108 | 4 | 1944 | 1620 | 107 |

**Table 009—Rate-dependent parameters for 40 MHz, $N_{SS}$ = 4 ($N_{ES}$ = 2)**

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data subcarriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 216 | 16-QAM | 1/2 | 4 | 108 | 4 | 1728 | 864 | 109 |
| 324 | 16-QAM | 3/4 | 4 | 108 | 4 | 1728 | 1296 | 110 |
| 432 | 64-QAM | 2/3 | 6 | 108 | 4 | 2592 | 1728 | 111 |
| 486 | 64-QAM | 3/4 | 6 | 108 | 4 | 2592 | 1944 | 112 |
| 540 | 64-QAM | 5/6 | 6 | 108 | 4 | 2592 | 2160 | 113 |

### 20.3.2.3 Timing related parameters

Table 010 is a list of timing parameters associated with the MIMO-OFDM PLCP.

**Table 010—Timing-related parameters**

| Parameter | Value (20 MHz modes) | Value (40 MHz modes) | Remarks |
|---|---|---|---|
| $N_{SD}$ : Number of data subcarriers | 54 | 108 | |
| $N_{SP}$ : Number of pilot subcarriers | 2 | 4 | |
| $N_{ST}$ : Number of subcarriers, total | 56 | 112 | $N_{ST} = N_{SD} + N_{SP}$ |
| $N_{OT}$: Index of outermost populated subcarrier | 28 | 58 | |
| $N_{TX}$: Number of transmit antennas | 2,3,4 | 1,2,3,4 | |
| $\Delta_F$: Subcarrier frequency spacing | 0.3125 MHz | 0.3125 MHz | $\Delta_F$ = 20/64 = 40/128 MHz |
| $T_{FFT}$ : IFFT/FFT period | 3.2 μs | 3.2 μs | $T_{FFT} = 1/\Delta_F$ |
| $T_{GI}$ : GI duration | 0.8 μs | 0.8 μs | ($T_{FFT}$ /4) |
| $T_{GI2}$ : Training symbol guard duration | 1.6 μs | 1.6 μs | |
| $T_{SYM}$ : Symbol interval | 4 μs | 4 μs | ($T_{GI} + T_{FFT}$ ) |

### 20.3.2.4 Mathematical conventions in the signal descriptions

The transmitted signal will be described in a complex baseband signal notation. The RF (radio frequency) signal issued from the antenna is related to the complex baseband signal by the following relation:

$$r_{RF}(t) = \mathrm{Re}\{r(t)\exp(j2\pi f_c t)\} \quad (1)$$

where Re(.) represents the real part of the complex argument, and $f_c$ denotes the carrier frequency. The actual RF signal over the air is the sum of RF signals emanated from each transmit antenna.

The transmitted baseband signal from any antenna is composed of contributions from several OFDM symbols, including preamble, signal, and data. Each symbol is constructed as an inverse Fourier transform of a set of coefficients $C_k$, with $C_k$ defined later as data, pilots, or training symbols in subclause 20.3.3 through 20.3.5:

$$r_{SYMBOL}(t) = w_{SYMBOL}(t) \sum_{k=-N_{OT}}^{N_{OT}} C_k \exp\left(j2\pi k\Delta_F \left(t - T_{GUARD}\right)\right). \quad (2)$$

The parameters $\Delta_F$ and $N_{OT}$ are defined in Table 010. The resulting waveform is periodic with a period of $T_{FFT} = 1/\Delta_F$. Shifting the time by $T_{GUARD}$ creates the "cyclic prefix" used in OFDM to avoid ISI from the previous symbol. Three kinds of $T_{GUARD}$ are defined: for the short training sequence (= 0μs), for the long training sequence (=$T_{GI2}$), and for data OFDM symbols (=$T_{GI}$). Informative considerations related to the windowing function $w_{SYMBOL}(t)$ and other implementation aspects, as specified in subclause 17.3.2.4, may also apply on a per-antenna basis in the MIMO-OFDM PHY.

The common way to implement the inverse Fourier transform, as shown in Equation (2), is by an inverse Fast Fourier Transform (IFFT) algorithm. If, for example, a 128-point IFFT is used to implement the 40 MHz transmission modes, the coefficients 3 to 58 are mapped to the same numbered IFFT inputs, while the coefficients -58 to -3 are copied into IFFT inputs 70 to 125. The rest of the inputs, 59 to 69, 1, 2, 126, 127, as well as the 0 (dc) input, shall be set to zero. This mapping is illustrated in Figure 006. After performing an IFFT, the output is cyclically extended to the desired length.

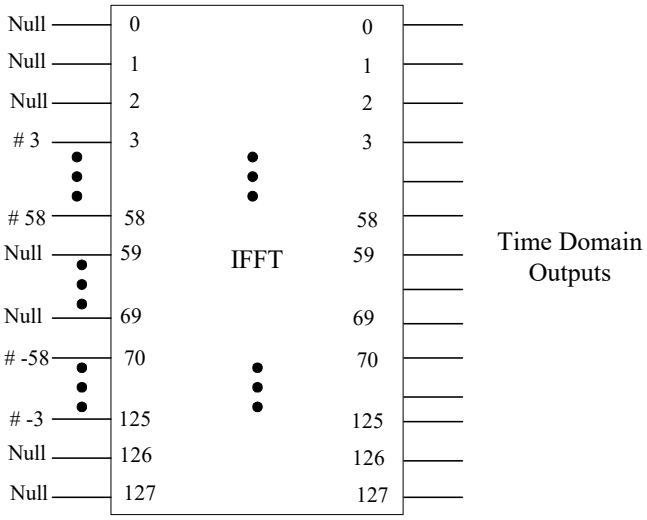



**Figure 006– Inputs and outputs of 128-point IDFT for 40 MHz data transmission**

### 20.3.3 PLCP preamble (SYNC)

The PLCP preamble field is used for synchronization. It consists of a sequence of short symbols and long symbols that are transmitted simultaneously from all transmit antennas, as described in this subclause.

Figure 007 shows the PLCP preamble format for greenfield 2TX mode in 20 MHz. The PLCP preamble is followed in this mode by the SIGNAL-N field and DATA. The total duration of the training symbols is 16 μsec. The short MIMO-OFDM training sequence transmitted from the first antenna consists of 12 subcarriers, which are modulated by elements of the sequence $SS_{20}$, given by

$SS_{20}[-28,28] = \sqrt{7/3} \times$ {0, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, –1–j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 0}. (3)

The second antenna transmits a cyclically shifted version of the sequence transmitted from the first antenna, such that the first sample of the short sequence transmitted from the first antenna is the sample that is transmitted 400 nsec after the start of the short sequence on the second antenna. This is denoted by "(400 ns cs)" in Figure 007. More generally, an indicator "S ($t_0$ ns cs)" in Figures 007 through 016 denotes that the transmitted sequence $r'(t)$ is obtained by cyclically shifting by $t_0$ nsec, the time-domain sequence $r(t)$ corresponding to frequency domain sequence S:

$$r'(t) = r(t - t_0 \text{ ns}). \quad (4)$$

The indicator "GI" or "GI2" in these figures denotes respectively the last $T_{GI}$ or $T_{GI2}$ duration of waveform of the immediately ensuing OFDM symbol, prepended to the OFDM symbol as a guard interval.

The short sequence is followed by a long OFDM training sequence which is generated by modulating the elements of the sequence

$LS_{20}[-28..28]$ = {1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 0, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, -1, -1}
(5)

according to the equation

$$r_{LONG}(t) = w_{TLONG}(t) \sum_{k=-N_{ST}/2}^{N_{ST}/2} LS_{20}[k] \exp\left(j2\pi k\Delta_F \left(t - T_{GI2}\right)\right), \quad (6)$$

where $T_{GI2}$ = 1.6 μsec. Two periods of the long symbol are transmitted for improved channel estimation accuracy. The long training sequence is also transmitted simultaneously from both antennas. The second antenna transmits a 1600 nsec cyclically shifted version of the long training symbols transmitted from the first antenna.

The PLCP preamble format for 2TX mixed-mode operation in 20 MHz is shown in Figure 008. The definition of the long and short sequences, as well as relative cyclic shifts between transmit antennas in this mode shall follow the description provided in Figure 008. The first and second TX antennas simultaneously transmit the first and second rows respectively of the MIMO-OFDM training structure shown in the figure.

Figure 009 and 010 define the PLCP preamble format for the 3TX and 4TX modes in 20 MHz, with greenfield access and mixed-mode access respectively. In the 3TX modes, only the first three rows shown in the corresponding MIMO-OFDM training structure are transmitted.

Figures 011, 013, and 015 show the PLCP preamble format for the 1TX, 2 TX, and 3TX/4TX greenfield modes in 40 MHz. The short sequence in these modes are obtained by modulating the elements of the sequence

$SS_{40GF}[-58,58] = \sqrt{2} \times$ {0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0}
(7)

on the subcarriers of the OFDM signal. The ensuing long sequence for 40 MHz greenfield operation is defined by the sequence

$LS_{40GF}[-58..58]$ = {1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, -1, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, -1, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1,

1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1} (8)

The mixed mode training structures for 1TX, 2TX, and 3TX/4TX modes in 40 MHz are defined in Figure 012, 014, and 016 respectively. The additional short and long sequences used in these modes are defined by the following frequency domain sequences:

$SS_{40MM}[-58..58] = \sqrt{7/3} \times$ {0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0} (9)

$LS_{40MM}[-58..58]$ = {1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 0, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, -1, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 0, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1}. (10)

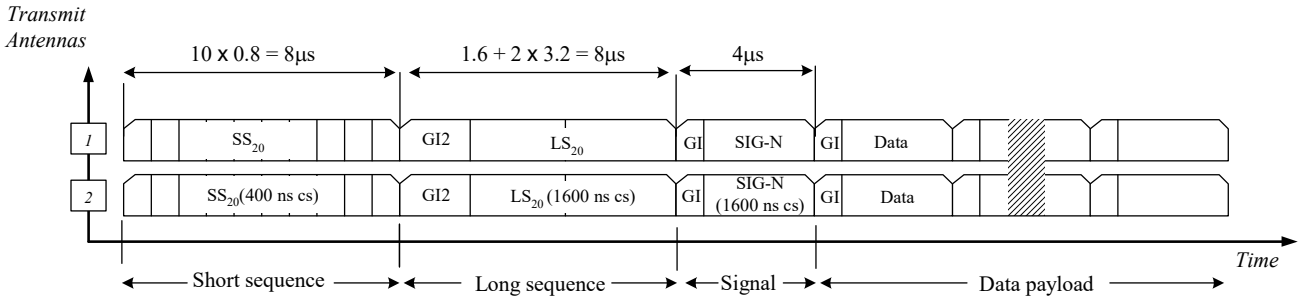



**Figure 007 – MIMO-OFDM Training structure for $N_{TX}$ = 2, 20 MHz, greenfield operation**

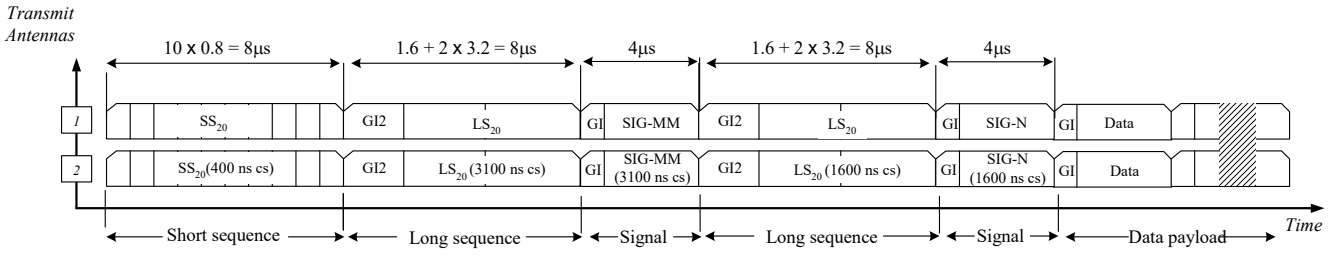



**Figure 008 – MIMO-OFDM Training structure for $N_{TX}$ = 2, 20 MHz, mixed mode operation**

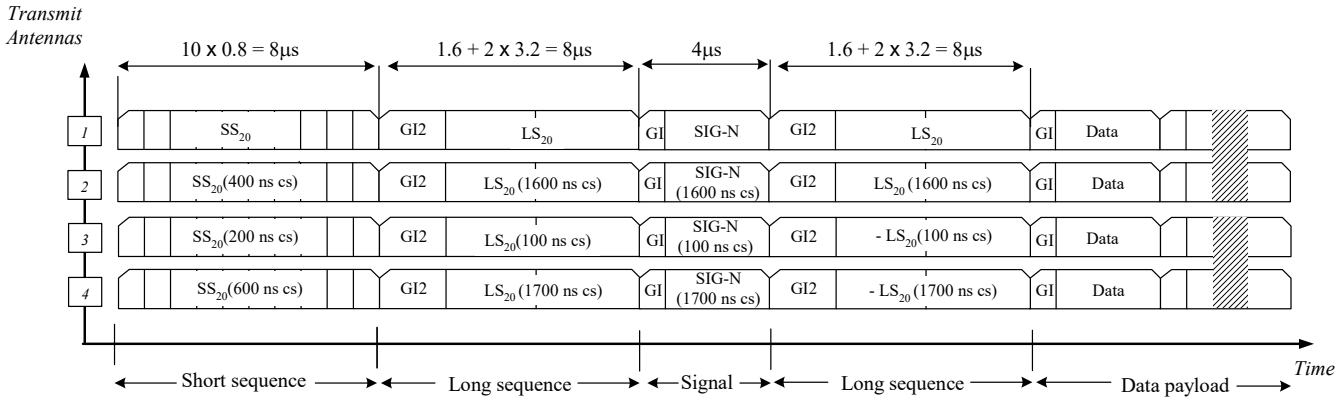



**Figure 009 – MIMO-OFDM Training structure for $N_{TX}$ = 3 and 4, 20 MHz, greenfield operation**

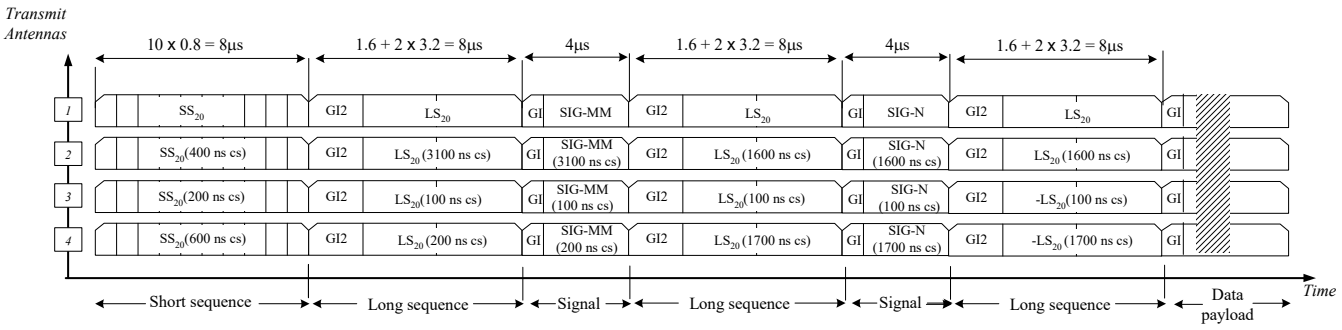



**Figure 010 – MIMO-OFDM Training structure for $N_{TX}$ = 3, 4, 20 MHz, mixed mode operation**

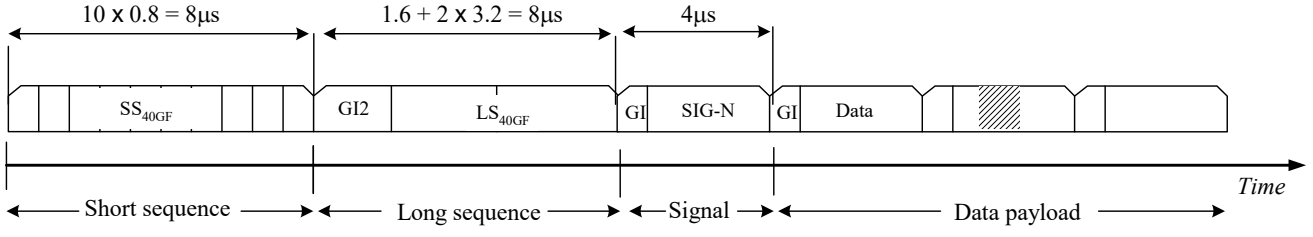



**Figure 011 – MIMO-OFDM Training structure for $N_{TX}$=1, 40 MHz, greenfield operation**

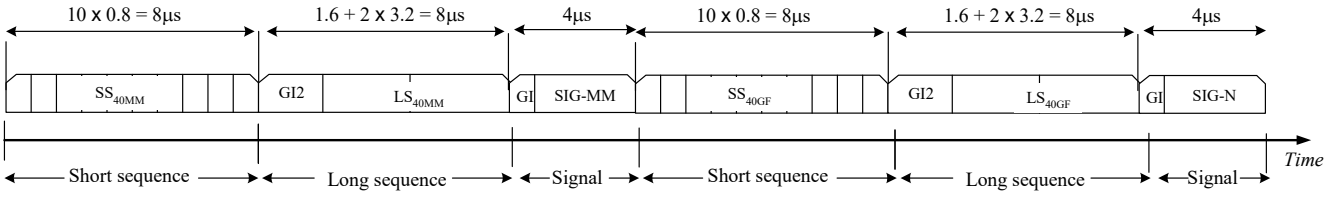



**Figure 012 – MIMO-OFDM Training structure for $N_{TX}$=1, 40 MHz, mixed mode operation**

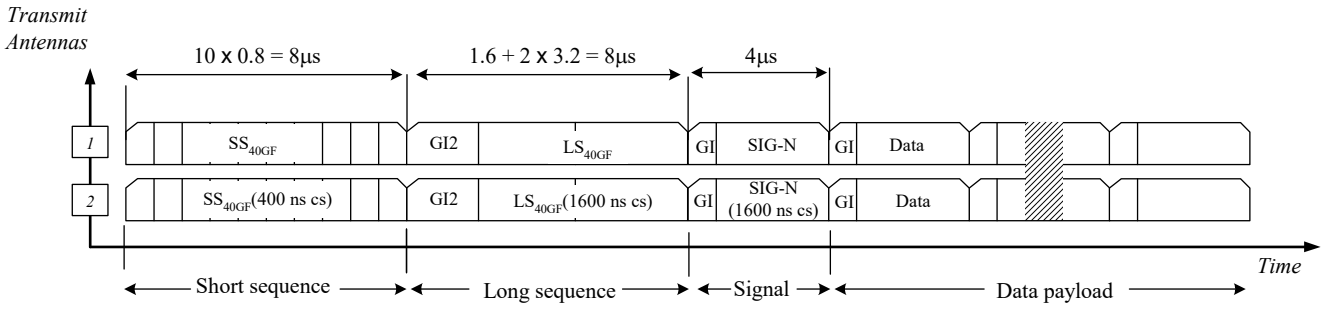



**Figure 013 – MIMO-OFDM Training structure for $N_{TX}$ = 2, 40 MHz, greenfield operation**

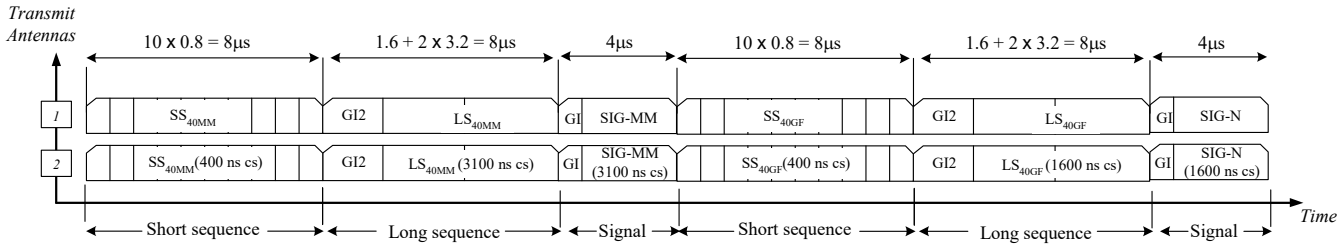



**Figure 014 – MIMO-OFDM Training structure for $N_{TX}$ = 2, 40 MHz, mixed mode operation**

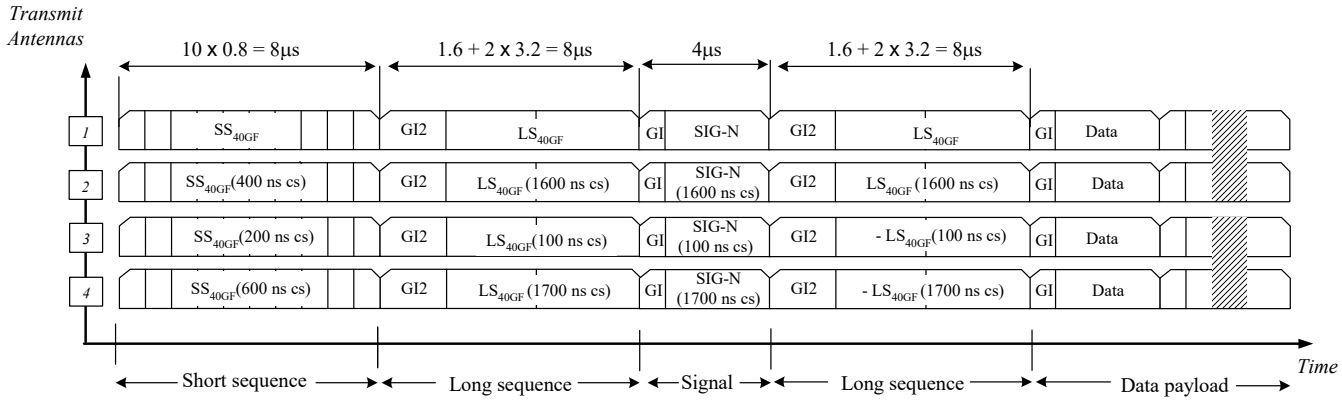



**Figure 015 – MIMO-OFDM Training structure for $N_{TX}$ = 3 and 4, 40 MHz, greenfield operation**

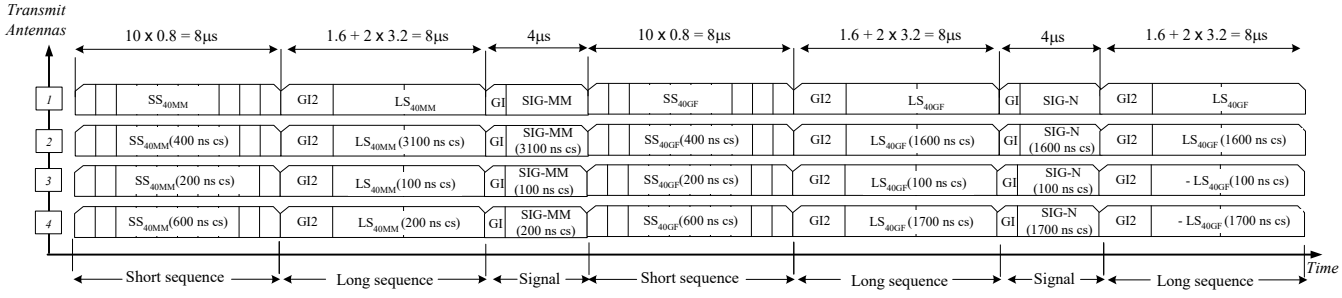



**Figure 016 – MIMO-OFDM Training structure for $N_{TX}$ = 3, 4, 40 MHz, mixed mode operation**

### 20.3.4 Signal fields (SIG-N and SIG-MM)

The SIGNAL-N field (SIG-N) is composed of a single MIMO-OFDM symbol that provides all length and configuration parameters associated with a MIMO-OFDM PPDU. The SIGNAL-N field is composed of 54 bits, which shall be interpreted according to the bit assignment specified in Figure 017 and Table 011.

**Table 011—SIG-N field bit assignment**

| Bits | Field | Subfield | Parameter | Values |
|---|---|---|---|---|
| b0 : b5 | RSVD | | Reserved bits | 111111, Bits shall be ignored at the receiver |

| | | | | |
|---|---|---|---|---|
| b6 : b21 | CONFIG | | Configuration | |
| b6: b8 | | NSS | Number of spatial streams | 000: 1, 001: 2, 010: 3, 011: 4 |
| b9 : b11 | | NTX | Number of transmit antennas | 000: 1, 001: 2, 010: 3, 011: 4 |
| b12 : b13 | | BW | Bandwidth | 00: 20 MHz, 01: 40 MHz |
| b14: b16 | | R | Code rate | 000: 1/2, 001: 2/3, 010: 3/4, 011: 5/6 |
| b17 : b18 | | CT | ECC type | 00 : convolutional, 01 : LDPC |
| b19 : b21 | | CON | Constellation type | 000: BPSK, 001: QPSK, 010: 16-QAM, 011: 64-QAM |
| b22 : b34 | LEN | | Length | Number of bytes in the payload |
| b35 | LPI | | Last PSDU indicator | 1 indicates that this is the last PSDU to be aggregated into the current PPDU |
| b36 : b43 | RSVD | | Reserved | 00000000, Bits shall be ignored at the receiver |
| b44 : b47 | CRC | | Cyclic Redundancy Check | CRC calculated on bits 0-43 using generator polynomial $x^4+x+1$ |
| b48 : b53 | TAIL | | | 000000 |

In all 20 MHz modes, the encoding of the single SIG-N MIMO-OFDM symbol shall be performed with QPSK modulation of the subcarriers of the first antenna and shall use convolutional coding at R = 1/2. In all 40 MHz modes, the encoding of the single SIG-N MIMO-OFDM symbol shall be performed with BPSK modulation of the subcarriers of the first antenna and shall use using convolutional coding at R = 1/2. The contents of the SIG-N field are not scrambled.

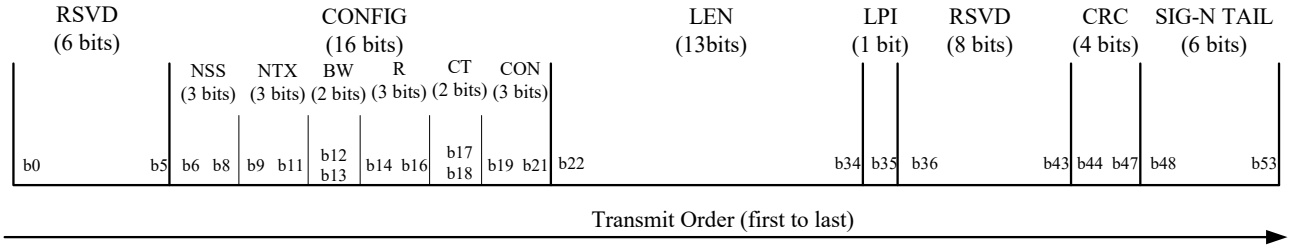



**Figure 017 – SIG-N field bit assignment**

The SIG-N MIMO-OFDM symbol is transmitted simultaneously from all TX antennas in all modes, with the same values of relative cyclic shift between antennas as are used to transmit the long training symbol preceding the SIG-N symbol. The value of the cyclic shift in each operating mode is specified in Figures 007 through 016 in subclause 20.3.3.

With mixed-mode access, another symbol, denoted as SIGNAL-MM (SIG-MM) is sent in the PLCP header. The SIG-MM field is encoded and transmitted from the first antenna as per IEEE 802.11a-1999 subclause 17.3.4. The remaining antennas simultaneously transmit the same OFDM symbol, with relative cyclic shifts defined in subclause 20.3.3. The reserved bit in the SIG-MM field shall be set to signal a MIMO-OFDM PPDU transmission. The duration for which the medium will be used by the MIMO-OFDM PPDU transmission is signaled to non MIMO-OFDM stations via the LENGTH and RATE fields of the SIG-MM symbol.

In 40 MHz mixed-mode operation, the SIG-MM field shall be transmitted such that it can be decoded by non-MIMO-OFDM stations operating in either the upper or the lower 20 MHz band.

### 20.3.5 DATA field

The DATA field contains the SERVICE field, the PSDU, the TAIL bits, and the PAD bits, if needed, as described in 20.3.5.2 and 20.3.5.4. All bits in the DATA field except the TAIL bits are scrambled, as described in 20.3.5.4.

#### 20.3.5.1 Service field (SERVICE)

The IEEE 802.11 SERVICE field has 16 bits, which shall be denoted as bits 0-15. The bit 0 shall be transmitted first in time. The bits 0-6 of the SERVICE field, which are transmitted first, are set to zeros and are used to synchronize the descrambler in the receiver. The remaining 9 bits (7-15) of the SERVICE field shall be reserved for future use. All reserved bits shall be set to zero. Refer to Figure 112, IEEE 802.11a-1999 subclause 17.3.5.1.

#### 20.3.5.2 PPDU tail bits

The PPDU tail bits shall follow IEEE 802.11a-1999 subclause 17.3.5.2.

#### 20.3.5.3 PAD bits

The number of bits in the DATA field shall be a multiple of $N_{CBPS}$, the number of coded bits in an OFDM symbol. To achieve that, the length of the message is extended so that it becomes a multiple of $N_{DBPS}$, the number of data bits per OFDM symbol. At least 6 bits per encoding stream ($N_{ES}$) are appended to the message, in order to accommodate the TAIL bits, as described in 20.3.5.2. The number of MIMO-OFDM symbols, $N_{SYM}$; the number of bits in the DATA field, $N_{DATA}$; and the number of pad bits, $N_{PAD}$, are computed from the length of the PSDU (LENGTH) as follows:

$$N_{SYM} = \text{Ceiling}\left((16 + 8 \times \text{LENGTH} + 6 \times N_{ES})/N_{DBPS}\right) \quad (11)$$

$$N_{DATA} = N_{SYM} \times N_{DBPS} \quad (12)$$

$$N_{PAD} = N_{DATA} - (16 + 8 \times \text{LENGTH} + 6 \times N_{ES}) \quad (13)$$

The appended bits ("pad bits") are set to "zeros" and are subsequently scrambled with the rest of the bits in the DATA field.

#### 20.3.5.4 PLCP data scrambler and descrambler

The PPDU data scrambler and descrambler shall follow IEEE 802.11a-1999 subclause 17.3.5.4.

#### 20.3.5.5 Convolutional encoder

The DATA field, composed of SERVICE, PSDU, tail, and pad parts, shall be coded with a convolutional encoder that conforms to IEEE 802.11a-1999 subclause 17.3.5.5 for code rates of R = 1/2, 2/3, and 3/4. Additionally, the code rate of R = 5/6 shall be implemented according to the puncturing pattern illustrated in Figure 018.

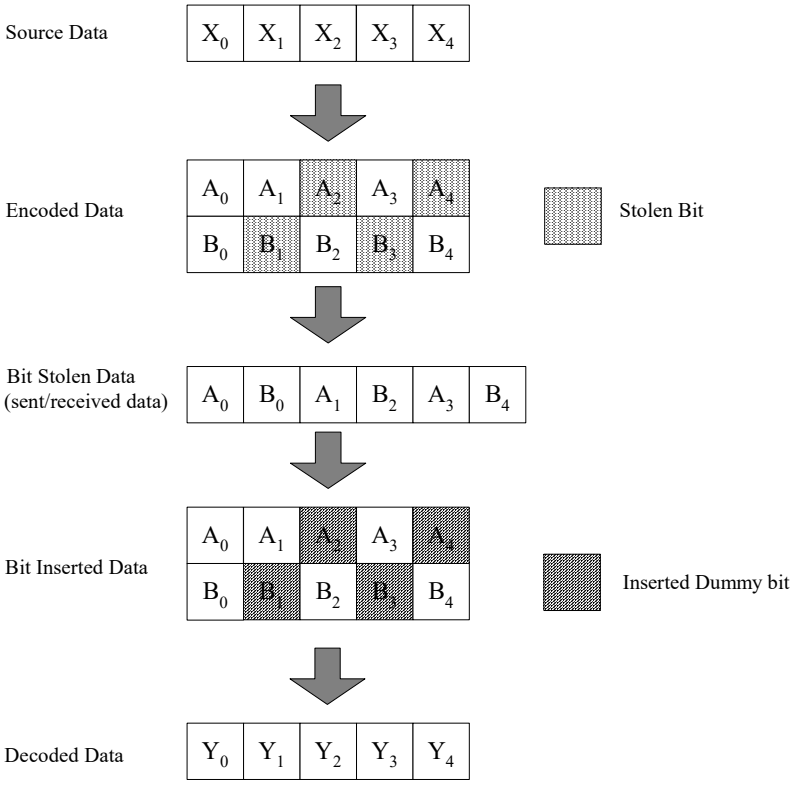


**Figure 018 – An illustration of the bit stealing and bit insertion procedure for R = 5/6**

### 20.3.5.6 Interleaver

All encoded bits shall be interleaved by a block interleaver with a block size equal to the number of bits in a single MIMO-OFDM symbol, $N_{CBPS}$. The interleaver is defined by the following series of permutations.

We shall denote by $k$ the index of the coded bits before interleaving, $k = 0, 1 \ldots N_{CBPS}-1$. $n = 0, 1 \ldots N_{SS}-1$ denotes the index of the spatial streams. The bits are first distributed across spatial streams by inputting the bit with index $k_n \times N_{SS} + n$ into the $n$th spatial stream. This is illustrated in Figure 019.

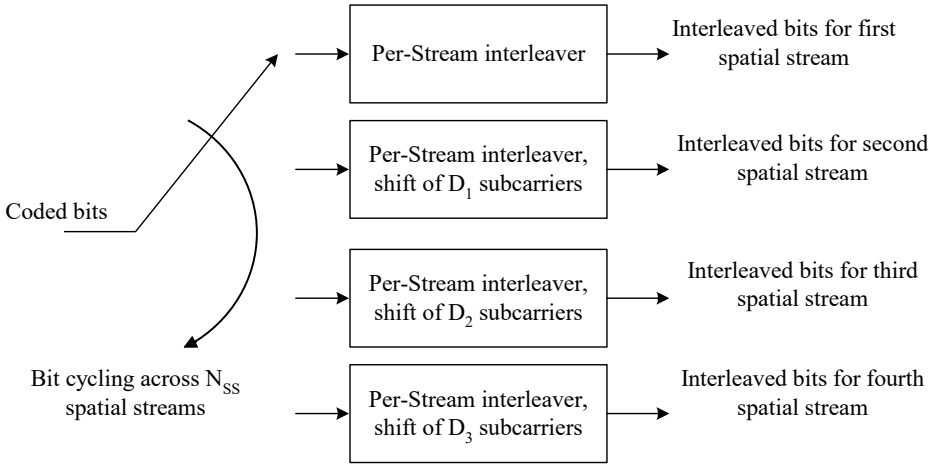



**Figure 019 – Illustration of the interleaver function**

The interleaver for spatial stream $n$ within its block of $N_{CBPS}/N_{SS}$ bits is defined by the following relations.

$$k = k_n \times N_{ss} + n$$

$$i = ((N_{CBPS}/N_{SS})/I_{DEPTH})\,(k_n \bmod I_{DEPTH}) + \text{floor}\,(k_n/I_{DEPTH}) \qquad k_n = 0, 1 \ldots (N_{CBPS}/N_{SS})-1$$

$$j = s \times \text{floor}(i/s) + (i + N_{CBPS}/N_{SS} - \text{floor}\,(I_{DEPTH} \times i / (N_{CBPS}/N_{SS}))) \bmod s \qquad s = \max(N_{BPSC}/2,1)$$

$$j_n = (j + N_{CBPS}/N_{SS} - N_{BPSC}\, D_n) \bmod (N_{CBPS}/N_{SS}). \qquad (14)$$

The parameter $D_n$ which denotes the shift in subcarriers for spatial stream $n$ is given by

$$D_n = 5n. \qquad (15)$$

The interleaving depth $I_{DEPTH}$ shall conform to the values given in Table 012.

**Table 012—Interleaving parameters**

| $N_{SS}$ | $N_{SD}$ | $I_{DEPTH}$ |
|---|---|---|
| 1, 2, 3, 4 | 54 | 6 |
| 2,3,4 | 108 | 6 |
| 1 | 108 | 12 |

The deinterleaver, which performs the inverse relation, is defined by the following series of permutations.

$$k_d = \bmod (k_n + N_{CBPS}/N_{SS} + 2sD_n) \bmod (N_{CBPS}/N_{SS})$$

$i_d = s \cdot \text{floor}(k_d / s) + (k_d + \text{floor}(I_{DEPTH} \times k_d / (N_{CBPS}/N_{SS}))) \bmod s$

$j_{dn} = I_{DEPTH} \times i_d - ((N_{CBPS}/N_{SS}) - 1) \times \text{floor}(I_{DEPTH} \times i_d / (N_{CBPS}/N_{SS}))$. (16)

where s and $D_n$ are as defined for the interleaver.

#### 20.3.5.7 Low density parity check codes (optional ECC)

This subclause describes the LDPCCs to be optionally used in the MIMO-OFDM system as high-performance ECC technique, instead of the convolutional code (20.3.5.5). The rate-dependent parameters in subclause 20.3.2.2 shall still apply.

When this subclause applies, the following clauses are to be considered no more applicable:

20.3.2.1: changes needed, as described in 20.3.5.7.3;
20.3.5.2: not used;
20.3.5.3: replaced by 20.3.5.7.3;
20.3.5.5: replaced by 20.3.5.7.4;
20.3.5.6: not used.

#### 20.3.5.7.1 LDPCC Code Rates and Block Sizes

The supported code rates, information block size, and coded block size are described in Table 013.

**Table 013— LDPCC parameters**

| Code rate (R) | LDPC information bits (bits) | LDPC codeword length (bits) |
|---|---|---|
| 1/2 | 972 | 1944 |
| 2/3 | 1296 | 1944 |
| 3/4 | 1458 | 1944 |
| 5/6 | 1620 | 1944 |

#### 20.3.5.7.3 LDPCC PPDU encoding process

a) Produce the PLCP preamble fields for each transmit antenna based on the TRANSMISSION_MODE field of the TXVECTOR. Refer to 20.3.3 for details.

b) Produce the PLCP header field from the LENGTH, DATARATE, and SERVICE fields of the TXVECTOR by filling the appropriate bit fields, as described in subclause 20.3.4 and subclause 20.3.5.1.

c) Compute the integer number of LDPCC codewords to be transmitted, $L_1$, and the possible remainder $K_1$.

$L_1 = \text{ceil}( (\text{LENGTH} \times 8 + 16)/1944/R)$,

$K_1 = \text{rem}( (\text{LENGTH} \times 8 + 16) , 1944 \times R)$. (17)

d) If $K_1 > 0$ compute the number of zeros for padding in order to encode the last codeword as

$N_{P1} = 1944 \times R - K_1$. (18)

These bits will not be transmitted nor scrambled. If $K_1 > 0$, the last frame has an effective information frame (i.e. information frame excluding padded zeros) of size $K_1$, generally less than *k.* The last codeword includes a fixed number of parity bits equal to $p = (1944 - k)$. This implies the code rate for the last codeword is different from the overall target code rate and is given by:

$$\frac{K_1}{K_1 + (1944 - k)}. \tag{19}$$

e) Compute the number of coded bits to be transmitted (including the shortened codeword) as

$$L_2 = \begin{cases} 1944 \times L_1, & K_1 = 0 \\ 1944 \times (L_1 - 1) + 1944 \times (1 - R) + K_1, & K_1 \neq 0 \end{cases} \tag{20}$$

f) Compute the integer number of MIMO-OFDM symbols $N_{S1}$ and the possible reminder $R_{S1}$:

$$N_{S1} = \text{ceil}(L_2/N_{CBPS}),$$

$$R_{S1} = \text{rem}(L_2, N_{CBPS}). \tag{21}$$

g) If $R_{S1} > 0$ append $N_{P2}$ zeros to info bits in order to fill an integer number of MIMO-OFDM symbols

$$N_{P2} = N_{CBPS} - R_{S1.} \tag{22}$$

h) The service field at the beginning of the resulting sequence is used to initialize a scrambler, which is then used to scramble the rest of the sequence including the zeros appended in step g).

k) The resulting PSDU is then coded by the LDPCC at the proper code rate (R) and block size (i.e. 1944 bits for all frames). The last codeword is encoded extending the info bits with $N_{P1}$ zeros; these $N_{P1}$ bits are not transmitted. The last $N_{P2}$ bits are not encoded.

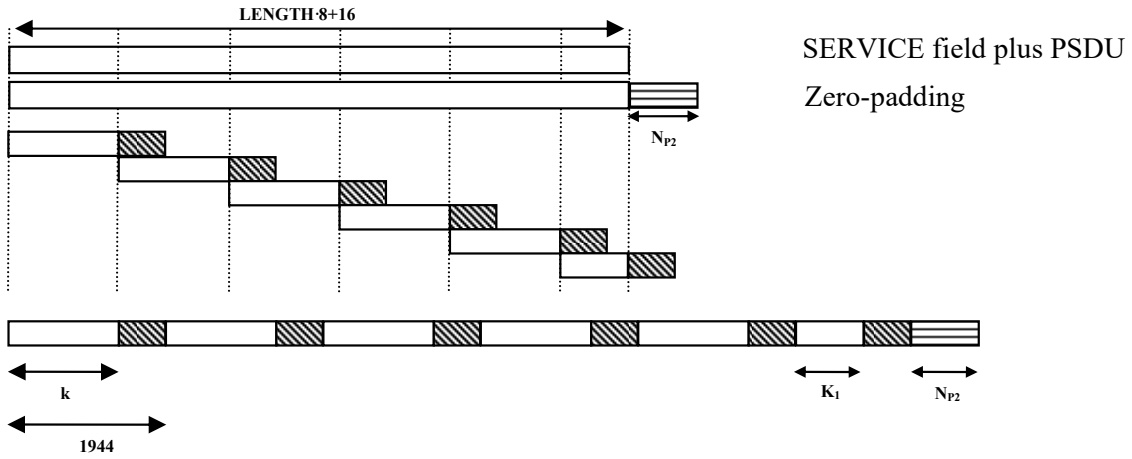



**Figure 020 – LDPC PPDU encoding**

### 20.3.5.7.4 LDPCC Encoder

A characteristic feature of the considered LDPCCs is that combining rows of the parity-check matrix (**H**) for the lowest rate code produces **H** for higher rates. This is equivalent to replacing a group of check nodes with a single

check node that sums all the edges coming into each of the original check nodes. Direct consequences are that all code rates have the same block length and the same variable node degree distribution.

The LDPCC encoder is systematic, i.e. encodes an information block of size $k$, $I=(i_0,i_1,\ldots i_{(k-1)})$ into a codeword $\mathbf{C}$ of size $n$ $\mathbf{C}=(i_0,i_1,\ldots i_{(k-1)}, p_0, p_1,\ldots, p_{(n-k-1)})$ by adding $n-k$ parity bits obtained so that $\mathbf{H}\cdot\mathbf{c}^T = \mathbf{0}$.

$k$ and $n$ are defined in Table 013 according to the selected rate.

The parity check matrix used to generate all the code rates is rate 1/2 (i.e. number of rows $n-k$ = 972, number of columns
$n$ = 1944). This belongs to the class of the so-called structured parity check matrices (compared to "random" generated codes). More specifically, the matrix can be partitioned into square sub-blocks of size 27x27 which are either cyclic permutations of the diagonal identity matrix or null sub-matrices. A few of them – specifically 2 in the rate 1/2 matrix described in Table A.1 – may contain two (cyclically shifted) diagonals.

In addition, in order to enable a simple encoding process, the parity-check matrices include a block lower triangular structure at the right-hand side. This allows a linear-complexity encoder (based on back substitution). More precisely, the parity-check matrix is of the type:

$$H_{(n-k)\times n} = [A_{(n-k)\times k}\ B_{(n-k)\times(n-k)}] \tag{23}$$

where $B$ is block lower triangular, i.e. has the structure reported in Fig. 021.

$$B_{(n-k)\times(n-k)} = \begin{pmatrix} b_{11} & 0 & & \cdots & & 0 \\ b_{21} & b_{22} & 0 & & & \\ & b_{32} & \ddots & \ddots & & \vdots \\ \vdots & & \ddots & \ddots & 0 & \\ & & & \ddots & & 0 \\ b_{(n-k)1} & & \cdots & & & b_{(n-k)(n-k)} \end{pmatrix},$$

$b_{ij}$ =circulant permutation matrix; $(i,j)$ sub-matrix indexes.

**Figure 021 – lower triangular part of the parity check matrix**

In order to generate variable rate LDPCCs, the following criteria apply:

a) Row-combining of rows who do not have a '1' in the same position (this implies a same resulting variable node degree distribution for all the code rates).
b) The selection of rows to be summed preserves the lower triangular structure of the right-hand side of the matrix through all the rates.

Taking into account above-mentioned criteria, the code rates are obtained as follows:

- Code rate 2/3:
row $i$ (the rows are enumerated from top to bottom) is generated by summing row $i$ of $\mathbf{H}$ of rate 1/2 code and the row with index $i+M/2$ where $M$ is the total number of check equations in rate 1/2 code, for all the rows where $i < M/3$.

- Code rate 3/4:
row $i$ is generated by summing row $i$ of $\mathbf{H}$ of rate 1/2 code and the row with index $i+M/2$ where $M$ is the total number of $\mathbf{H}$ rows (i.e. check equations) in rate 1/2 code.

- Code rate 5/6:

Rows are summed three at a time as: row *i* plus the row with index *i+M/3* plus the row with index *I* + 2*M*/3.

The codes are designed to avoid length 4 cycles and to avoid small stopping sets.

#### 20.3.5.7.5 Parity check matrix

In Table A.1 in Annex A the rate 1/2 parity check matrix is reported. All the other rates can be derived by properly combining its rows as explained in 20.3.5.7.4.

The table describes the "matrix prototype", i.e. a structure of size 36x72 where the basic elements are squared sub-matrices whose size is 27x27. Each sub matrix is either a null matrix or a cyclic permutation of the identity matrix (or the lower bidiagonal matrix at the right hand bottom of the matrix).

Figure 022 illustrates some examples (for a 10x10 matrix) of the basic circular permutation matrix $S_i$., clarifying how cyclic shift indexes *i* are to be interpreted. The last line in Table A.1, indicated as "st", indicates the staircase (or bi-diagonal) structure ($S_d$ in Fig. 021).

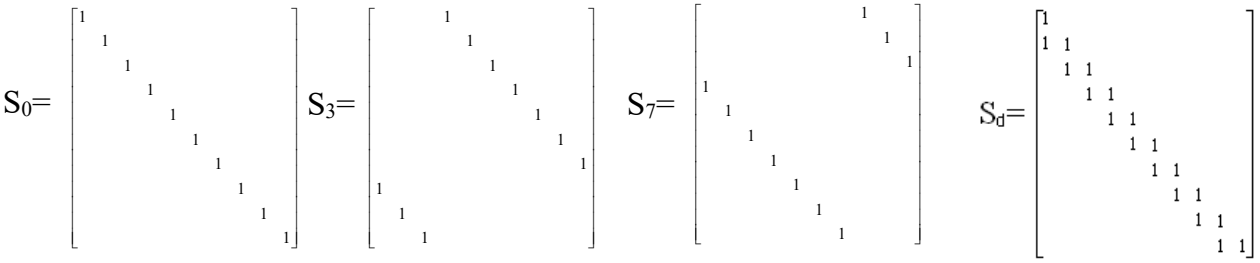



**Figure 022 – Structure of the cyclic permutations of the identity matrix. Matrix $S_i$ is produced by cyclically shifting the columns of the identity matrix to the right *i* places.**

Table A.1 follows the following format: Row number - Column number - Cyclic shift to the right (of columns). Rows are enumerated from top to bottom, columns from left to right.

#### 20.3.5.8 Subcarrier modulation mapping

The subcarrier modulation mapping shall follow IEEE 802.11a-1999 clause 17.3.5.7 for each transmit antenna.

#### 20.3.5.9 Pilot tones

The subcarriers with index -21 and +21 are dedicated in all 20 MHz modes to transmit pilot signals during each OFDM symbol, in order to increase robustness against frequency offsets and phase noise. In the 40 MHz modes, 4 subcarriers are dedicated to transmitting pilots. These subcarriers have indexes -42, -14, +14, and +42.

The relative polarity of the pilots transmitted from various antennas shall be determined using the following relations. We shall number the MIMO-OFDM symbols transmitted in a PSDU sequentially, with $n = 1$ denoting the first symbol that follows the PLCP preamble. We shall use $p_n$ to denote the $n$th element of the sequence $p_{0\ldots126v}$ specified in equation (25) of IEEE 802.11a-1999 subclause 17.3.5.9. We define the following matrices:

$$A=\begin{bmatrix}+1 & +1 & +1 & -1\\ +1 & -1 & +1 & +1\end{bmatrix}$$

$$B=\begin{bmatrix}+1 & +1 & -1 & -1\\ +1 & -1 & +1 & -1\\ -1 & +1 & +1 & -1\end{bmatrix}$$

$$C=\begin{bmatrix}+1 & +1 & +1 & -1\\ +1 & +1 & -1 & +1\\ +1 & -1 & +1 & +1\\ -1 & +1 & +1 & +1\end{bmatrix} \quad (24)$$

Furthermore, we define $a_{i,j}$, $b_{i,j}$, and $c_{i,j}$ as the element on the $i$th row and $j$th column of the matrices A, B, and C, respectively. For example, $i$ =0, 1, 2; $j$ = 0, 1, 2, 3 for matrix B. Then the pilot values sent from the $m$th antenna ($m$ = 1, 2, …4) during the $n$th OFDM symbol in the 20 MHz modes shall be given by the corresponding value in Table 014, multiplied with $p_{n \bmod 127}$. The function f(.) referred to in Table 014 is defined in Table 016. The pilot value in the 40 MHz modes shall be given by the corresponding value in Table 015, multiplied with $p_{n \bmod 127}$.The value of the pilot signals sent from the first antenna during the SIG-N symbol shall be obtained by setting $n$ = 0 in this subclause. The pilot signals sent during the SIG-MM symbol in the mixed mode preambles shall follow IEEE 802.11a-1999 subclause 17.3.5.9, and the polarity of the sequence $p_{0...126v}$ shall be reset after the SIG-MM symbol is transmitted.

**Table 014—Pilot value sent from *m*th antenna during *n*th OFDM symbol in 20 MHz modes**

| Subcarrier index | 2TX mode | 3TX mode | 4TX mode |
|---|---|---|---|
| -21 | $a_{\text{m-1, } n \bmod 2}$ | $b_{\text{m-1, f}(n \bmod 4)}$ | $c_{\text{m-1, f}(n \bmod 4)}$ |
| +21 | $a_{\text{m-1, } (n+1) \bmod 2}$ | $b_{\text{m-1, f}((n+2) \bmod 4)}$ | $c_{\text{m-1, f}((n+2) \bmod 4)}$ |

**Table 015—Pilot value sent from *m*th antenna during *n*th OFDM symbol in 40 MHz modes**

| Subcarrier index | 1TX mode | 2TX mode | 3TX mode | 4TX mode |
|---|---|---|---|---|
| -42 | +1 | $a_{\text{m-1, } n \bmod 4}$ | $b_{\text{m-1, } n \bmod 4}$ | $c_{\text{m-1, } n \bmod 4}$ |
| -14 | +1 | $a_{\text{m-1, } (n+1) \bmod 4}$ | $b_{\text{m-1, } (n+1) \bmod 4}$ | $c_{\text{m-1, } (n+1) \bmod 4}$ |
| +14 | +1 | $a_{\text{m-1, } (n+2) \bmod 4}$ | $b_{\text{m-1, } (n+2) \bmod 4}$ | $c_{\text{m-1, } (n+2) \bmod 4}$ |
| +42 | -1 | $a_{\text{m-1, } (n+3) \bmod 4}$ | $b_{\text{m-1, } (n+3) \bmod 4}$ | $c_{\text{m-1, } (n+3) \bmod 4}$ |

**Table 016—Definition of the function f(.)**

| *l* | f(*l*) |
|---|---|
| 0 | 0 |
| 1 | 2 |
| 2 | 1 |
| 3 | 3 |

Figure 023 provides an illustration of the relative polarity of pilot signals transmitted in the 2TX, 20 MHz mode of operation

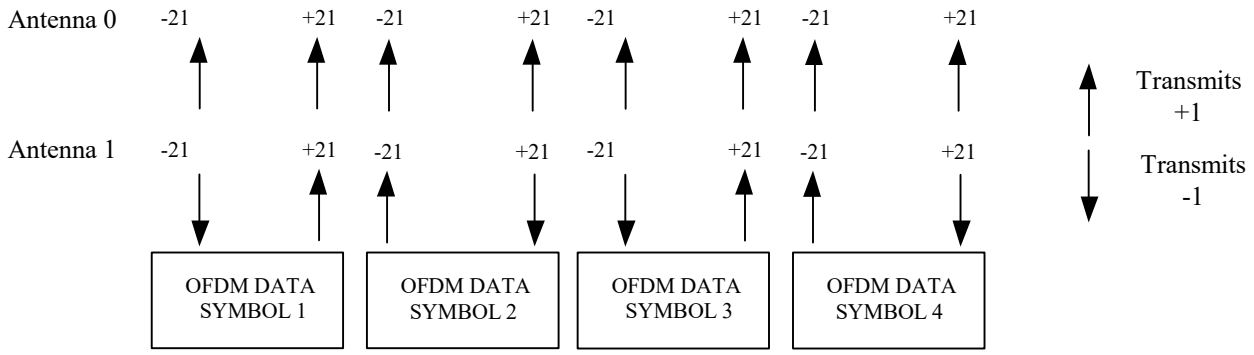



**Figure 023 – An illustration of the relative polarity of pilot signals in the 2TX, 20 MHz mode. "-21" and "+21" indicate the subcarrier indexes on which pilot signals are sent**

### 20.3.5.10 Space-time block coding (STBC)

This subclause defines a set of robust transmission rates which are applicable when $N_{TX,}$ the number of TX antennas, is greater than $N_{SS,}$ the number of transmitted spatial streams. These rates are based on space time block coding. Implementation of all modes defined in this subclause is optional.

The space time block encoding scheme for $N_{TX}$ =2, $N_{SS}$ =1 in 20 MHz and 40 MHz is defined as follows. The bits output from the interleaver of the (single) spatial stream are mapped to the subcarriers of the first antenna, according to subclause 20.3.5.8. We denote the pair of complex numbers transmitted on subcarrier *k* from this antenna during the *j-1*th and *j*th OFDM symbol as $s_{j-1}$ and $s_j$ respectively. Then the corresponding transmission from the second antenna, on the same subcarrier index and during the same OFDM symbols, shall be $-s^*_j$ and $s^*_{j-1}$ where * denotes complex conjugate. This encoding scheme shall hereafter be referred to as the "STBC encoding rule".

Since encoding takes place across pairs of MIMO-OFDM symbols in this subclause, the number of pad bits inserted in subclause 20.3.5.3 shall be sufficient to ensure that an even number of MIMO-OFDM symbols are transmitted in the PPDU.

**Table 017—Rate-dependent parameters for 20 MHz, $N_{TX}$ = 2, $N_{SS}$ = 1**

| Data rate (Mbits/s) | Modulation | Code rate (R) | Coded bits per subcarrier per antenna ($N_{BPSC}$) | Number of data subcarriers ($N_{SD}$) | Number of pilots ($N_{SP}$) | Coded bits per MIMO-OFDM symbol ($N_{CBPS}$) | Data bits per MIMO-OFDM symbol ($N_{DBPS}$) | Clause 10.4.4.2 rate code |
|---|---|---|---|---|---|---|---|---|
| 6 .75 | BPSK | 1/2 | 1 | 54 | 2 | 54 | 27 | 114 |
| 10.125 | BPSK | 3/4 | 1 | 54 | 2 | 54 | 40.5 | 115 |
| 13.5 | QPSK | 1/2 | 2 | 54 | 2 | 108 | 54 | 116 |
| 20.25 | QPSK | 3/4 | 2 | 54 | 2 | 108 | 81 | 117 |
| 27 | 16-QAM | 1/2 | 4 | 54 | 2 | 216 | 108 | 118 |
| 40.5 | 16-QAM | 3/4 | 4 | 54 | 2 | 216 | 162 | 119 |
| 54 | 64-QAM | 2/3 | 6 | 54 | 2 | 324 | 216 | 120 |
| 60.75 | 64-QAM | 3/4 | 6 | 54 | 2 | 324 | 243 | 121 |
| 67.5 | 64-QAM | 5/6 | 6 | 54 | 2 | 324 | 270 | 122 |

The RATE-dependent parameters for 20 MHz, $N_{TX} = 3$, $N_{SS} = 2$ are defined in Table 003. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8.

The RATE-dependent parameters for 20 MHz, $N_{TX} = 4$, $N_{SS} = 2$ are defined in Table 003. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream, and on the third and fourth antennas using bits from the second spatial stream.

The RATE-dependent parameters for 20 MHz, $N_{TX} = 4$, $N_{SS} = 3$ are defined in Table 004. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8. Bits from the third spatial stream shall be mapped to subcarriers of the fourth transmit antenna, according to subclause 20.3.5.8.

The RATE-dependent parameters for 40 MHz, $N_{TX} = 2$, $N_{SS} = 1$ are defined in Table 006. In this configuration, the STBC encoding rule shall be applied on the first and second antennas.

The RATE-dependent parameters for 40 MHz, $N_{TX} = 3$, $N_{SS} = 2$ are defined in Table 007. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8.

The RATE-dependent parameters for 40 MHz, $N_{TX} = 4$, $N_{SS} = 2$ are defined in Table 007. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream, and on the third and fourth antennas using bits from the second spatial stream.

The RATE-dependent parameters for 40 MHz, $N_{TX} = 4$, $N_{SS} = 3$ are defined in Table 008. In this configuration, the STBC encoding rule shall be applied on the first and second antennas using bits from the first spatial stream. Bits from the second spatial stream shall be mapped to subcarriers of the third transmit antenna, according to subclause 20.3.5.8. Bits from the third spatial stream shall be mapped to subcarriers of the fourth transmit antenna, according to subclause 20.3.5.8.

### 20.3.6 Clear channel assessment

PLCP shall provide the capability to perform CCA and report the result to the MAC. The CCA mechanism shall detect a “medium busy” condition with a performance specified in 20.3.10.5. This medium status report is indicated by the primitive PHY_CCA.indicate.

### 20.3.7 PLCP data modulation and modulation rate change

The PLCP preamble shall be transmitted using a set of OFDM-modulated fixed waveforms, specified in subclause 20.3.3 for each transmit antenna for each mode of operation defined in the MIMO-OFDM PHY. The SIG-N field, composed of 54 bits, shall indicate the bandwidth, modulation, code rate, code type, number of TX antennas, and number of spatial streams that shall be used to transmit the MPDU. The transmitter (receiver) shall initiate the modulation constellation, code rate, code type, and other configuration parameters according to the CONFIG indicated in the SIG-N field. The MPDU transmission rate shall be set by the DATARATE parameter in the TXVECTOR, issued with the PHY-TXSTART.request primitive described in 20.2.

### 20.3.8 PMD operating specifications

Subclauses 20.3.8.1 through 20.3.8.8 provide general specifications for the various modes and options defined in the MIMO-OFDM PMD sublayer. These specifications apply to both the receive and transmit functions and general operation of the MIMO-OFDM PHY.

#### 20.3.8.1 TX Block diagram

The general block diagram of the transmitter for the MIMO-OFDM PHY is shown in Figure 024. The blocks that are shaded in the figure may be replicated $N_{TX}$ times in a MIMO-OFDM system with $N_{TX}$ transmit antennas.

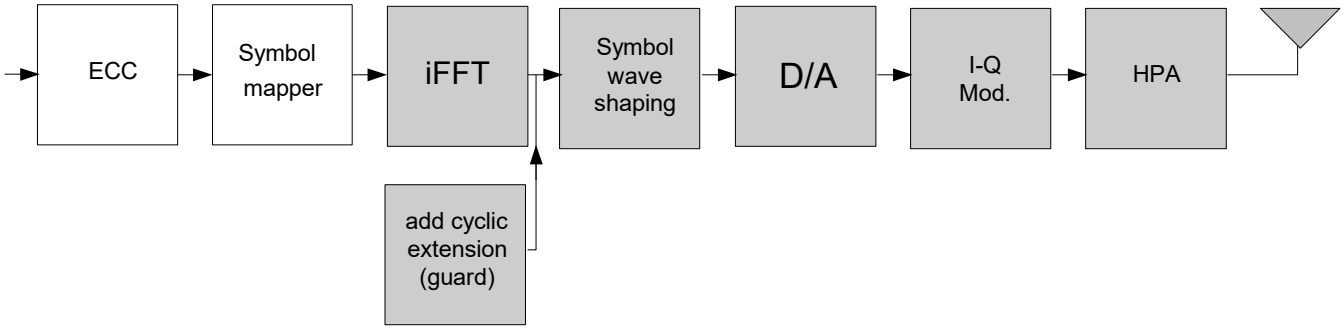



**Figure 024 – Transmitter block diagram for the MIMO-OFDM PHY**

#### 20.3.8.2 Regulatory requirements

All systems shall comply with the local regulatory requirements for operation in the band in which they are implemented. For 2.4 GHz operation, refer to FCC 15.247, 15.249, 15.205, and 15.209 for the USA; ETS 300-328 for Europe; and MPHPT article 49-20 for Japan. For 5 GHz operation in the USA, refer to FCC CFR47, Part 15, sections 15.205 and 15.209; and Subpart E, sections 15.401-15.407.

The documents listed here are provided for information only, and are subject to change or revision at any time.

#### 20.3.8.3 Operating channel frequencies

The range of operating frequencies for the MIMO-OFDM PHY shall be 2400-2497 MHz and 4920-5805 MHz. The channel numbering shall be as defined in IEEE 802.11b-1999 clause 18.4.6.2, and clause 17.3.8.3.2 of IEEE P802.11j/D1.5, May 2004. The relationship between center frequency and channel number is given by the following equations:

Channel center frequency = 5000 + (channel number) × 5 (MHz) for center frequency > 5000 MHz (25)

Channel center frequency = 4000 + (channel number) × 5 (MHz) for 4900 ≤ center frequency ≤ 5000 MHz (26)

40 MHz operation shall be restricted to the 5 GHz band only. Each 40 MHz channel shall occupy two 20 MHz channels, with the center frequency of the 40 MHz transmission selected to be midway between the center frequencies of the two occupied 20 MHz channels. For example, if the two occupied 20 MHz channels are centered at channel number 149 and 153, then the 40 MHz transmission shall be centered at channel number 151.

#### 20.3.8.4 Spurious emissions

The spurious emissions shall conform to IEEE 802.11a-1999 subclause 17.3.8.4

#### 20.3.8.5 TX RF delay

The TX RF delay shall follow IEEE 802.11a-1999 subclause 17.3.8.5.

#### 20.3.8.6 Slot time

The slot time shall follow IEEE 802.11a-1999 subclause 17.3.8.6 for 5 GHz bands and IEEE 802.11g-1999 subclause 19.4.4 for 2.4 GHz bands.

#### 20.3.8.7 Transmit and receive antenna port impedance

The transmit and receive antenna port impedance for each transmit and receive antenna shall follow IEEE 802.11a-1999 subclause 17.3.8.7.

#### 20.3.8.8 Transmit and receive operating temperature range

The transmit and receive temperature range shall follow IEEE 802.11a-1999 subclause 17.3.8.8.

### 20.3.9 PMD TX specifications

Subclauses 20.3.9.1 through 20.3.9.7 describe the transmit specifications associated with the PMD sublayer. In general, these are specified by primitives from the PLCP, and the transmit PMD entity provides the actual means by which the signals required by the PLCP primitives are imposed into the medium.

#### 20.3.9.1 TX power levels

The maximum allowable output power shall conform to national regulatory constraints on the maximum radiated power allowed in any frequency band.

#### 20.3.9.2 TX spectrum mask

The transmitted spectral density of the transmitted signal shall conform to subclause IEEE 802.11a-1999 17.3.9.2 for all 20 MHz transmissions. The transmitted spectrum for 40 MHz transmissions shall have a 0 dBr bandwidth not exceeding 38 MHz, -20 dBr at 21 MHz frequency offset, -28 dBr at 30 MHz frequency offset, -38 dBr at 50 MHz frequency offset, and -40 dBr at 52 MHz frequency offset and above. The transmitted spectral density of the 40 MHz transmitted signal shall fall within the spectral mask shown in Figure 025. The measurements shall be made using a 100 kHz resolution bandwidth and a 30 kHz video bandwidth.

#### 20.3.9.3 TX spurious

Spurious transmissions from Clause 20 compliant devices shall conform to national regulations.

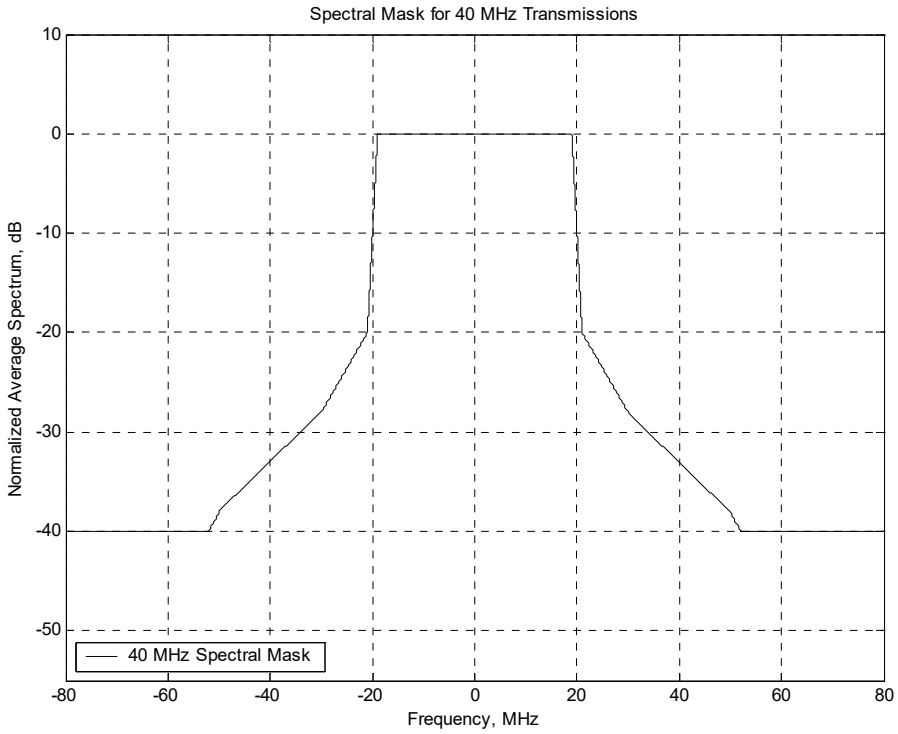



**Figure 025 –Transmit spectrum mask for 40 MHz transmissions**

#### 20.3.9.4 TX center frequency tolerance

The transmitted center frequency tolerance shall be ±20 ppm maximum for 5 GHz bands and ±25 ppm for 2.4 GHz bands. The transmit center frequency and the symbol clock frequency for all transmit antennas shall be derived from the same reference oscillator.

.

#### 20.3.9.5 TX symbol clock frequency tolerance

The symbol clock frequency tolerance shall be ±20 ppm maximum for 5 GHz bands and ±25 ppm for 2.4 GHz bands. The transmit center frequency and the symbol clock frequency for all transmit antennas shall be derived from the same reference oscillator.

#### 20.3.9.6 Modulation accuracy

Transmit modulation accuracy specifications are described in this subclause. The test method is described in 20.3.9.7.

#### 20.3.9.6.1 TX center frequency leakage

TX center frequency leakage shall follow IEEE 802.11a-1999 subclause 17.3.9.6.1 for all 20 MHz modes of transmission. For 40 MHz modes, the center frequency leakage shall not exceed -18 dB relative to overall transmitted power, or,equivalently, +2 dB relative to the average energy of the rest of the subcarriers.

#### 20.3.9.6.2 TX spectral flatness

For 20 MHz transmissions, the average energy of the constellation in each of the spectral lines -16…-1 and +1…+16 will deviate no more than ±2 dB of their average energy. The average energy of the constellations in

each of the spectral lines -28…-17 and +17…+28 will deviate no more than +2/-4 dB from the average energy of the spectral lines -16…-1 and +1…+16.

For 40 MHz transmissions, the average energy of the constellation in each of the spectral lines -32…-3 and +3…+32 will deviate no more than ±2 dB of their average energy. The average energy of the constellations in each of the spectral lines -58…-33 and +33…+58 will deviate no more than +2/-4 dB from the average energy of the spectral lines -32…-3 and +3…+32.

#### 20.3.9.6.3 TX constellation error

The relative constellation RMS error, averaged over subcarriers, transmit spatial streams, OFDM frames, and packets, shall not exceed a constellation and code rate dependent value according to Table 018 for the all modes in which the number of spatial streams is equal to the number of transmit antennas.

**Table 018—Allowed relative constellation error versus constellation type and code rate**

| Constellation size | Code Rate | Relative constellation error (dB) |
|---|---|---|
| 16-QAM | 1/2 | -17 |
| 16-QAM | 3/4 | -20 |
| 64-QAM | 2/3 | -24 |
| 64-QAM | 3/4 | -26 |
| 64-QAM | 5/6 | -27 |

#### 20.3.9.7 TX modulation accuracy (EVM) test

The transmit modulation accuracy test shall be performed by instrumentation capable of converting the transmitted signals into a stream of complex samples at 20 Msamples/s or more for 20 MHz modes, and 40 Msamples/s or more for 40 MHz modes, with sufficient accuracy in terms of I/Q arm amplitude and phase balance, DC offsets, phase noise, etc. A possible embodiment of such a setup is converting the signals to a low IF frequency with a microwave synthesizer, sampling the signals with a digital oscilloscope, and decomposing them digitally into quadrature components.

The test procedure for this requirement is as follows: Matrices $H_{1TX}$, $H_{2TX}$, $H_{3TX}$, and $H_{4TX}$ are defined to give the connections from the transmit antennas to the receive antennas for the 1TX, 2TX, 3TX, and 4TX cases respectively. They are specified as follows:

$$H_{1TX} = \alpha \cdot 1$$

$$H_{2TX} = \alpha \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

$$H_{3TX} = \alpha \begin{bmatrix} -1 & 2 & 2 \\ 2 & -1 & 2 \\ 2 & 2 & -1 \end{bmatrix}$$

$$H_{4TX} = \alpha \begin{bmatrix} -1 & 1 & 1 & 1 \\ 1 & -1 & 1 & 1 \\ 1 & 1 & -1 & 1 \\ 1 & 1 & 1 & -1 \end{bmatrix} \quad (27)$$

The elements of the above matrices $h_{ij}$ specify the connection from the $j^{th}$ transmitter to the $i^{th}$ receiver, where $h_{ij}$ is the element of the $i^{th}$ row and $j^{th}$ column where $i = 1,\ldots, N_{RX}$ and $j = 1,\ldots, N_{TX}$. The attenuation $\alpha$ is chosen to ensure an appropriate received signal power at the test equipment. Figure 026 shows an example test setup for a 2TX mode.

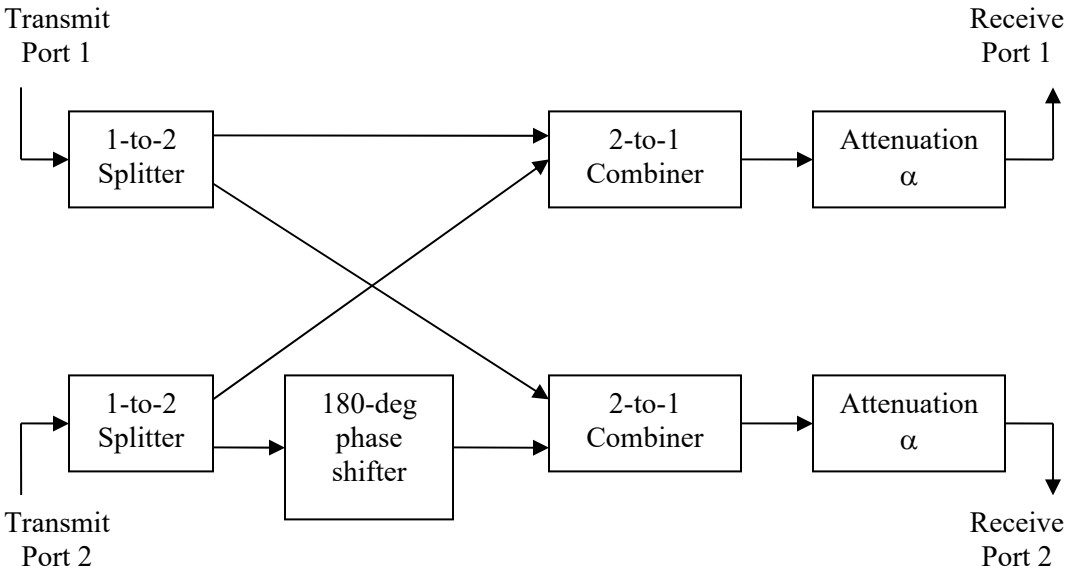



**Figure 026 –EVM test setup**

The 180 degree phase shifter shall be 180 +/- 10 degrees. The relative amplitudes of the connections $h_{ij}$ shall be within +/-1 dB of the relative values specified in the H matrices above.

The sampled signals shall be processed in a manner similar to an actual receiver, according to the following steps, or an equivalent procedure:

a) Start of frame shall be detected.
b) Transition from short sequences to channel estimation sequences shall be detected, and fine timing (with one sample resolution) shall be established.
c) Coarse and fine frequency offsets shall be estimated.
d) The packet shall be derotated according to estimated frequency offset.
e) The complex channel response coefficients shall be estimated for each of the subcarriers.
f) For each of the data OFDM symbols: transform the symbol into subcarrier received values, estimate the phase from the pilot subcarriers, derotate the subcarrier values according to estimated phase, and apply an MMSE channel equalizer to each vector of received subcarrier values based on complex estimated channel response coefficients found in (e).
g) For each data-carrying subcarrier of each transmitted stream, find the closest constellation point and compute the Euclidean distance from it.
h) Compute the RMS average of all errors in a packet. It is given by:

$$Error_{RMS} = \frac{\sum_{i=1}^{N_f} \sqrt{\frac{\sum_{l=1}^{N_{SS}} \sum_{j=1}^{L_P} \sum_{k=1}^{N_{ST}} \{(I(i,j,k,l) - I_0(i,j,k,l))^2 + (Q(i,j,k,l) - Q_0(i,j,k,l))^2\}}{N_{ST} L_P P_0 N_{SS}}}}{N_f} \quad (28)$$

where

$L_P$ is the length of the packet;
$N_{SS}$ is the number of spatial streams;
$N_f$ is the number of frames for the measurement;
$N_{ST}$ is the total number of subcarriers (data and pilots) per OFDM symbol;
$(I_0(i,j,k,l), Q_0(i,j,k,l))$ denotes the ideal symbol point of the $i^{th}$ frame, $j^{th}$ OFDM symbol of the frame, $k^{th}$ subcarrier, and $l^{th}$ spatial stream of the OFDM symbol in the complex plane;
$(I(i,j,k,l), Q(i,j,k,l))$ denotes the observed point of the $i^{th}$ frame, $j^{th}$ OFDM symbol of the frame, $k^{th}$ subcarrier, and $l^{th}$ spatial stream of the OFDM symbol in the complex plane;
$P_0$ is the average power of the constellation.

The vector error on a phase plane is shown in Figure 121 in IEEE 802.11a-1999 subclause 17.3.9.7.

The test shall be performed over at least 20 frames ($N_f$), and the RMS average shall be taken. The packets under test shall be at least 16 OFDM symbols long. Random data shall be used for the symbols.

### 20.3.10 PMD RX specifications

Subclauses 20.3.10.1 through 20.3.10.5 describe the receive specifications associated with the PMD sublayer.

#### 20.3.10.1 RX minimum input level sensitivity

The packet error rate (PER) shall be less than 10% at a PSDU length of 1000 bytes for rate-dependent input levels shall be the numbers listed in Table 019 or less. The minimum input levels are measured at the antenna connectors and are referenced as the average power per receive antenna.

**Table 019—Receiver minimum input level sensitivity**

| Constellation size | Code Rate | Minimum sensitivity (dBm) |
|---|---|---|
| BPSK | ½ | -82 |
| BPSK | ¾ | -81 |
| QPSK | ½ | -79 |
| QPSK | ¾ | -77 |
| 16-QAM | ½ | -74 |
| 16-QAM | ¾ | -70 |
| 64-QAM | 2/3 | -66 |
| 64-QAM | ¾ | -65 |
| 64-QAM | 5/6 | -64 |

#### 20.3.10.2 RX maximum input level

The RX maximum input level shall be defined as the maximum at any or all antennas, and shall follow IEEE 802.11a-1999 subclause 17.3.10.4 for the 4920-5805 MHz band, and follow IEEE 802.11g-2003 subclause 19.5.3 for the 2400-2497 MHz band.

#### 20.3.10.3 CCA sensitivity

The CCA sensitivity of all Clause 20 compliant devices shall conform to IEEE 802.11a-2003 subclause 17.3.10.5. When operating in 40 MHz mode, the receiver shall also provide a secondary channel carrier sense. The start of a valid OFDM transmission at a receive level equal to or greater than the minimum 6 Mbit/s sensitivity (-82 dBm) shall cause the secondary channel CCA to indicate busy with a probability of >90% within 4us. The receiver shall hold the secondary channel CCA busy for any signal 20 dB above the minimum 6 Mbit/s sensitivity (-62 dBm).

### 20.3.11 PLCP TX procedure

The transmit PLCP is shown in Figure 029. In order to transmit data, PHY-TXSTART.request shall be enabled so that the PHY entity shall be in the transmit state. Further, the PHY shall be set to operate at the appropriate frequency through station management via the PLME. Other transmit parameters, such as DATARATE, TRANSMISSION_MODE, NUM_STREAMS, and TXPWR_LEVEL, are set via the PHY-SAP with the PHY-TXSTART.request(TXVECTOR), as described in 20.2.

A clear channel shall be indicated by PHY-CCA.indicate(IDLE). The MAC considers this indication before issuing the PHY-TXSTART.request. Transmission of the PPDU or A-PPDU shall be initiated after receiving the PHYTXSTART. request(TXVECTOR) primitive. The TXVECTOR elements for the PHY-TXSTART.request are the PLCP header parameters LENGTH, DATARATE, TRANSMISSION_MODE, NUM_STREAMS, CODE_TYPE, SERVICE, LPI, and BURST_DURATION, and the PMD parameter TXPWR_LEVEL.

The PLCP shall issue PMD_TXPWRLVL, PMD_RATE, PMD_NUM_STREAMS, and PMD_TRANSMISSION_MODE, primitives to configure the PHY. The PLCP shall then issue a PMD_TXSTART.request, and transmission of the PLCP preamble and PLCP header, based on the parameters passed in the PHY-TXSTART.request primitive will begin. Once PLCP preamble transmission is started, the PHY entity shall immediately initiate data scrambling and data encoding. The scrambled and encoded data shall then be exchanged between the MAC and the PHY through a series of PHYDATA.request(DATA) primitives issued by the MAC, and PHY-DATA.confirm primitives issued by the PHY. The modulation rate change, if any, shall be initiated from the SERVICE field data of the PLCP header, as described in 20.3.2. The PHY proceeds with PSDU transmission through a series of data octet transfers from the MAC. The PLCP header parameter, SERVICE, and PSDU are encoded by the convolutional encoder with the bit-stealing function described in 20.3.5.5. At the PMD layer, the data octets are sent in bit 0–7 order and presented to the PHY through PMD_DATA.request primitives. In the PMD, the GI shall be inserted in every OFDM symbol as a countermeasure against severe delay spread.

Transmission of a PSDU can be prematurely terminated by the MAC through the primitive PHY-TXEND.request. PHY-TXSTART shall be disabled by the issuance of the PHY-TXEND.request. Normal transmission of a PSDU occurs after the transmission of the final bit of the last PSDU octet, according to the number of bytes supplied in the PLCP header LENGTH.

Each PHY-TXEND.request is acknowledged with a PHY-TXEND.confirm primitive from the PHY. If the coded PSDU (C-PSDU) is not multiples of the OFDM symbol, bits shall be stuffed to make the C-PSDU length multiples of the OFDM symbol.

If an aggregated PPDU (A-PPDU) is being transmitted as indicated by the TXVECTOR LPI parameter, the PHY will wait for the next PHY_TXSTART.request from the MAC. The process of transmitting the subsequent

MPDUs as part of the A-PPDU is identical to the first MPDU except that the PLCP will not issue PMD primitives to configure the PHY.

Normal termination of the A-PPDU occurs at the termination of the transmission of the last PSDU, indicated by the PHY PLCP header LPI field. A permaturely terminated PSDU transmission from the MAC will prematurely terminate the transmission of the A-PPDU.

The A-PPDU transmission shall be completed and the PHY entity shall enter the receive state (i.e., PHY-TXSTART shall be disabled).

A typical state machine implementation of the transmit PLCP is provided in Figure 027. Requests (.req) and confirmations(.confirm) are issued once with designated states.

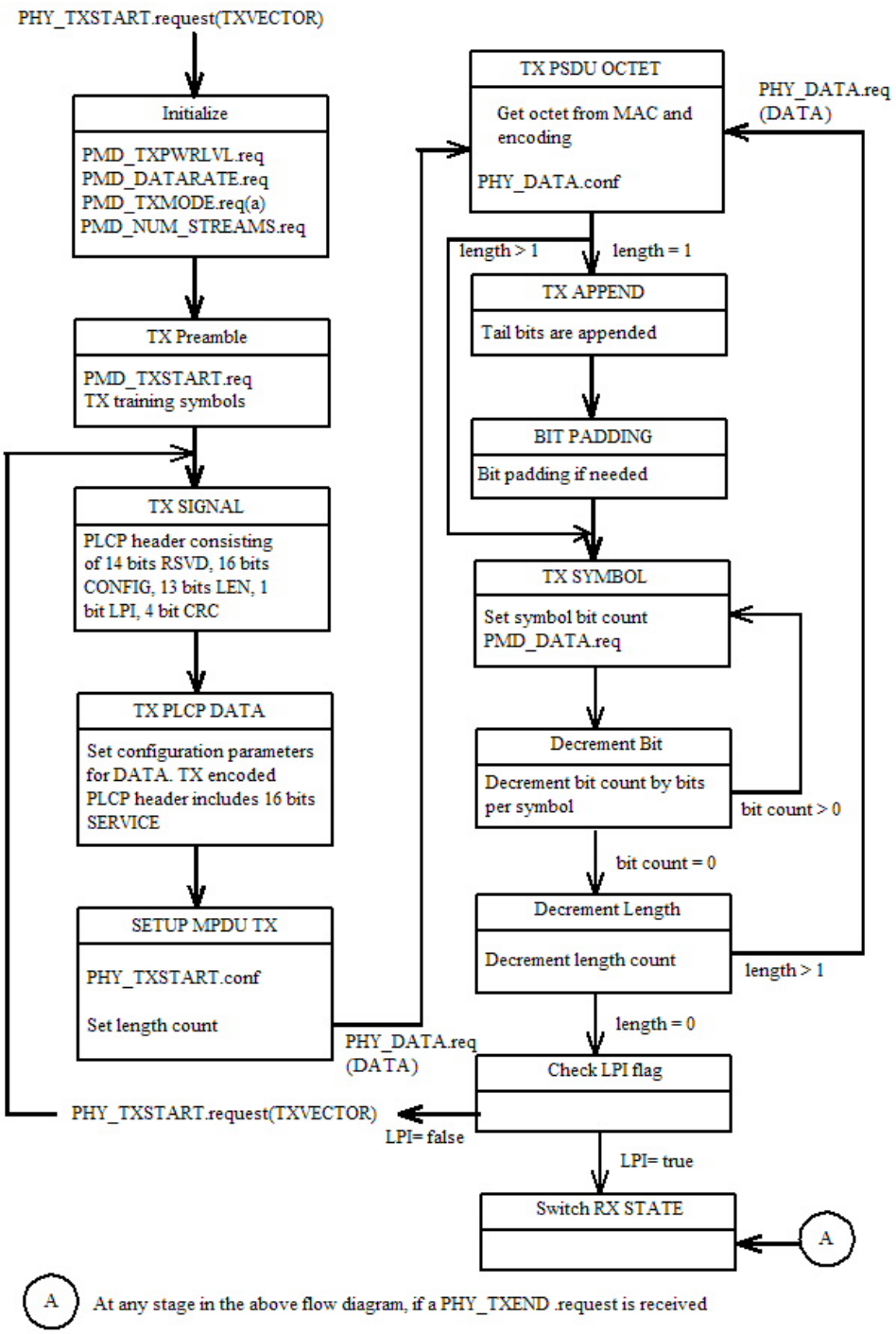



**Figure 027 –PLCP transmit state machine**

### 20.3.12 PLCP RX procedure

The receive PLCP is shown in Figure 030. In order to receive data, PHY-TXSTART.request shall be disabled so that the PHY entity is in the receive state. Further, through station management (via the PLME) the PHY is set to the appropriate frequency. Other receive parameters, such as RSSI and indicated DATARATE, TRANSMISSION_MODE, NUM_STREAMS, CODE_TYPE, LPI, and BURST_DURATION may be accessed via the PHY-SAP.

Upon receiving the transmitted PLCP preamble, PMD_RSSI.indicate shall report a significant received signal strength level to the PLCP. This indicates activity to the MAC via PHY_CCA.indicate.
PHY_CCA.indicate(BUSY) shall be issued for reception of a signal prior to correct reception of the PLCP frame. The PMD primitive PMD_RSSI is issued to update the RSSI and parameter reported to the MAC.

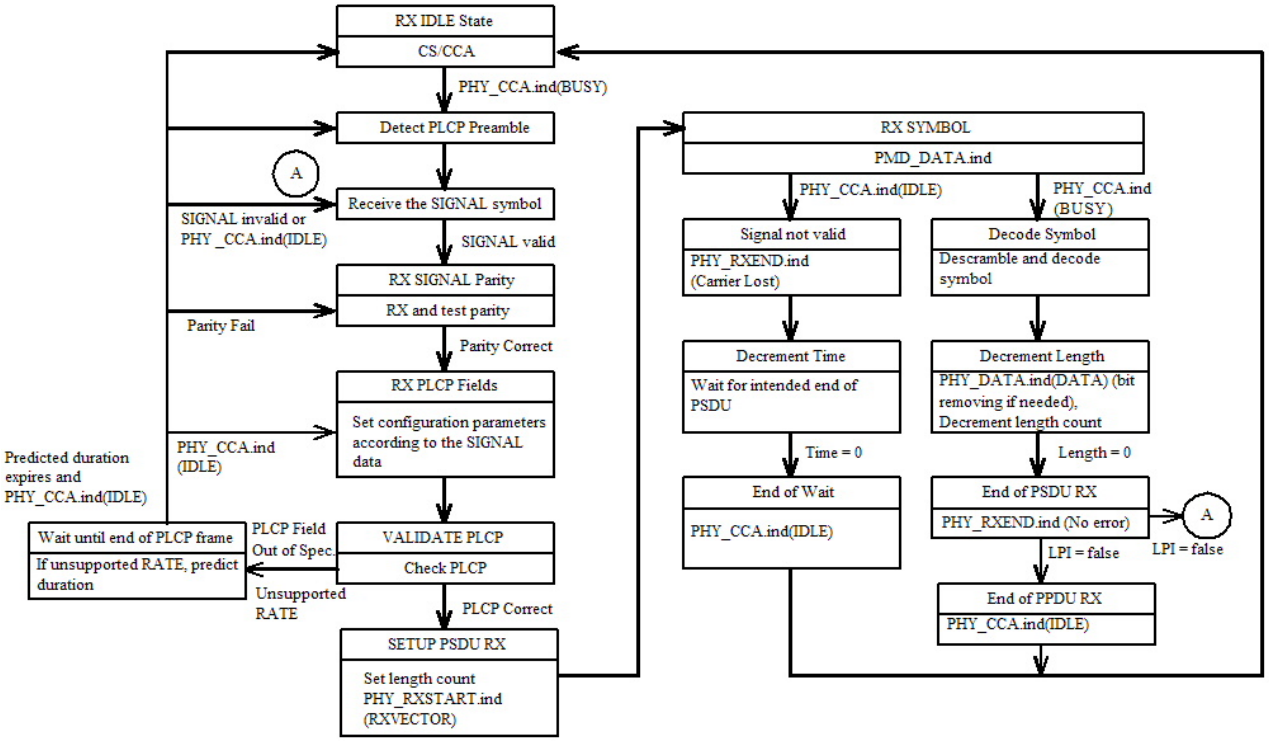



**Figure 028 – PLCP receive state machine**

After PHY-CCA.indicate is issued, the PHY entity shall begin receiving the training symbols and searching for the SIGNAL in order to set the length of the data stream, the demodulation type, and the decoding rate. Once the SIGNAL is detected without any errors detected by the CRC checker, FEC decode shall be initiated and the PLCP SERVICE fields and data shall be received, and decoded. Should the status of CCA return to the IDLE state during reception prior to completion of the full PLCP processing, the PHY receiver shall return to the RX IDLE state.

If the PLCP header reception is successful (and the SIGNAL field is completely recognizable and supported), a PHY-RXSTART.indicate(RXVECTOR) shall be issued. The RXVECTOR associated with this primitive includes the SIGNAL fields, the SERVICE field, the PSDU length in bytes, and the RSSI. Also, in this case, the HT PHY will ensure that the CCA shall indicate a busy medium for the intended duration of the transmitted frame, as indicated by the LENGTH field. The received PSDU bits are assembled into octets, decoded, and presented to the MAC using a series of PHY-DATA.indicate(DATA) primitive exchanges. The rate change indicated in the SIGNAL field shall be initiated from the SERVICE field data of the PLCP header, as described in 20.3.2. The PHY shall proceed with PSDU reception. After the reception of the final bit of the last PSDU octet indicated by the PLCP header LENGTH field, the receiver shall transition to the RX IDLE state if LPI is 1 or to the RX SIGNAL state if LPI is 0 in the RXVECTOR associated with this primitive, as shown in Figure 030. If the LPI is 1 in the RXVECTOR, a PHY-RXEND.indicate(NoError) primitive shall also be issued.

In the event that a change in the RSSI causes the status of the CCA to return to the IDLE state before the complete reception of the PSDU, as indicated by the PLCP LENGTH field, the error condition PHYRXEND.indicate(CarrierLost) shall be reported to the MAC. The HT PHY will ensure that the CCA

indicates a busy medium for the intended duration of the transmitted packet. If the indicated rate in the SIGNAL field is not receivable, a PHY-RXSTART.indicate will not be issued. The PHY shall issue the error condition PHY-RXEND.indicate(UnsupportedRate). If the PLCP header is receivable, but the FCS check of the PLCP header is not valid, a PHY-RXSTART.indicate will not be issued. The PHY shall issue the error condition PHY-RXEND.indicate(FormatViolation). Any data received after the indicated data length are considered pad bits (to fill out an OFDM symbol) and should be discarded. A typical state machine implementation of the receive PLCP is given in Figure 028.

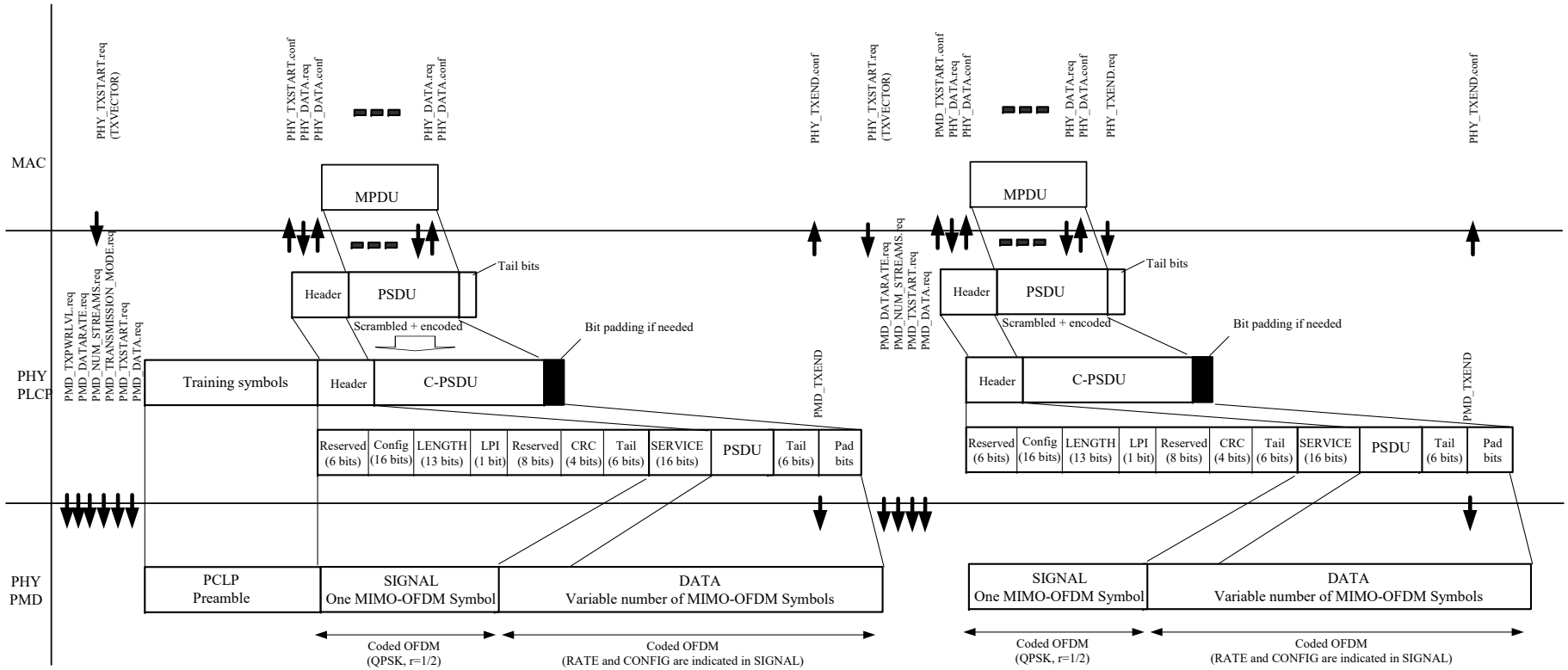



**Fig. 029 PLCP transmit procedure for A-PPDU transmission in greenfield 20 MHz modes**

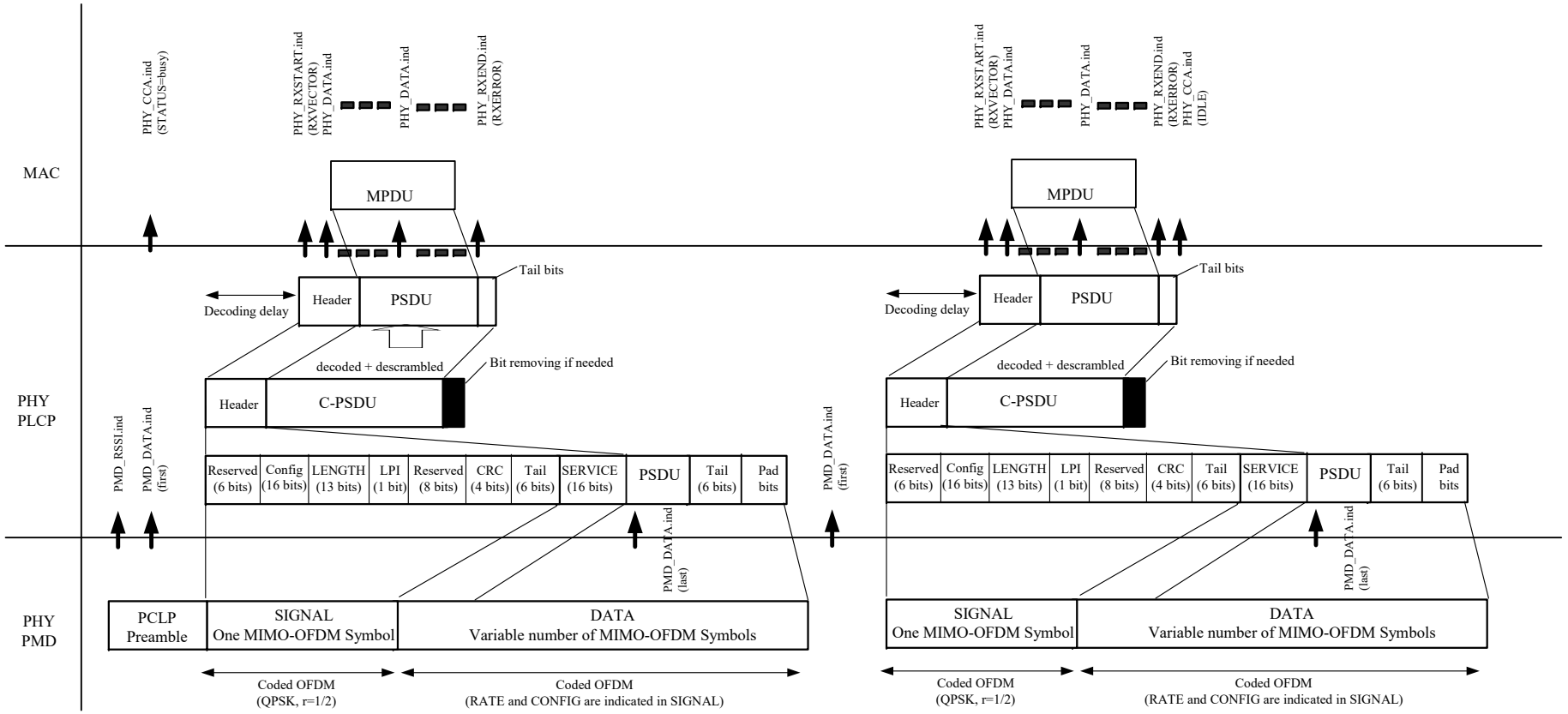



**Fig. 030 PLCP receive procedure for A-PPDU reception in greenfield 20 MHz modes**

# 20.4 MIMO-OFDM PMD operating specifications

### 20.4.1 PLME_SAP sublayer management primitives

Table 20.4.2T1 lists the MIB attributes that may be accessed by the PHY entities and the intralayer of higher level LMEs. These attributes are accessed via the PLME-GET, PLME-SET, PLME-RESET, and PLME-CHARACTERISTICS primitives defined in 10.4.

### 20.4.2 MIMO-OFDM management information base

All MIMO-OFDM PHY MIB attributes are defined in Clause 13, with specific values defined in Table 20.4.2.T1. The column titled "Operational semantics" in Table 20.4.2.T1 contains two types: static and dynamic. Static MIB attributes are fixed and cannot be modified for a given PHY implementation. Dynamic MIB attributes can be modified by some management entity.

**Table 20.4.2T1 MIB attribute default values/ranges**

| Managed Object | Default Value / Range | Operational Semantics |
|---|---|---|
| dot11 PHY Operation Table | | |
| dot11PHYtype | HTP (Value to be assigned) | Static |
| dot11CurrentRegDomain | Implementation dependent | Static |
| dot11TempType | Implementation dependent | Static |
| **dot11 PHY Antenna Table** | | |
| dot11CurrentTxAntenna | Implementation dependent | Dynamic |
| dot11DiversitySupport | Implementation dependent | Static |
| dot11CurrentRxAntenna | Implementation dependent | Dynamic |
| **Dot11 PHY Tx Power Table** | | |
| dot11NumberSupportedPowerLevels | Implementation dependent | Static |
| dot11TxPowerLevel1 | Implementation dependent | Static |
| dot11TxPowerLevel2 | Implementation dependent | Static |
| dot11TxPowerLevel3 | Implementation dependent | Static |
| dot11TxPowerLevel4 | Implementation dependent | Static |
| dot11TxPowerLevel5 | Implementation dependent | Static |
| dot11TxPowerLevel6 | Implementation dependent | Static |
| dot11TxPowerLevel7 | Implementation | Static |

| | | |
|---|---|---|
| | dependent | |
| dot11TxPowerLevel8 | Implementation dependent | Static |
| dot11CurrentTxPowerLevel | Implementation dependent | Dynamic |
| **dot11 Phy DSSS Table** | | |
| dot11CurrentChannel | Implementation dependent | Dynamic |
| **dot11 Reg Domains Supported Table** | | |
| dot11RegDomainsSupportedValue (s) | Implementation dependent | Static |
| **dot11 PHY Antennas List Table** | | |
| dot11SupportedTxAntenna | Implementation dependent | Static |
| dot11SupportedRxAntenna | Implementation dependent | Static |
| dot11DiversitySelectionRx | Implementation dependent | Dynamic |
| **dot11 Supported Data Rates Tx Table** | | |
| dot11SupportedDataratesTxValue | See Clause 10.4.4.2 rate code columns of Tables 003-009 and Table 016 | Static |
| **dot11 Supported Data Rates Rx Table** | | |
| dot11SupportedDataRatesRxValue | See Clause 10.4.4.2 rate code columns of Tables 003-009 and Table 016 | Static |
| **dot11 PHY HTP Table** | | |
| dot11CurrentFrequency | Implementation dependent | Dynamic |
| dot11SupportedTransmissionModes | Assign optional types in TRANSMISSION_MODE of Table 001 to bits in bit mask | Static |
| dot11SupportedNumStreams | X'0' = Support 1 and 2 streams<br>X'1' = Support 1, 2, and 3 streams<br>X'2' = Support 1, 2, and 4 streams<br>X'3' = Support 1, 2, 3, and 4 streams | Static |
| dot11SupportedCodeTypes | X'0' = convolutional only<br>X'1' = convolutional and LDPC | Static |

### 20.4.3 MIMO-OFDM TXTIME calculation

The value of the TXTIME parameter returned by the PLME-TXTIME.confirm primitive shall be calculated according to the following equation:

TXTIME = $TXTIME_{CONV}$ if CODE_TYPE is convolutional and $TXTIME_{LDPC}$ if CODE_TYPE is LDPC

where

$$TXTIME_{CONV} = T_{MIXED} + T_{PREAMBLE} + T_{SIGNAL} + T_{SYM} \times \text{Ceiling}((16 + 8 \times LENGTH + 6 \times N_{ES})/N_{DBPS})$$

$$TXTIME_{LDPC} = T_{MIXED} + T_{PREAMBLE} + T_{SIGNAL} + T_{SYM} \cdot N_{S1}$$

$T_{MIXED}$ is 20μs if TRANSMISSION_MODE is a mixed mode and 0μs if it is a greenfield mode

$T_{PREAMBLE}$ is 16μs if TRANSMISSION_MODE specifies $N_{TX} = 2$ and 28μs if TRANSMISSION_MODE specifies $N_{TX} = 3$ or 4

$T_{SIGNAL}$ is 4μs

$N_{DBPS}$ is derived from the DATARATE parameter (Ceiling is a function that returns the smallest integer value greater than or equal to its argument value)

$N_{S1}$ is defined in subclause 20.3.5.7.3.

### 20.4.4 MIMO-OFDM PHY characteristics

**Table 20.4.4.1—MIMO-OFDM PHY characteristics**

| Characteristic | Value |
|---|---|
| aSlotTime | 9 μs |
| aSIFSTime | 16 μs |
| aRIFSTime | 2 μs |
| aCCATime | <4 μs |
| aRxTxTurnaroundTime | Implementation dependent as long as the requirements of aSIFSTime are met. |
| aTxRxTurnaroundTime | Implementation dependent as long as the requirements of aSIFSTime are met. |
| aTxPLCPDelay | Implementation dependent as long as the requirements of aRxTxTurnaroundTime are met. |
| aRxPLCPDelay | Implementation dependent as long as the requirements of aSIFSTime and aCCATime are met |
| aRxTxSwitchTime | Implementation dependent |
| aTxRampOnTime | Implementation dependent as long as the requirements of aRxTxTurnaroundTime are met |
| aTxRampOffTime | Implementation dependent as long as the requirements of aSIFSTime are met |
| ATxRFDelay | Implementation dependent as long as the requirements of aRxTxTurnaroundTime are met |
| ARxRFDelay | Implementation dependent as long as the requirements of aSIFSTime and aCCATime are met |
| aAirPropagationTime | <<1 μs |
| aMACProcessingDelay | <2 μs |
| aPreambleLength | 16 μs |
| aPLCPHeaderLength | 4 μs |
| aMPDUMaxLength | 8191 |

| | |
|---|---|
| aCWmin | 15 |
| aCWmax | 1023 |

# 20.5 MIMO-OFDM operating specifications

## 20.5.1 Scope and field of application

This subclause describes the PMD services provided to the PLCP for the MIMO-OFDM PHY.

## 20.5.2 Overview of service

The MIMO-OFDM sublayer accepts PLCP sublayer service primitives and provides the actual means by which data is transmitted or received from the medium. The combined functions of the MIMO-OFDM PMD sublayer primitives and parameters for the receive function result in a data stream, timing information, and associated received signal parameters being delivered to the PLCP sublayer. A similar functionality is provided for data transmission.

## 20.5.3 Overview of interactions

The primitives associated with the PLCP sublayer to the MIMO-OFDM fall into two basic categories

a) Service primitives that support PLCP peer-to-peer interactions;
b) Service primitives that have local significance and that support sublayer-to-sublayer interactions.

## 20.5.4 Basic services and options

All of the service primitives described in this subclause are considered mandatory, unless otherwise specified.

### 20.5.4.1 PMD_SAP peer-to-peer service primitives

Table 20.5.4.1 indicates the primitives for peer-to-peer interactions.

**Table 20.5.4.1 PMD_SAP peer-to-peer services**

| Primitive | Request | Indicate | Confirm | Response |
|---|---|---|---|---|
| PMD_Data | X | X | | |

### 20.5.4.2 PMD_SAP sublayer-to-sublayer service primitives

Table 19.9.4.2 indicates the primitives for sublayer-to-sublayer interactions.

**Table 19.9.4.2 PMD_SAP sublayer-to-sublayer services**

| Primitive | Request | Indicate | Confirm | Response |
|---|---|---|---|---|
| PMD_TXSTART | X | | | |
| PMD_TXEND | X | | | |
| PMD_ANTSEL | X | | | |
| PMD_TXPWRLVL | X | | | |
| PMD_TRANSMISSION_MODE | X | | | |
| PMD_NUM_STREAMS | X | | | |
| PMD_DATARATE | X | | | |
| PMD_RSSI | | X | | |

### 20.5.4.3 PMD_SAP service primitive parameters

Table 19.9.4.3 shows the parameters used by one or more of the PMD_SAP service primitives.

**Table 20.5.4.3 List of parameters for the PMD primitives**

| Parameter | Associated primitive | Value | Description |
|---|---|---|---|
| TXD_UNIT | PMD_DATA.request | 0 to (2^n)-1, where n is the number of bits per symbol for the transmission mode, number of streams, and data rate specified in PMD_TRANSMISSION_MODE.request, PMD_NUM_STREAMS.request, and PMD_DATARATE.request primitives. | This parameter represents a single block of data, which, in turn, is used by the PMD to be encoded into a transmitted symbol. |
| RXD_UNIT | PMD_DATA.indicate | 0 to (2^n)-1, where n is the number of bits per symbol for the transmission mode, number of streams, and data rate specified in PMD_TRANSMISSION_MODE.request, PMD_NUM_STREAMS.request, and PMD_DATARATE.request primitives. | This parameter represents a single symbol that has been demodulated by the PMD entity. |
| TRANSMISSION_MODE | PMD_TRANSMISSION_MODE.request | See Table 001 in 20.2 | This parameter specifies to the PMD layer, which transmission mode is used. |
| ANT_STATE | PMD_ANTSEL.request | 1 to 256 | ANT_STATE selects which of the available antennas is used for transmission. The number of available antennas is |

| | | | |
|---|---|---|---|
| | | | determined from the MIB table parameters. |
| TXPWR_LEVEL | PMD_TXPWRLVL.request | 1-8 | TXPWR_LEVEL selects which of the optional transmit power levels should be used for the current PPDU transmission. The number of available power levels is determined from the MIB table parameters. |
| DATARATE | PMD_DATARATE.request | See Clause 10.4.4.2 rate code columns of Tables 003-009 and Table 016 | DATARATE selects which of the data rates is used for PSDU transmission. |
| RSSI | PMD_RSSI.indicate | 8 bits of RSSI (256 levels) | The RSSI is a measure of the RF energy received. Mapping of the RSSI values to actual received power is implementation dependent. |

### 20.5.5 PMD_SAP detailed service specification

The following subclauses describe the services provided by each PMD primitive.

#### 20.5.5.1 PMD_DATA.request

This primitive is the same as that defined in 17.5.5.1 and 18.4.5.1 except that the parameter TXD_UNIT is expanded in scope to reflect the supported transmission formats defined in 20.5.4.3.

#### 20.5.5.2 PMD_DATA.indicate

This primitive is the same as that defined in 17.5.5.2 and 18.4.5.2 except that the parameter RXD_UNIT is expanded in scope to reflect the supported transmission formats defined in 20.5.4.3.

#### 20.5.5.3 PMD_TRANSMISSION_MODE.request

This primitive is the same as that defined in 18.4.5.3 except that the parameter MODULATION of that section is expanded in scope to reflect the supported transmission formats defined in 20.5.4.3.

#### 20.5.5.4 PMD_TXSTART.request

This primitive is the same as that defined in 17.5.5.3 and 18.4.5.6.

#### 20.5.5.5 PMD_TXEND.request

This primitive is the same as that defined in 17.5.5.4 and 18.4.5.7.

#### 20.5.5.6 PMD_ANTSEL.request

This primitive is the same as that defined in 18.4.5.8, including the definition of the parameter ANT_STATE.

#### 20.5.5.7 PMD_TXPRWLVL.request

This primitive is the same as that defined in 17.5.5.5, including the definition of the parameter TXPWR_LEVEL.

#### 20.5.5.8 PMD_DATARATE.request

This primitive is the same as that defined in 17.5.5.6 and 18.4.5.10, except that the parameter DATARATE is expanded in scope to reflect the supported MIMO-OFDM transmission modes as defined in 20.5.4.3.

#### 20.5.5.9 PMD_RSSI.indicate

This primitive is the same as that defined in 17.5.5.7 and 18.4.5.11, including the parameter RSSI. This primitive is used to aid in link optimization algorithms such as roaming decisions.

# Annex A – LDPC matrix definitions

(normative)

**Table A.1 – Description of the matrix prototype of the rate 1/2 parity check matrix**

| Row | Col | Shift |
|---|---|---|
| 0 | 3 | 9 |
| 0 | 7 | 15 |
| 0 | 16 | 5 |
| 0 | 22 | 23 |
| 0 | 32 | 6 |
| 0 | 35 | 12 |
| 0 | 36 | 23 |
| 1 | 2 | 12 |
| 1 | 6 | 16 |
| 1 | 10 | 19 |
| 1 | 26 | 12 |
| 1 | 31 | 23 |
| 1 | 36 | 5 |
| 1 | 37 | 24 |
| 2 | 2 | 9 |
| 2 | 9 | 15 |
| 2 | 16 | 2 |
| 2 | 29 | 15 |
| 2 | 37 | 8 |
| 2 | 37 | 9 |
| 2 | 38 | 2 |
| 3 | 1 | 11 |
| 3 | 5 | 15 |
| 3 | 14 | 17 |
| 3 | 22 | 7 |
| 3 | 36 | 12 |
| 3 | 38 | 19 |
| 3 | 39 | 25 |
| 4 | 4 | 15 |
| 4 | 8 | 3 |
| 4 | 10 | 15 |
| 4 | 26 | 16 |
| 4 | 34 | 6 |
| 4 | 39 | 6 |
| 4 | 40 | 10 |
| 5 | 4 | 20 |
| 5 | 10 | 24 |
| 5 | 11 | 17 |
| 5 | 23 | 4 |
| 5 | 33 | 25 |
| 5 | 40 | 24 |
| 5 | 41 | 15 |
| 6 | 1 | 14 |
| 6 | 5 | 17 |
| 6 | 13 | 0 |
| 6 | 28 | 14 |
| 6 | 35 | 16 |
| 6 | 41 | 24 |
| 6 | 42 | 5 |
| 7 | 1 | 7 |
| 7 | 9 | 7 |
| 7 | 11 | 3 |
| 7 | 21 | 12 |
| 7 | 30 | 18 |
| 7 | 42 | 15 |
| 7 | 43 | 21 |
| 8 | 2 | 9 |
| 8 | 7 | 25 |
| 8 | 10 | 4 |
| 8 | 18 | 15 |
| 8 | 34 | 15 |
| 8 | 43 | 18 |
| 8 | 44 | 18 |
| 9 | 4 | 13 |
| 9 | 9 | 5 |
| 9 | 18 | 6 |
| 9 | 20 | 3 |
| 9 | 39 | 8 |
| 9 | 44 | 14 |
| 9 | 45 | 15 |
| 10 | 0 | 3 |
| 10 | 7 | 11 |
| 10 | 11 | 10 |
| 10 | 23 | 21 |
| 10 | 33 | 17 |
| 10 | 45 | 13 |
| 10 | 46 | 12 |
| 11 | 1 | 11 |
| 11 | 9 | 9 |
| 11 | 11 | 15 |
| 11 | 29 | 6 |
| 11 | 38 | 11 |

| | | |
|---|---|---|
| 11 | 46 | 9 |
| 11 | 47 | 5 |
| 12 | 5 | 16 |
| 12 | 5 | 22 |
| 12 | 10 | 9 |
| 12 | 24 | 0 |
| 12 | 45 | 5 |
| 12 | 47 | 7 |
| 12 | 48 | 10 |
| 13 | 3 | 13 |
| 13 | 10 | 0 |
| 13 | 13 | 20 |
| 13 | 20 | 23 |
| 13 | 42 | 7 |
| 13 | 48 | 21 |
| 13 | 49 | 14 |
| 14 | 3 | 8 |
| 14 | 7 | 1 |
| 14 | 11 | 3 |
| 14 | 25 | 24 |
| 14 | 46 | 3 |
| 14 | 49 | 3 |
| 14 | 50 | 7 |
| 15 | 0 | 8 |
| 15 | 9 | 0 |
| 15 | 11 | 5 |
| 15 | 19 | 26 |
| 15 | 31 | 8 |
| 15 | 50 | 5 |
| 15 | 51 | 2 |

| | | |
|---|---|---|
| 16 | 4 | 4 |
| 16 | 8 | 6 |
| 16 | 15 | 4 |
| 16 | 19 | 11 |
| 16 | 43 | 20 |
| 16 | 51 | 5 |
| 16 | 52 | 16 |
| 17 | 1 | 10 |
| 17 | 5 | 24 |
| 17 | 10 | 13 |
| 17 | 27 | 3 |
| 17 | 32 | 26 |
| 17 | 52 | 7 |
| 17 | 53 | 24 |
| 18 | 4 | 10 |
| 18 | 8 | 8 |
| 18 | 12 | 10 |
| 18 | 30 | 21 |
| 18 | 48 | 7 |
| 18 | 53 | 16 |
| 18 | 54 | 17 |
| 19 | 4 | 23 |
| 19 | 6 | 15 |
| 19 | 14 | 14 |
| 19 | 28 | 4 |
| 19 | 50 | 5 |
| 19 | 54 | 13 |
| 19 | 55 | 11 |
| 20 | 3 | 9 |
| 20 | 6 | 18 |

| | | |
|---|---|---|
| 20 | 15 | 16 |
| 20 | 25 | 5 |
| 20 | 40 | 0 |
| 20 | 55 | 12 |
| 20 | 56 | 8 |
| 21 | 0 | 4 |
| 21 | 6 | 20 |
| 21 | 11 | 6 |
| 21 | 24 | 9 |
| 21 | 55 | 20 |
| 21 | 56 | 24 |
| 21 | 57 | 12 |
| 22 | 2 | 10 |
| 22 | 8 | 12 |
| 22 | 12 | 12 |
| 22 | 27 | 4 |
| 22 | 53 | 3 |
| 22 | 57 | 0 |
| 22 | 58 | 19 |
| 23 | 0 | 2 |
| 23 | 9 | 17 |
| 23 | 17 | 17 |
| 23 | 21 | 9 |
| 23 | 49 | 14 |
| 23 | 58 | 22 |
| 23 | 59 | 23 |
| 24 | 1 | 16 |
| 24 | 7 | 5 |
| 24 | 17 | 7 |
| 24 | 29 | 12 |

| | | |
|---|---|---|
| 24 | 56 | 19 |
| 24 | 59 | 23 |
| 24 | 60 | 4 |
| 25 | 0 | 8 |
| 25 | 8 | 13 |
| 25 | 18 | 1 |
| 25 | 28 | 25 |
| 25 | 44 | 1 |
| 25 | 60 | 26 |
| 25 | 61 | 13 |
| 26 | 4 | 1 |
| 26 | 9 | 1 |
| 26 | 21 | 10 |
| 26 | 26 | 12 |
| 26 | 52 | 3 |
| 26 | 61 | 6 |
| 26 | 62 | 18 |
| 27 | 3 | 21 |
| 27 | 5 | 8 |
| 27 | 22 | 13 |
| 27 | 27 | 17 |
| 27 | 59 | 21 |
| 27 | 62 | 21 |
| 27 | 63 | 12 |
| 28 | 1 | 13 |
| 28 | 8 | 26 |
| 28 | 20 | 18 |
| 28 | 32 | 11 |
| 28 | 58 | 21 |
| 28 | 63 | 23 |

| | | |
|---|---|---|
| 28 | 64 | 3 |
| 29 | 2 | 16 |
| 29 | 5 | 6 |
| 29 | 19 | 10 |
| 29 | 25 | 17 |
| 29 | 54 | 20 |
| 29 | 64 | 16 |
| 29 | 65 | 8 |
| 30 | 3 | 16 |
| 30 | 7 | 15 |
| 30 | 16 | 1 |
| 30 | 31 | 0 |
| 30 | 41 | 13 |
| 30 | 65 | 15 |
| 30 | 66 | 17 |
| 31 | 0 | 20 |
| 31 | 6 | 8 |
| 31 | 15 | 4 |
| 31 | 34 | 1 |
| 31 | 51 | 22 |
| 31 | 66 | 4 |
| 31 | 67 | 8 |
| 32 | 2 | 11 |
| 32 | 7 | 17 |
| 32 | 13 | 3 |
| 32 | 33 | 12 |
| 32 | 57 | 20 |
| 32 | 67 | 7 |
| 32 | 68 | 3 |
| 33 | 0 | 19 |

| | | |
|---|---|---|
| 33 | 6 | 22 |
| 33 | 14 | 8 |
| 33 | 30 | 14 |
| 33 | 35 | 18 |
| 33 | 68 | 16 |
| 33 | 69 | 0 |
| 34 | 3 | 6 |
| 34 | 6 | 0 |
| 34 | 17 | 16 |
| 34 | 24 | 19 |
| 34 | 47 | 12 |
| 34 | 69 | 1 |
| 34 | 70 | 21 |
| 35 | 2 | 22 |
| 35 | 8 | 22 |
| 35 | 12 | 26 |
| 35 | 23 | 1 |
| 35 | 70 | 5 |
| 35 | 71 | st |

1

2 **Table A.2 – Description of the**
3 **matrix prototype of the rate 2/3**
4 **parity check matrix**

| Row | Col | Shift |
|---|---|---|
| 0 | 5 | 16 |
| 0 | 5 | 22 |
| 0 | 10 | 9 |
| 0 | 24 | 0 |
| 0 | 45 | 5 |

| | | |
|---|---|---|
| 0 | 47 | 7 |
| 0 | 48 | 10 |
| 1 | 3 | 13 |
| 1 | 10 | 0 |
| 1 | 13 | 20 |
| 1 | 20 | 23 |
| 1 | 42 | 7 |
| 1 | 48 | 21 |
| 1 | 49 | 14 |
| 2 | 3 | 8 |
| 2 | 7 | 1 |
| 2 | 11 | 3 |
| 2 | 25 | 24 |
| 2 | 46 | 3 |
| 2 | 49 | 3 |
| 2 | 50 | 7 |
| 3 | 0 | 8 |
| 3 | 9 | 0 |
| 3 | 11 | 5 |
| 3 | 19 | 26 |
| 3 | 31 | 8 |
| 3 | 50 | 5 |
| 3 | 51 | 2 |
| 4 | 4 | 4 |
| 4 | 8 | 6 |
| 4 | 15 | 4 |
| 4 | 19 | 11 |

| | | |
|---|---|---|
| 4 | 43 | 20 |
| 4 | 51 | 5 |
| 4 | 52 | 16 |
| 5 | 1 | 10 |
| 5 | 5 | 24 |
| 5 | 10 | 13 |
| 5 | 27 | 3 |
| 5 | 32 | 26 |
| 5 | 52 | 7 |
| 5 | 53 | 24 |
| 6 | 3 | 9 |
| 6 | 4 | 10 |
| 6 | 7 | 15 |
| 6 | 8 | 8 |
| 6 | 12 | 10 |
| 6 | 16 | 5 |
| 6 | 22 | 23 |
| 6 | 30 | 21 |
| 6 | 32 | 6 |
| 6 | 35 | 12 |
| 6 | 36 | 23 |
| 6 | 48 | 7 |
| 6 | 53 | 16 |
| 6 | 54 | 17 |
| 7 | 2 | 12 |
| 7 | 4 | 23 |
| 7 | 6 | 15 |

| | | |
|---|---|---|
| 7 | 6 | 16 |
| 7 | 10 | 19 |
| 7 | 14 | 14 |
| 7 | 26 | 12 |
| 7 | 28 | 4 |
| 7 | 31 | 23 |
| 7 | 36 | 5 |
| 7 | 37 | 24 |
| 7 | 50 | 5 |
| 7 | 54 | 13 |
| 7 | 55 | 11 |
| 8 | 2 | 9 |
| 8 | 3 | 9 |
| 8 | 6 | 18 |
| 8 | 9 | 15 |
| 8 | 15 | 16 |
| 8 | 16 | 2 |
| 8 | 25 | 5 |
| 8 | 29 | 15 |
| 8 | 37 | 8 |
| 8 | 37 | 9 |
| 8 | 38 | 2 |
| 8 | 40 | 0 |
| 8 | 55 | 12 |
| 8 | 56 | 8 |
| 9 | 0 | 4 |
| 9 | 1 | 11 |

| | | |
|---|---|---|
| 9 | 5 | 15 |
| 9 | 6 | 20 |
| 9 | 11 | 6 |
| 9 | 14 | 17 |
| 9 | 22 | 7 |
| 9 | 24 | 9 |
| 9 | 36 | 12 |
| 9 | 38 | 19 |
| 9 | 39 | 25 |
| 9 | 55 | 20 |
| 9 | 56 | 24 |
| 9 | 57 | 12 |
| 10 | 2 | 10 |
| 10 | 4 | 15 |
| 10 | 8 | 3 |
| 10 | 8 | 12 |
| 10 | 10 | 15 |
| 10 | 12 | 12 |
| 10 | 26 | 16 |
| 10 | 27 | 4 |
| 10 | 34 | 6 |
| 10 | 39 | 6 |
| 10 | 40 | 10 |
| 10 | 53 | 3 |
| 10 | 57 | 0 |
| 10 | 58 | 19 |
| 11 | 0 | 2 |
| 11 | 4 | 20 |
| 11 | 9 | 17 |
| 11 | 10 | 24 |
| 11 | 11 | 17 |
| 11 | 17 | 17 |
| 11 | 21 | 9 |
| 11 | 23 | 4 |
| 11 | 33 | 25 |
| 11 | 40 | 24 |
| 11 | 41 | 15 |
| 11 | 49 | 14 |
| 11 | 58 | 22 |
| 11 | 59 | 23 |
| 12 | 1 | 14 |
| 12 | 1 | 16 |
| 12 | 5 | 17 |
| 12 | 7 | 5 |
| 12 | 13 | 0 |
| 12 | 17 | 7 |
| 12 | 28 | 14 |
| 12 | 29 | 12 |
| 12 | 35 | 16 |
| 12 | 41 | 24 |
| 12 | 42 | 5 |
| 12 | 56 | 19 |
| 12 | 59 | 23 |
| 12 | 60 | 4 |
| 13 | 0 | 8 |
| 13 | 1 | 7 |
| 13 | 8 | 13 |
| 13 | 9 | 7 |
| 13 | 11 | 3 |
| 13 | 18 | 1 |
| 13 | 21 | 12 |
| 13 | 28 | 25 |
| 13 | 30 | 18 |
| 13 | 42 | 15 |
| 13 | 43 | 21 |
| 13 | 44 | 1 |
| 13 | 60 | 26 |
| 13 | 61 | 13 |
| 14 | 2 | 9 |
| 14 | 4 | 1 |
| 14 | 7 | 25 |
| 14 | 9 | 1 |
| 14 | 10 | 4 |
| 14 | 18 | 15 |
| 14 | 21 | 10 |
| 14 | 26 | 12 |
| 14 | 34 | 15 |
| 14 | 43 | 18 |
| 14 | 44 | 18 |
| 14 | 52 | 3 |
| 14 | 61 | 6 |

| | | |
|---|---|---|
| 14 | 62 | 18 |
| 15 | 3 | 21 |
| 15 | 4 | 13 |
| 15 | 5 | 8 |
| 15 | 9 | 5 |
| 15 | 18 | 6 |
| 15 | 20 | 3 |
| 15 | 22 | 13 |
| 15 | 27 | 17 |
| 15 | 39 | 8 |
| 15 | 44 | 14 |
| 15 | 45 | 15 |
| 15 | 59 | 21 |
| 15 | 62 | 21 |
| 15 | 63 | 12 |
| 16 | 0 | 3 |
| 16 | 1 | 13 |
| 16 | 7 | 11 |
| 16 | 8 | 26 |
| 16 | 11 | 10 |
| 16 | 20 | 18 |
| 16 | 23 | 21 |
| 16 | 32 | 11 |
| 16 | 33 | 17 |
| 16 | 45 | 13 |
| 16 | 46 | 12 |
| 16 | 58 | 21 |

| | | |
|---|---|---|
| 16 | 63 | 23 |
| 16 | 64 | 3 |
| 17 | 1 | 11 |
| 17 | 2 | 16 |
| 17 | 5 | 6 |
| 17 | 9 | 9 |
| 17 | 11 | 15 |
| 17 | 19 | 10 |
| 17 | 25 | 17 |
| 17 | 29 | 6 |
| 17 | 38 | 11 |
| 17 | 46 | 9 |
| 17 | 47 | 5 |
| 17 | 54 | 20 |
| 17 | 64 | 16 |
| 17 | 65 | 8 |
| 18 | 3 | 16 |
| 18 | 7 | 15 |
| 18 | 16 | 1 |
| 18 | 31 | 0 |
| 18 | 41 | 13 |
| 18 | 65 | 15 |
| 18 | 66 | 17 |
| 19 | 0 | 20 |
| 19 | 6 | 8 |
| 19 | 15 | 4 |
| 19 | 34 | 1 |

| | | |
|---|---|---|
| 19 | 51 | 22 |
| 19 | 66 | 4 |
| 19 | 67 | 8 |
| 20 | 2 | 11 |
| 20 | 7 | 17 |
| 20 | 13 | 3 |
| 20 | 33 | 12 |
| 20 | 57 | 20 |
| 20 | 67 | 7 |
| 20 | 68 | 3 |
| 21 | 0 | 19 |
| 21 | 6 | 22 |
| 21 | 14 | 8 |
| 21 | 30 | 14 |
| 21 | 35 | 18 |
| 21 | 68 | 16 |
| 21 | 69 | 0 |
| 22 | 3 | 6 |
| 22 | 6 | 0 |
| 22 | 17 | 16 |
| 22 | 24 | 19 |
| 22 | 47 | 12 |
| 22 | 69 | 1 |
| 22 | 70 | 21 |
| 23 | 2 | 22 |
| 23 | 8 | 22 |
| 23 | 12 | 26 |

| | | |
|---|---|---|
| 23 | 23 | 1 |
| 23 | 70 | 5 |
| 23 | 71 | st |

**Table A.3 – Description of the matrix prototype of the rate 3/4 parity check matrix**

| Row | Col | Shift |
|---|---|---|
| 0 | 3 | 9 |
| 0 | 4 | 10 |
| 0 | 7 | 15 |
| 0 | 8 | 8 |
| 0 | 12 | 10 |
| 0 | 16 | 5 |
| 0 | 22 | 23 |
| 0 | 30 | 21 |
| 0 | 32 | 6 |
| 0 | 35 | 12 |
| 0 | 36 | 23 |
| 0 | 48 | 7 |
| 0 | 53 | 16 |
| 0 | 54 | 17 |
| 1 | 2 | 12 |
| 1 | 4 | 23 |
| 1 | 6 | 15 |
| 1 | 6 | 16 |
| 1 | 10 | 19 |
| 1 | 14 | 14 |
| 1 | 26 | 12 |
| 1 | 28 | 4 |
| 1 | 31 | 23 |
| 1 | 36 | 5 |
| 1 | 37 | 24 |
| 1 | 50 | 5 |
| 1 | 54 | 13 |
| 1 | 55 | 11 |
| 2 | 2 | 9 |
| 2 | 3 | 9 |
| 2 | 6 | 18 |
| 2 | 9 | 15 |
| 2 | 15 | 16 |
| 2 | 16 | 2 |
| 2 | 25 | 5 |
| 2 | 29 | 15 |
| 2 | 37 | 8 |
| 2 | 37 | 9 |
| 2 | 38 | 2 |
| 2 | 40 | 0 |
| 2 | 55 | 12 |
| 2 | 56 | 8 |
| 3 | 0 | 4 |
| 3 | 1 | 11 |
| 3 | 5 | 15 |
| 3 | 6 | 20 |
| 3 | 11 | 6 |
| 3 | 14 | 17 |
| 3 | 22 | 7 |
| 3 | 24 | 9 |
| 3 | 36 | 12 |
| 3 | 38 | 19 |
| 3 | 39 | 25 |
| 3 | 55 | 20 |
| 3 | 56 | 24 |
| 3 | 57 | 12 |
| 4 | 2 | 10 |
| 4 | 4 | 15 |
| 4 | 8 | 3 |
| 4 | 8 | 12 |
| 4 | 10 | 15 |
| 4 | 12 | 12 |
| 4 | 26 | 16 |
| 4 | 27 | 4 |
| 4 | 34 | 6 |
| 4 | 39 | 6 |
| 4 | 40 | 10 |
| 4 | 53 | 3 |
| 4 | 57 | 0 |
| 4 | 58 | 19 |
| 5 | 0 | 2 |
| 5 | 4 | 20 |
| 5 | 9 | 17 |

| | | |
|---|---|---|
| 5 | 10 | 24 |
| 5 | 11 | 17 |
| 5 | 17 | 17 |
| 5 | 21 | 9 |
| 5 | 23 | 4 |
| 5 | 33 | 25 |
| 5 | 40 | 24 |
| 5 | 41 | 15 |
| 5 | 49 | 14 |
| 5 | 58 | 22 |
| 5 | 59 | 23 |
| 6 | 1 | 14 |
| 6 | 1 | 16 |
| 6 | 5 | 17 |
| 6 | 7 | 5 |
| 6 | 13 | 0 |
| 6 | 17 | 7 |
| 6 | 28 | 14 |
| 6 | 29 | 12 |
| 6 | 35 | 16 |
| 6 | 41 | 24 |
| 6 | 42 | 5 |
| 6 | 56 | 19 |
| 6 | 59 | 23 |
| 6 | 60 | 4 |
| 7 | 0 | 8 |
| 7 | 1 | 7 |

| | | |
|---|---|---|
| 7 | 8 | 13 |
| 7 | 9 | 7 |
| 7 | 11 | 3 |
| 7 | 18 | 1 |
| 7 | 21 | 12 |
| 7 | 28 | 25 |
| 7 | 30 | 18 |
| 7 | 42 | 15 |
| 7 | 43 | 21 |
| 7 | 44 | 1 |
| 7 | 60 | 26 |
| 7 | 61 | 13 |
| 8 | 2 | 9 |
| 8 | 4 | 1 |
| 8 | 7 | 25 |
| 8 | 9 | 1 |
| 8 | 10 | 4 |
| 8 | 18 | 15 |
| 8 | 21 | 10 |
| 8 | 26 | 12 |
| 8 | 34 | 15 |
| 8 | 43 | 18 |
| 8 | 44 | 18 |
| 8 | 52 | 3 |
| 8 | 61 | 6 |
| 8 | 62 | 18 |
| 9 | 3 | 21 |

| | | |
|---|---|---|
| 9 | 4 | 13 |
| 9 | 5 | 8 |
| 9 | 9 | 5 |
| 9 | 18 | 6 |
| 9 | 20 | 3 |
| 9 | 22 | 13 |
| 9 | 27 | 17 |
| 9 | 39 | 8 |
| 9 | 44 | 14 |
| 9 | 45 | 15 |
| 9 | 59 | 21 |
| 9 | 62 | 21 |
| 9 | 63 | 12 |
| 10 | 0 | 3 |
| 10 | 1 | 13 |
| 10 | 7 | 11 |
| 10 | 8 | 26 |
| 10 | 11 | 10 |
| 10 | 20 | 18 |
| 10 | 23 | 21 |
| 10 | 32 | 11 |
| 10 | 33 | 17 |
| 10 | 45 | 13 |
| 10 | 46 | 12 |
| 10 | 58 | 21 |
| 10 | 63 | 23 |
| 10 | 64 | 3 |

| | | |
|---|---|---|
| 11 | 1 | 11 |
| 11 | 2 | 16 |
| 11 | 5 | 6 |
| 11 | 9 | 9 |
| 11 | 11 | 15 |
| 11 | 19 | 10 |
| 11 | 25 | 17 |
| 11 | 29 | 6 |
| 11 | 38 | 11 |
| 11 | 46 | 9 |
| 11 | 47 | 5 |
| 11 | 54 | 20 |
| 11 | 64 | 16 |
| 11 | 65 | 8 |
| 12 | 3 | 16 |
| 12 | 5 | 16 |
| 12 | 5 | 22 |
| 12 | 7 | 15 |
| 12 | 10 | 9 |
| 12 | 16 | 1 |
| 12 | 24 | 0 |
| 12 | 31 | 0 |
| 12 | 41 | 13 |
| 12 | 45 | 5 |
| 12 | 47 | 7 |
| 12 | 48 | 10 |
| 12 | 65 | 15 |

| | | |
|---|---|---|
| 12 | 66 | 17 |
| 13 | 0 | 20 |
| 13 | 3 | 13 |
| 13 | 6 | 8 |
| 13 | 10 | 0 |
| 13 | 13 | 20 |
| 13 | 15 | 4 |
| 13 | 20 | 23 |
| 13 | 34 | 1 |
| 13 | 42 | 7 |
| 13 | 48 | 21 |
| 13 | 49 | 14 |
| 13 | 51 | 22 |
| 13 | 66 | 4 |
| 13 | 67 | 8 |
| 14 | 2 | 11 |
| 14 | 3 | 8 |
| 14 | 7 | 1 |
| 14 | 7 | 17 |
| 14 | 11 | 3 |
| 14 | 13 | 3 |
| 14 | 25 | 24 |
| 14 | 33 | 12 |
| 14 | 46 | 3 |
| 14 | 49 | 3 |
| 14 | 50 | 7 |
| 14 | 57 | 20 |

| | | |
|---|---|---|
| 14 | 67 | 7 |
| 14 | 68 | 3 |
| 15 | 0 | 8 |
| 15 | 0 | 19 |
| 15 | 6 | 22 |
| 15 | 9 | 0 |
| 15 | 11 | 5 |
| 15 | 14 | 8 |
| 15 | 19 | 26 |
| 15 | 30 | 14 |
| 15 | 31 | 8 |
| 15 | 35 | 18 |
| 15 | 50 | 5 |
| 15 | 51 | 2 |
| 15 | 68 | 16 |
| 15 | 69 | 0 |
| 16 | 3 | 6 |
| 16 | 4 | 4 |
| 16 | 6 | 0 |
| 16 | 8 | 6 |
| 16 | 15 | 4 |
| 16 | 17 | 16 |
| 16 | 19 | 11 |
| 16 | 24 | 19 |
| 16 | 43 | 20 |
| 16 | 47 | 12 |
| 16 | 51 | 5 |

| | | |
|---|---|---|
| 16 | 52 | 16 |
| 16 | 69 | 1 |
| 16 | 70 | 21 |
| 17 | 1 | 10 |
| 17 | 2 | 22 |
| 17 | 5 | 24 |
| 17 | 8 | 22 |
| 17 | 10 | 13 |
| 17 | 12 | 26 |
| 17 | 23 | 1 |
| 17 | 27 | 3 |
| 17 | 32 | 26 |
| 17 | 52 | 7 |
| 17 | 53 | 24 |
| 17 | 70 | 5 |
| 17 | 71 | st |

**Table A.4 – Description of the matrix prototype of the rate 5/6 parity check matrix**

| Row | Col | Shift |
|---|---|---|
| 0 | 1 | 16 |
| 0 | 3 | 9 |
| 0 | 5 | 16 |
| 0 | 5 | 22 |
| 0 | 7 | 5 |
| 0 | 7 | 15 |
| 0 | 10 | 9 |
| 0 | 16 | 5 |
| 0 | 17 | 7 |
| 0 | 22 | 23 |
| 0 | 24 | 0 |
| 0 | 29 | 12 |
| 0 | 32 | 6 |
| 0 | 35 | 12 |
| 0 | 36 | 23 |
| 0 | 45 | 5 |
| 0 | 47 | 7 |
| 0 | 48 | 10 |
| 0 | 56 | 19 |
| 0 | 59 | 23 |
| 0 | 60 | 4 |
| 1 | 0 | 8 |
| 1 | 2 | 12 |
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| 1 | 6 | 16 |
| 1 | 8 | 13 |
| 1 | 10 | 0 |
| 1 | 10 | 19 |
| 1 | 13 | 20 |
| 1 | 18 | 1 |
| 1 | 20 | 23 |
| 1 | 26 | 12 |
| 1 | 28 | 25 |
| 1 | 31 | 23 |
| 1 | 36 | 5 |
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| 2 | 11 | 3 |
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| 11 | 29 | 6 |
| 11 | 38 | 11 |
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# Annex B – Closed Loop Information Exchange

Text in this section is informative.

Closed loop methods that improve transmission by providing feedback information from receiver to transmitter are compatible with this amendment. Specific management frames to feedback information are given in sections 7.4.5. These management frames enable both transmission mode feedback and channel feedback.

Transmission mode feedback allows a receiving station to inform a transmitting station of the preferred mode for the current channel conditions. The particular choice of mode is determined by the receiving station. The transmitting station may or may not use the particular mode, depending on its capabilities. A receiving station may also decline to provide a preferred mode.

Channel feedback provides a mechanism for a transmitting station to learn the precise channel seen at the receiver. This information may either be used as part of a calibration, for systems that assume channel reciprocity, or as direct channel feedback. The usage of channel feedback information is implementation dependent. Receiving stations may either provide a complete channel estimate or a null response.

# APPENDIX K

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# Abstract

The presentation summarizes the WWiSE proposal:

- What's new since the March meeting …
  - Membership update
  - Proposal updates
- The WWiSE proposal
  - Summary and overview
  - Details and technical information
- Conclusions
  - Towards Draft 1.0 …

# Expanded membership

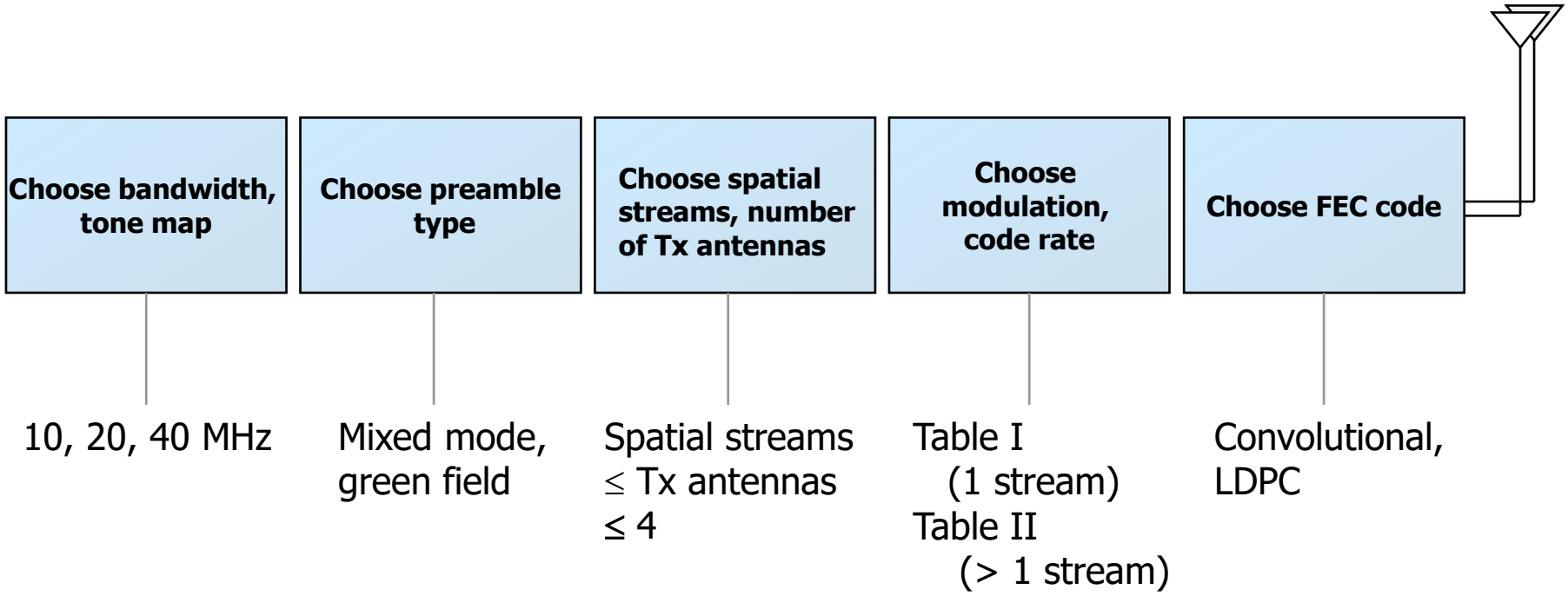
- Airgo Networks
- Broadcom
- Buffalo
- Conexant
- ETRI
- France Telecom
- *Hewlett Packard*
- Hughes Network Systems
- ITRI
- Motorola
- Nokia
- NTT
- Ralink
- Realtek Semiconductor
- *Siemens*
- STMicroelectronics
- Texas Instruments
- TrellisWare
- Winbond

# Summary of proposal changes

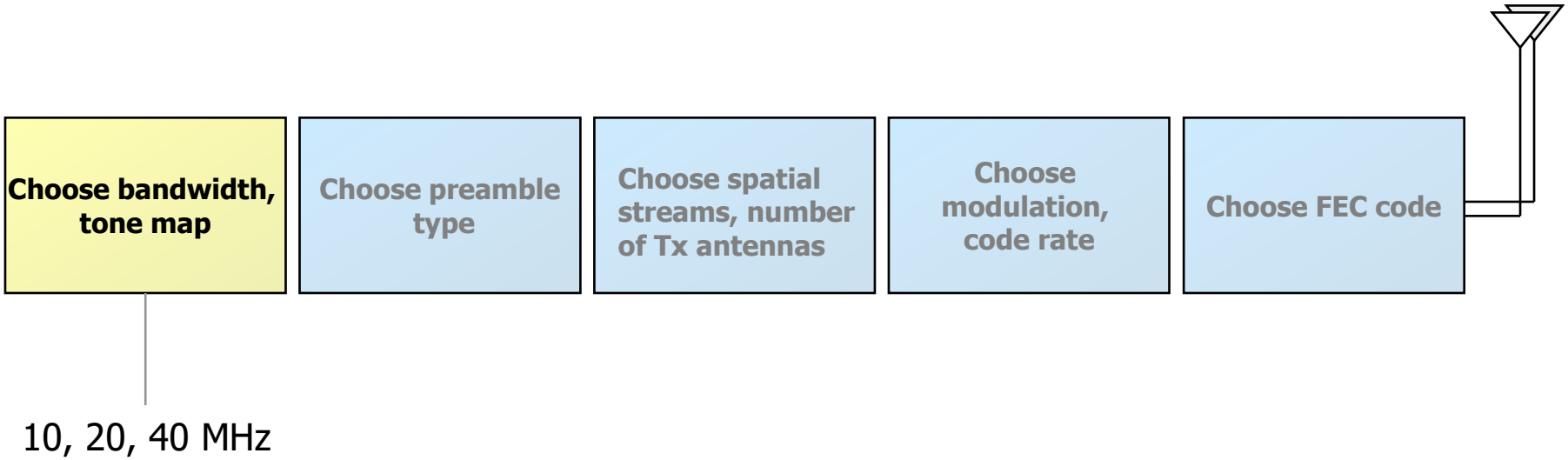
- Power save mechanism
- HT Block Ack
- Coexistence of Extended Range (ER) devices with Non-extended Range (NR) devices
- Secondary Channel Element
- Allowance and rules for zero-length PPDUs
- New LDPC code design
- Further beacon refinement for longer range, low rate

# WWiSE proposal summary

# WWiSE proposal summary (PHY)

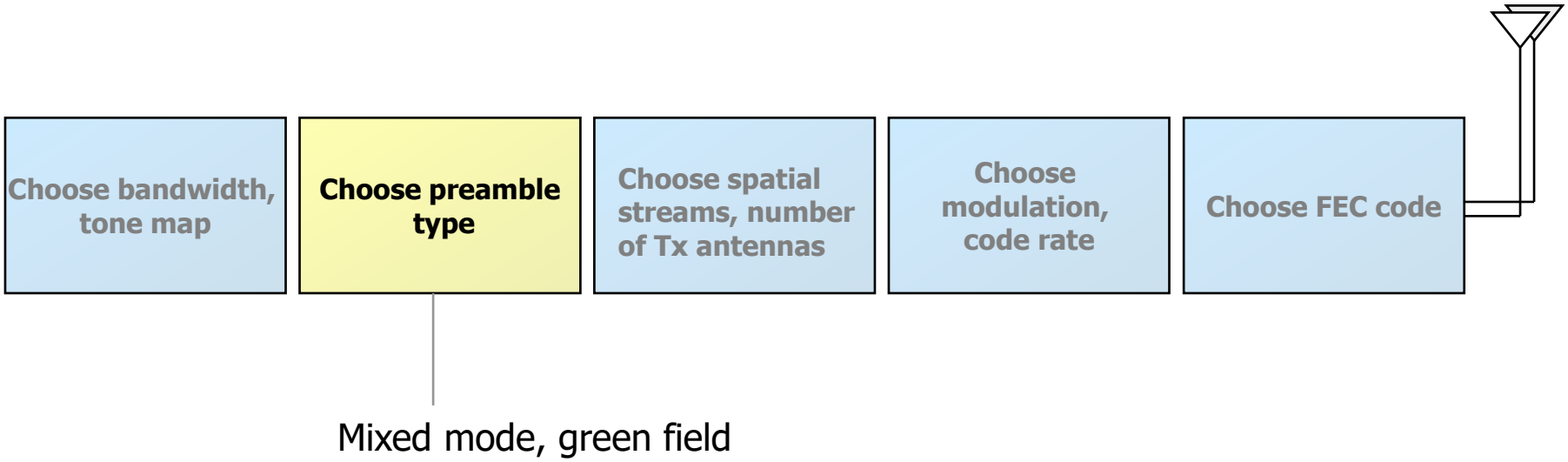


# WWiSE proposal summary, contd.



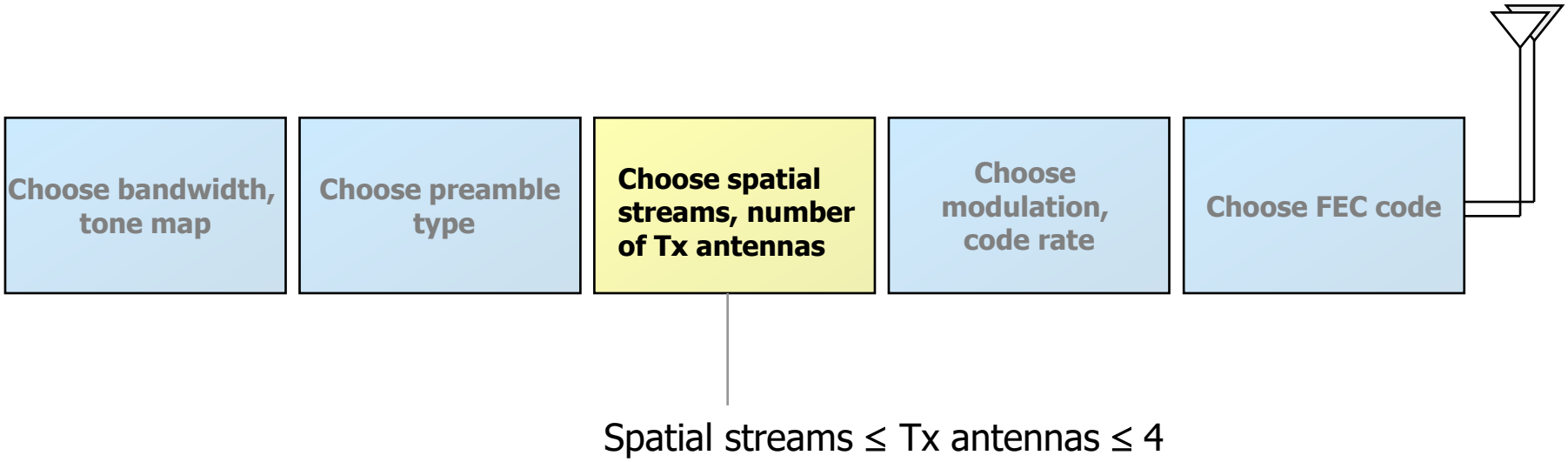

- Bandwidth determines tone map
- Increased efficiency for 10 & 20 MHz tone maps

# WWiSE proposal summary, contd.



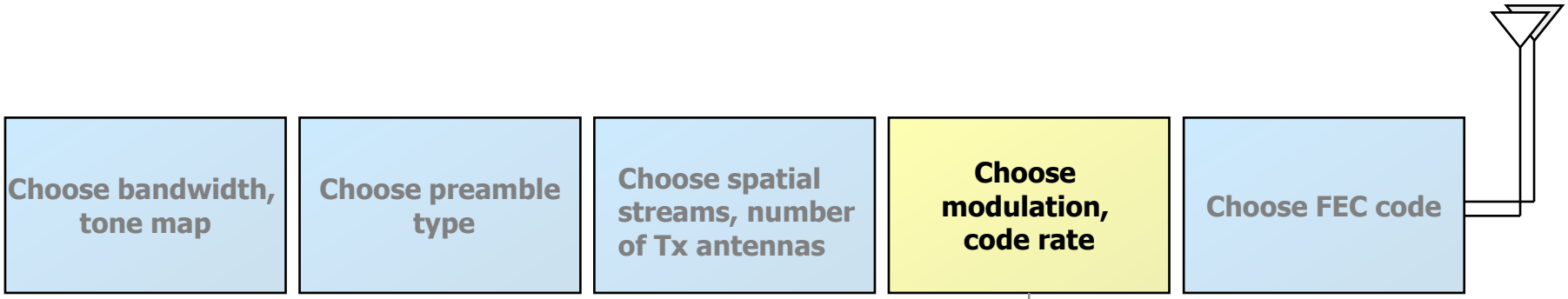

- Mixed mode preamble = green field preamble, with GF short replaced by full legacy preamble

# WWiSE proposal summary, contd.




- Simple two-symbol space-time block codes
- Cycle through transmit antennas for 3, 4 transmit antennas and single receive antenna

# WWiSE proposal summary, contd.




I

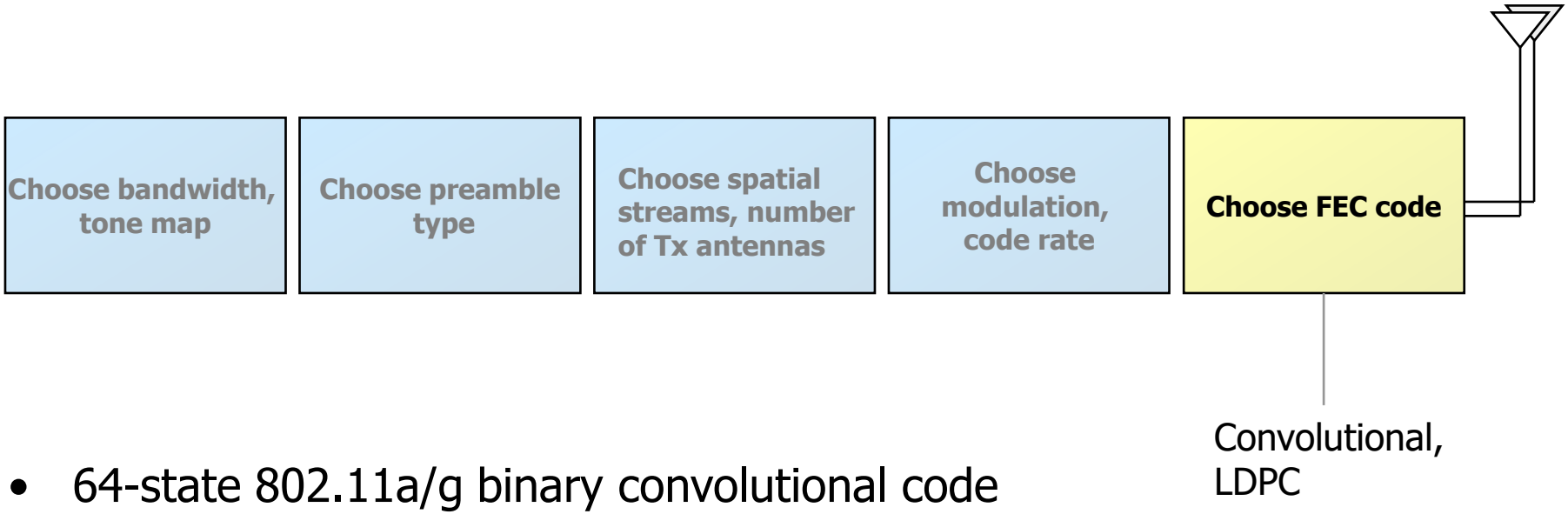
| Rate | Constellation |
|---|---|
| 1/2 | BPSK |
| 3/4 | " |
| 1/2 | QPSK |
| 3/4 | " |
| 1/2 | 16-QAM |
| 3/4 | " |
| 2/3 | 64-QAM |
| 3/4 | " |
| 5/6 | " |

II

| Rate | Constellation |
|---|---|
| 1/2 | 16-QAM |
| 3/4 | " |
| 2/3 | 64-QAM |
| 3/4 | " |
| 5/6 | " |

Table I (1 stream)
Table II (> 1 stream)

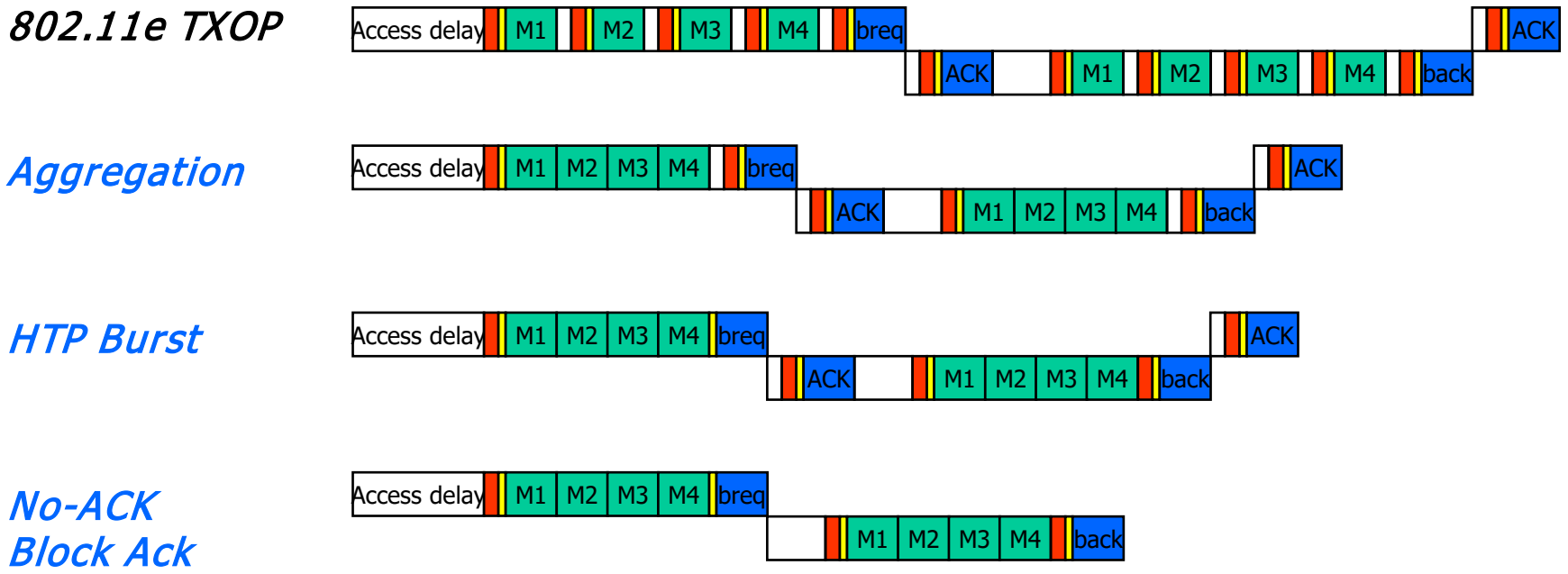
# WWiSE proposal summary, contd.




- 64-state 802.11a/g binary convolutional code
- Parallelized for > 2 spatial streams in 40 MHz, to enable efficient decoding
- LDPC code

# WWiSE proposal summary (MAC)

- WWiSE brings three simple efficiency enhancements over 802.11e:



# WWiSE proposal summary, contd.

- *Other features:*
  - Rate recommendation from receiver
  - Channel state information from receiver
  - 20/40 coexistence mechanisms
  - n-beacon, Long SIG

# Details and technical information on WWiSE proposal

# LDPC highlights

- The WWiSE LDPC code has been changed so that the four code rates have the corresponding uniform base matrix dimensions:
  - R=1/2 with base matrix size 12x24
  - R=2/3 with base matrix size 8x24
  - R=3/4 with base matrix size 6x24
  - R=5/6 with base matrix size 4x24
- The WWiSE proposal's three codeword sizes now having the following corresponding submatrix sizes:
  - N = 1944 using z = 81 (submatrix size)
  - N = 1296 using z = 54
  - N = 648 using z = 27

# LDPC highlights, contd.

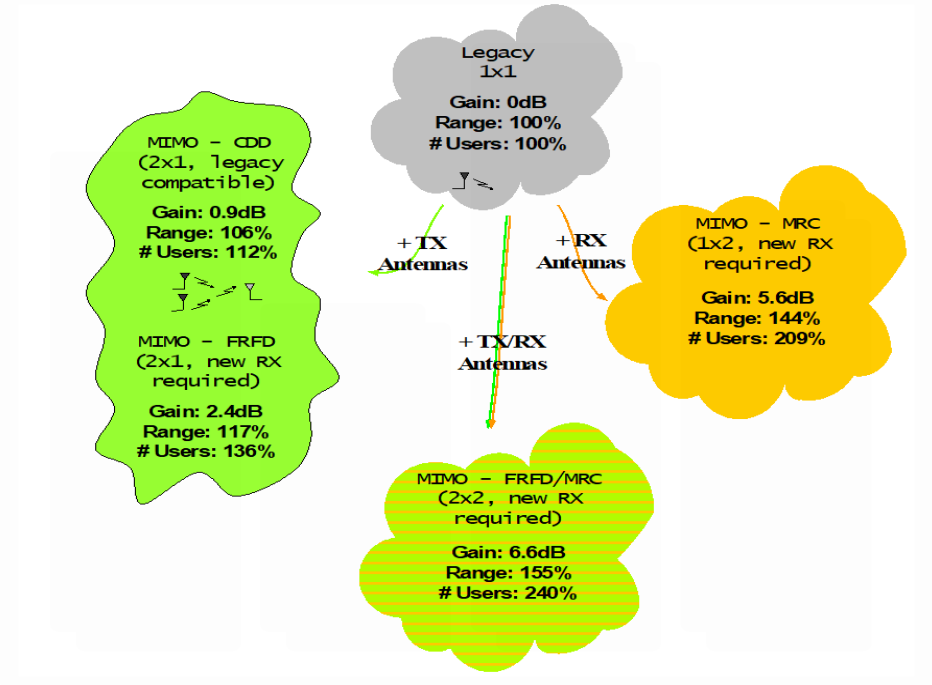
- Each code is designed with the following unified encoding structure:
  - Cyclically shifted identity matrices for the parity section
  - Modified block staircase for the information section
    - Modification allows for numerous high speed decoder architectures, including both high throughput Layered Belief Propagation and Turbo-like architectures
- The WWiSE proposal has improved error rate performance with no flooring exhibited across AWGN and fading channels.

# Extended Range features

- New & modified ER features:
  - The (optional) doubled length SIG field now has in addition a frequency domain permutation
    - This exploits frequency diversity and has performance consistent with robust STBC modes
  - MAC protection mechanisms have been finalized to allow peaceful Normal Range (NR), Extended Range (ER) coexistence
    - Both multiple/single TxOP protection schemes

# Range extension: from the PHY up to the MAC

- 4 main features need to be ensured to grant range extension
  - *Appropriate PHY modes:*
    - Enables enough coverage for handset applications: VoIP, video streaming
    - Allow a number of spatial streams lower than the number TX antennas!
  - *Beacon:* Enable association at extended range (ER): legacy beacon doesn't allow extended range stations to associate




- *Coexistence:* if PHY modes are not mandatory then MAC protection mechanisms are required to allow coexistence of extended/normal range (ER/NR) stations
- *Enable robust signaling:* define an 11n specific signal field that enables stations at a larger range to be able to understand the parameters of the incoming packets

# MAC features summary

There were three significant MAC modifications between March and July, relating to:

- PSAD mechanism
- HT Block Ack
- Coexistence of Extended Range (ER) devices with Non-extended Range (NR) devices
- Secondary Channel Element
- Allowance and rules for zero-length PPDUs.

# PSAD

- Power Save Aggregation Descriptor
  - Allows more precise management of power for power-saving devices
  - Effectively a multi-poll
    - Includes per-STA descriptor
      - Downlink information per STA: start, duration
      - Uplink information per STA: start, duration
    - Allows each STA to wake up for receipt of PSAD frame, then sleep again until specified Down and/or Up periods
    - New capability bit to indicate support

# HT Block Ack

- Added mechanisms to Block Ack from 802.11e
  - BA Request and BA frames with expanded fields to allow multiple TID request/reporting
    - BAR frame includes indication of whether BA shall be per MPDU or per MSDU
    - Variable length of BA bitmap – value indicated in frame
  - Implicit BA option
    - Allows per-”n” BA response
  - New BA negotiation options to enable new modes
    - Capability signaling

# ER Coexistence – issues

- WWISE proposal includes STBC rates for Extended Range
  - These rates are OPTIONAL
    - ER device
      - A device which optionally supports the STBC rates in addition to the mandatory rates
    - NR device
      - A device which optionally does NOT support the STBC rates, but supports the mandatory rates
  - Existence of two classes of devices (ER/NR) creates an opportunity for hidden nodes
    - ER devices can be attached to the BSS at a greater distance from the AP
    - At such range, the ER devices can no longer communicate with the AP at the non-ER rates (NR rates)
    - ER devices will miss NR "protective frames" e.g. RTS/CTS (any frame with a non-zero DUR field value)
    - This creates a hidden node situation

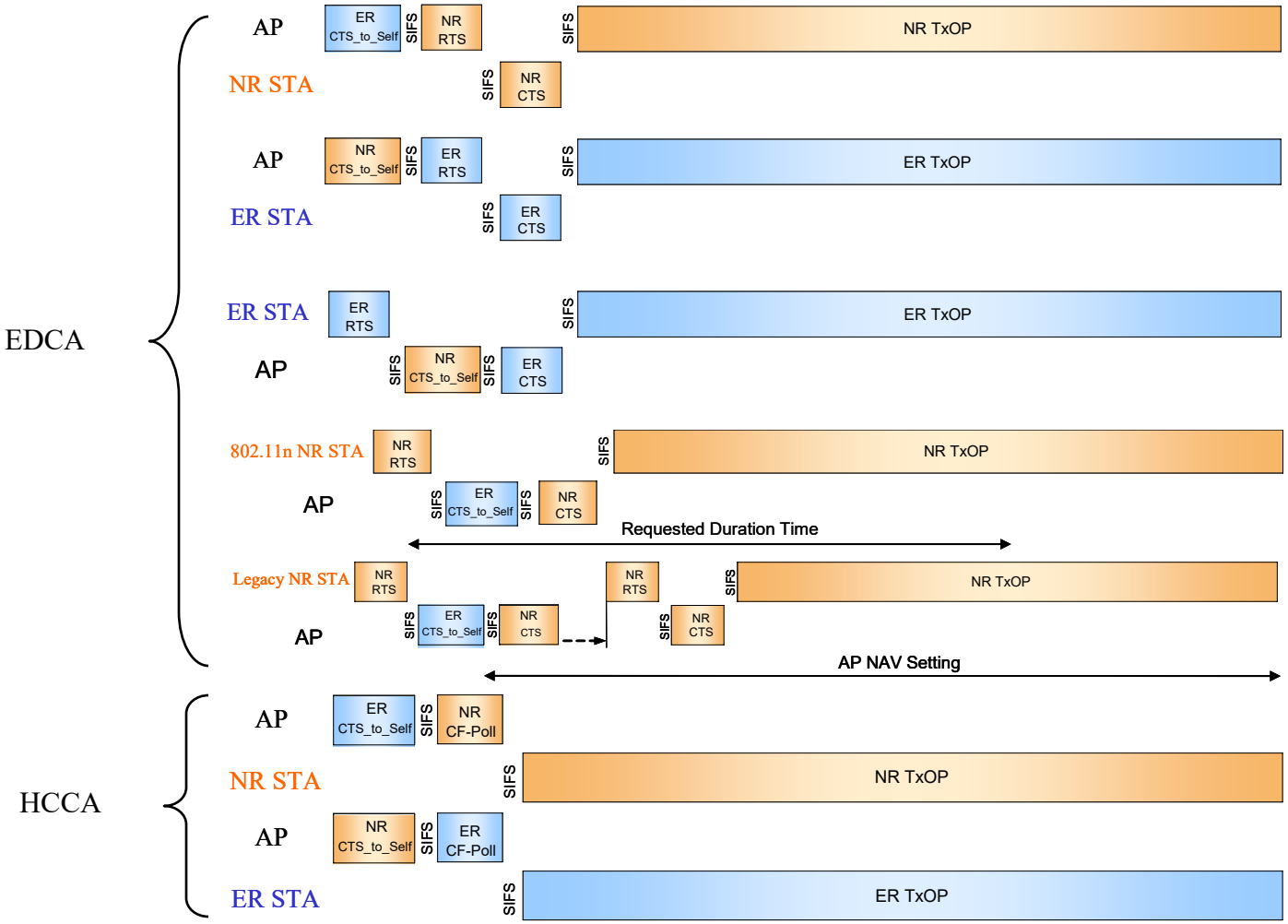
# ER coexistence

- ER Beacon, NR Beacon
  - Separate beacons with same periodicity, but ER TBTT offset from NR TBTT
  - ER MCAST follows ER Beacon
  - NR MCAST follows NR Beacon
  - TSF value is common, offset describes shift
    - Offset contained in beacons (new field in ERP Information Element)
- Use_ER_Protection signal (a new bit added to existing ERP Information element)
  - This Element is included in Beacons, Probe Responses
- ER Protection mechanisms
  - Self-managed
  - AP-managed

# ER-protection – Self-managed

- Self-managed protection
  - AP with ER STA associated
    - Sends NR CTS-to-self before ER exchange (either EDCA or HCCA)
    - Sends ER CTS-to-self before NR exchange (either EDCA or HCCA)
  - Non-AP ER STA send ER RTS, receive NR CTS followed by ER CTS
  - Non-AP NR STA send NR RTS, receive ER CTS followed by NR CTS
  - Legacy STA send NR RTS, receive ER CTS follwed by NR CTS
    - They either accept the "late CTS" and continue, or they declare a timeout and backoff and try again
      - Other devices in deferral due to the ER CTS and/or NR CTS during backoff

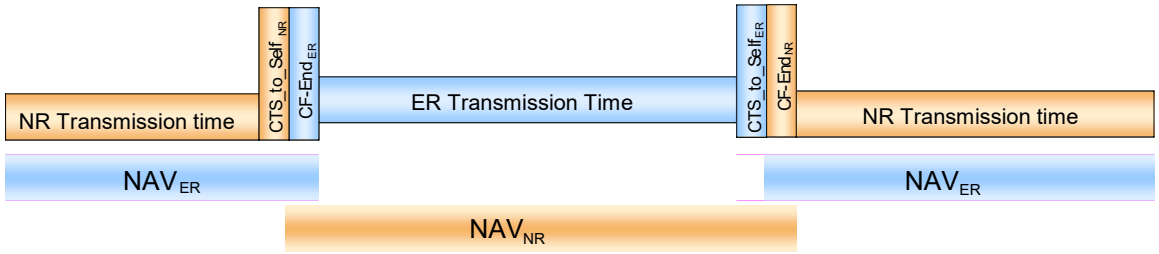
# Self-managed ER Protection



# ER-protection – AP-managed

- AP-managed protection
  - The AP creates separate time windows for ER operation and NR operation
    - Sends CTS-to-self/CF-end combination at the start of each period
      - E.g. NR CTS-to-self with ER CF-end to create ER-friendly period
    - Dynamic creation
    - Informatively described

# AP-managed ER Protection



# Zero-length PPDU

- Allow Zero-length PPDU
  - WWISE proposal includes A-PPDU aggregation
    - Aggregation of multiple PSDUs within a single PPDU
    - Each PSDU has its own signal field
    - New language allows use of signal fields with an indicated ZERO length
    - Allows for speculative A-PPDU aggregation
      - LP=0 for all frames
    - If TX FIFO underflow, then set LP=1 with ZERO length
    - LP shall be set to 1 when LEN=0
  - 20.3.4 (signal fields) – one sentence added:
    - When the LEN field is set to 0, no PSDU bits are present and the Last PSDU indicator (LPI) shall be set to 1 to end the current PPDU.

# New Secondary Channel Element

- Addition of a new element to provide information regarding the secondary channel
  - For cases when:
    - BSS moves from one 40-MHz pair to a different 40-MHz pair
    - BSS moves from a 20-MHz pair to a 40-MHz pair
  - Description of appropriate behavior for transition from a 40-MHz pair to a 20-MHz channel is also given
  - This new element is added to some management frames as part of the existing channel switch mechanisms:
    - Beacons
    - Probe resopnses
    - Channel Switch Announcement frames

# WWiSE proposal features, summary

- High-performance PHY and MAC
- Modularity and simplicity in PHY design
  - Eases interoperability and verification, enables faster time to market and provides true scalability
- Efficient, streamlined MAC extensions
  - High performance, no unnecessary complexity
- Well defined, stable technical specification
  - Suitable for immediate use as Draft 1.0

# References and further information


1. IEEE 802.11/05-0149-05-000n, "WWiSE group PHY and MAC specification," C. Kose, B. Edwards, et al.
2. IEEE 802.11/04-0877-09-000n, "WWiSE proposal response to functional requirements and comparison criteria," C. Hansen, M. Fischer, et al.
3. IEEE 802.11/04-0935-r3-000n and –r4-000n, IEEE 802.11/05-1591r3, "WWiSE complete proposal presentation," S. Coffey et al.
4. IEEE 802.11/05-0016-02-000n, "WWiSE MAC proposal for TGn," M. Fischer et al.


See also www.wwise.org

Or send email to info@wwise.org

# APPENDIX M

27-Jun-2023 22:19:44 ET

# Documents

Join group

Everything | 2005 | TGn (inactive)

July

| Created (ET) ▼ | Year | DCN | Rev | Group | Title | Author (Affiliation) | Uploaded (ET) | Actions |
|---|---|---|---|---|---|---|---|---|
| 27-Jul-2005 ET | 2005 | 665 | 0 | TGn | Tgn Minutes July 2005 Meeting | Garth Hillman (AMD) | 27-Jul-2005 00:00:00 ET | Download |
| 22-Jul-2005 ET | 2005 | 760 | 0 | TGn | Tgn July Closing Report | Bruce Kraemer (Conexant) | 22-Jul-2005 00:00:00 ET | Download |
| 21-Jul-2005 ET | 2005 | 557 | 1 | TGn | Tgn July 05 Opening Report | Bruce Kraemer (Conexant) | 21-Jul-2005 00:00:00 ET | Download |
| 19-Jul-2005 ET | 2005 | 737 | 1 | TGn | Wwise Complete Proposal Presentation July 2005 | Sean Coffey (RealTek) | 19-Jul-2005 00:00:00 ET | Download |
| 19-Jul-2005 ET | 2005 | 737 | 0 | TGn | Wwise Complete Proposal Presentation July 2005 | Sean Coffey (RealTek) | 19-Jul-2005 00:00:00 ET | Download |
| 18-Jul-2005 ET | 2005 | 706 | 0 | TGn | Single Stream Adhoc Minutes July 18 | Nico van Waes (Nokia) | 18-Jul-2005 00:00:00 ET | Download |
| 18-Jul-2005 ET | 2005 | 557 | 0 | TGn | Tgn July 05 Opening Report | Bruce Kraemer (Conexant) | 18-Jul-2005 00:00:00 ET | Download |

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# APPENDIX N

# TGn Opening Report – July '05

**Date:** 2005-07-16

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# This Opening Report 05-0557

## Administrative Intro

**Attendance server**
**http://802wirelessworld.com**
**Is not available**

**Mark attendance at registration desk**

1.

## *IEEE-SA Standards Board Bylaws* on Patents in Standards

**Approved by IEEE-SA Standards Board – May 2004**

### 6. Patents

IEEE standards may include the known use of essential patents and patent applications, provided the IEEE receives assurance from the patent holder or applicant with respect to patents essential for compliance with both mandatory and optional portions of the standard. This assurance shall be provided without coercion and prior to approval of the standard (or reaffirmation when a patent becomes known after initial approval of the standard). This assurance shall be a letter that is in the form of either:

a) A general disclaimer to the effect that the patentee will not enforce any of its present or future patent(s) whose use would be required to implement the proposed IEEE standard against any person or entity using the patent(s) to comply with the standard or

b) A statement that a license will be made available without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination

This assurance shall apply, at a minimum, from the date of the standard's approval to the date of the standard's withdrawal and is irrevocable during that period.

# Inappropriate Topics for IEEE WG Meetings

**Approved by IEEE-SA Standards Board – March 2003**

- **Don't discuss licensing terms or conditions**
- **Don't discuss product pricing, territorial restrictions or market share**
- **Don't discuss ongoing litigation or threatened litigation**
- **Don't be silent if inappropriate topics are discussed… do formally object.**

If you have questions,
contact the IEEE-SA Standards Board Patent Committee Administrator at patcom@ieee.org

# Additional Guidance

1. After a patent letter of assurance (LoA) has been accepted by PatCom, it is allowable for a presenter to state that an LoA has been filed by a Patent Holder, accepted by PatCom, and listed in the online listing of LoAs at http://standards.ieee.org/db/patents/index.html

2. Anyone seeking a copy of the accepted LoA should contact the PatCom Administrator.

3. Discussion of the content of accepted, submitted, or proposed LoAs is prohibited.

4. 3. Discussion of licensing terms and conditions is prohibited.

# Attendance, Voting & Document Status

**If you have Attendance questions during the session talk to Harry Worstell**

- **Questions on Voting status, Ballot pool, Access to Reflector**
- **– see Harry Worstell –**
  - hworstell@att.com
- **Make sure your badges are correct**
- **Make sure your submissions contain no company logos or advertising**

# Attendance Recording -802.11

- **A sign-in sheet will be located at the 802 Concierge desk (Street level)**
- **Each member must sign-in "once" (1) per day, between the hours of 0800 and 1800 local time**
- **Participants must "sign" their name in the appropriate place and state of attendance for 802.11 that day in terms of AM1/AM2, PM1/PM2, EV1 (if an evening meeting exists)**
  - Only **"sign-in"** for yourself, **do NOT "sign-in"** for and other participate.
- **Attendance will be checked against other 802 groups.**
- **Those found abusing the honor system will loose ALL credit for that day.**
- **These sheets are provided daily. If you don't sign up during the "regular sign-in" hours, you will NOT be given credit for that day.**

# TGn Quick Review
# of
# May 16-20 ’05 Meeting
# in
# Cairns, Queensland, Australia

# Activity Highlights - Plans for May

- ✓ **Proposal team Presentation of responses (6 hrs)**
  - ✓ Present original votes, remedies, responses
  - ✓ Present updated proposal
- ✓ **Group discussion, Q&A (6 hours)**
- ✓ **Other technical presentations**
- ✓ **Confirmation vote #2 (2 hr)**
- ▪ **Elect technical editor**
- ✓ **Coexistence Assurance document development with .19**
- ✓ **Plans for July**
- ▪ **Update timeline**
- ✓ **Create ad hoc to consider single spatial stream change to FR**

# New Documents posted between May – July '05 as of Monday July 18

**Submissions**

- 05-0416 r1 Garth Hillman "TGn May Minutes"
- 05-0550 r2 Single stream ad hoc telecon minutes
- 05-0559 r3 Single Stream ad hoc group
- 05-0149 r5 WWiSE Proposal
- 04-1372 r5 MITMOT TGn Complete Proposal Detailed Description
- 04-0891 r7 TGnSync Proposal "PHY results"
- 04-0888 r12 TGnSync Proposal "Presentation"
- 04-0889 r7 TGnSync Proposal "Technical Specification"
- 04-0893 r6 TGnSync Proposal "MAC1 simulation results"
- 04-0894 r6 TGnSync Proposal "MAC2 simulation results
- 04-0895 r6 TGnSync Proposal "MAC simulation results"
- 04-0889 r5 TGnSync Proposal "Technical Specification"
- 04-0892 r7 TGnSync Proposal "MAC Results"
- 05-0415 r1 Security aspects of MAC aggregation

# Additional TGnSync Documents posted during Monday Session

**Submissions**

- ✓ **05-0380 r0 TGnSync "Proposal Update to TGn May 2005" (ppt)**
- ✓ **05-0388 r1 TGnSync "PHY responses to reasons and cures" (ppt)**
- ✓ **05-0410 r0 TGnSync "MCS set details in response to reasons and cures"**
- ✓ **05-0414 r0 TGnSync "Calibration reasons and cures"**
- ✓ **05-0431 r0 TGnSync "LDPC codes responses to reasons and cures"**
- ✓ **05-0413 r1 TGnSync "MAC responses to reasons and cures"**
- ✓ **05-0421 r0 TGnSync "Link adaptation responses to reasons and cures"**
- ✓ **05-0425 r0 TGnSync "Frame-formats**
- ✓ **05-0432 r0 TGnSync "Aggregation**
- ✓ **05-0430 r0 TGnSync "Frame-formats**
- ✓ **05-0424 r0 TGnSync "Pair-wise spoofing**

# Additional TGnSync Documents posted during Tuesday Session

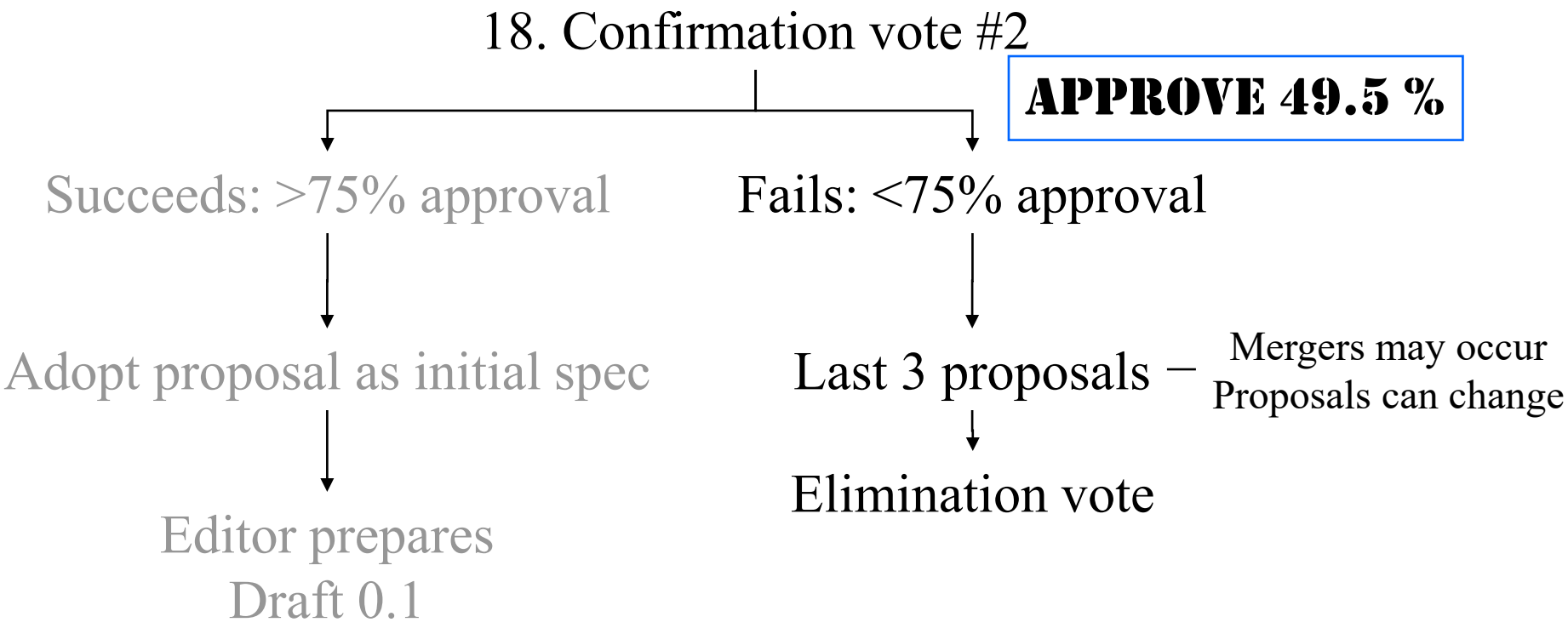
**Submissions**

- ✓ **05-0405 r0 TGnSync "Reverse Direction response to reasons and cures" (ppt)**
- ✓ **05-0396 r0 TGnSync "ICB/DCB Frames response to reasons and cures" (ppt)**
- ✓ **05-0418 r0 TGnSync "PHY updates to Proposal"**
- ✓ **05-0447 r0 TGnSync "PHY questions for TGn"**
- ✓ **05-0444 r0 TGnSync "MAC questions for TGn"**

# Other Presentations
# Wed 1:30

- 05-0399 Handset related Technical requirements (30 min)
- 05-0415 Security aspects of MAC aggregation (20 min)
- 05-0485 Comments on TGnSync Proposal

# Next Steps


18. Confirmation vote #2
APPROVE 49.5 %
Succeeds: >75% approval
Fails: <75% approval
Adopt proposal as initial spec
Last 3 proposals –
Mergers may occur
Proposals can change
Editor prepares Draft 0.1
Elimination vote

# .11n Technical Editor Election

- **Nominations are closed**
- **Technical editors meeting 7 - 8 am**
  - Meeting room #7
- **Elections planned for Thursday 16:00**

- **Candidates: Adrian Stephens, Sean Coffey**
- **Move to delay the technical editor election until a proposal is formally confirmed.**
- **Move: Adrian**
- **Second: Sean**
- **Approved by unanimous consent**

# Plans for July

**Reuse Agenda for January as a place holder for now**

- **Which in rough outline form will be:**

**Now to July**

- **Update technical proposals posted by 10 days prior to July meeting**
- **Email questions**

**Single Stream adhoc teleconferences every 2 weeks beginning June 6**

**In Session July 18-22**

- **Proposal presentations**
- **Q&A**
- **Elimination vote**

# TGn May Minutes 05-0416r1 Summary

- **Executive Summary (also see Chairs' meeting doc 11-05-0315r5 and closing report doc. 11-05-0470r0):**
- **TGn Sync responded to all Reasons & Cures (6 hours).**
- **There were a total of 20 input documents including the chair's running agenda document.**
- **There were 2 output documents, the closing report and these minutes.**
- **Approximately 6 hours were devoted to Q&A from the floor.**
- **Roll Call Confirmation Vote #2 was held and failed (96 for, 98 against) to achieve the required 75% threshold. [Roll Call vote spread sheet is appended to these minutes.]**
- **The Time Line was not updated due to the uncertainty resulting from the failed Confirmation Vote #2.**
- **The election of a Technical Editor was deterred until such time as a confirmation vote is successful and a baseline document therefore identified.**
- **Motion was passed to hold TGn biweekly teleconference calls, starting June 6, to develop a Coexistence Assurance (CA) document. Note that TGn will likely be the first TG to develop a CA document. [Logistics TBD]**
- **Motion was passed to form a subcommittee to update the Functional Requirements to recognize the importance and uniqueness of single stream devices (e.g., handhelds). Tim Wakeley and Marc de Courville volunteered to co-chair the subcommittee. Biweekly teleconference calls will be held starting June 1. [Logistics TBD]**
- **Plans for July are dependent on the activities between this meeting and the July Plenary as a consequence of the failed Confirmation Vote #2. Roughly speaking, if there is no merger the agenda will revert to the January 2005 agenda where three proposals were considered – TGn Sync, TGn WWiSE and TGn MitMot (Motorola); and an Elimination Vote will be held.**

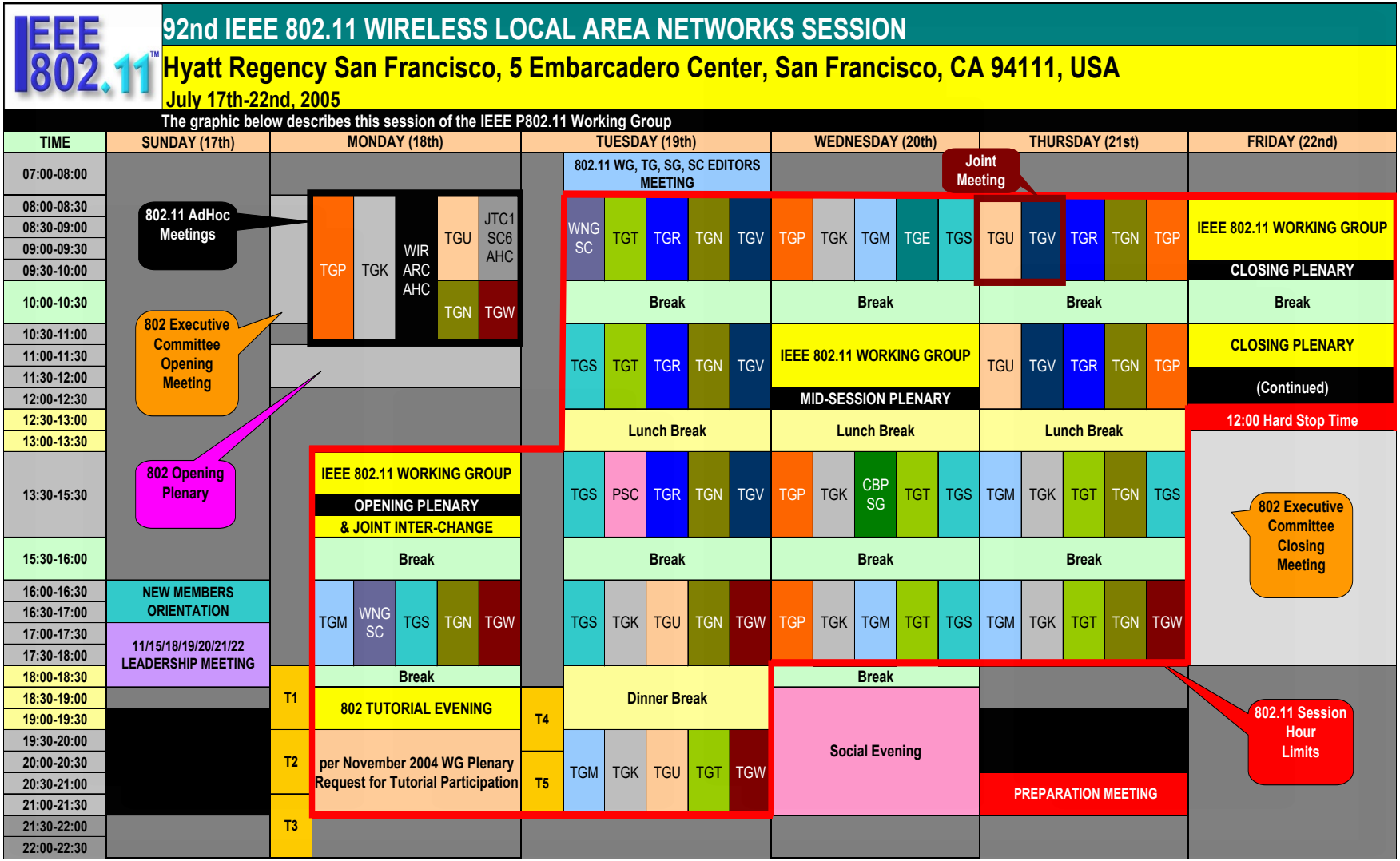
# Approve Minutes

- **Motion to approve minutes as contained in 05-0416-r1**

- **Move:**
- **Second:**

# Current Plans for July

# WG Agenda – 05-0452r2 – July 2005

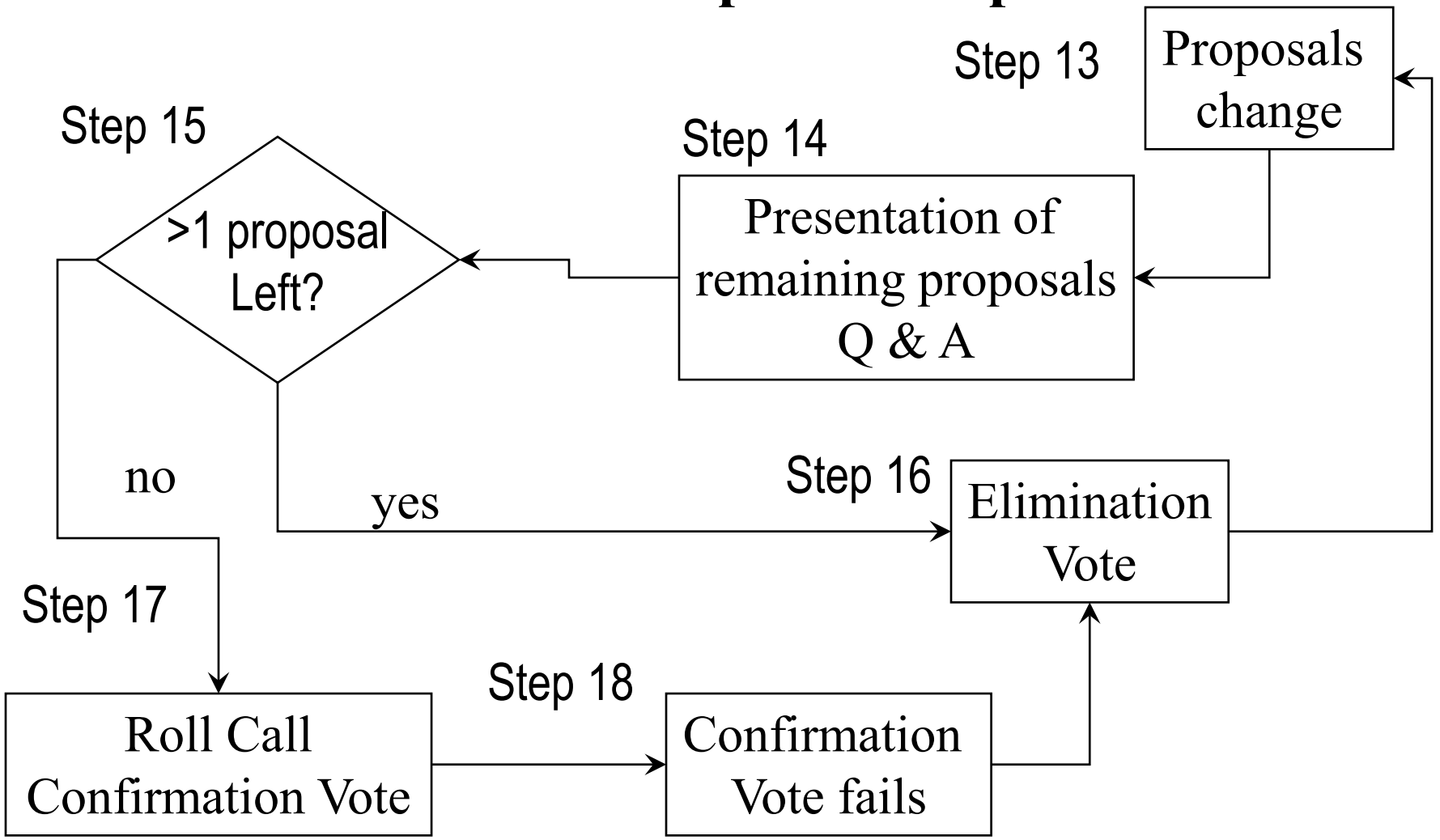


# TGn - July Schedule

**Meeting Room:**

| | July 18 | July 17 | July 18 | July 19 | July 20 |
|---|---|---|---|---|---|
| Time | Monday | Tuesday | Wednesday | Thursday | Friday |
| 8:00-10:00 | ⊘ | 4 | ⊘ | 12 | |
| 10:30-12:30 | ⊘ | 6 | ⊘ | 14 | |
| 13:30-15:30 | ⊘ | 8 | ⊘ | 16 | |
| 16:00-18:00 | 2 | 10 | ⊘ | 18 | |
| 19:30-21:30 | ⊘ | ⊘ | ⊘ | ⊘ | |

# Simplified graphic from TGn Selection Procedure 03-665r9 Step 13 to Step 17



# 03-665r9 Step 17

17. When one proposal is left, there shall be a confirmation roll call vote either in favor of the proposal or for none of the above. The proposal shall be required to achieve a 75% majority in order to be submitted to the IEEE 802.11n Editor as the initial technical specification. If the remaining proposal fails to achieve a 75% majority, the members who voted "no" shall be requested to provide to the chair their reason(s) for voting no and what would be required to change their vote to affirmative. The proposer shall have an opportunity to respond to the concerns of the no voters, after which a roll call vote will be taken to approve the proposal.

# Procedure from doc.: IEEE 802.11-03/665r9

- **Step 16:**
- **Rounds of voting will be held that successively eliminate one candidate proposal at a time. On each round of voting, the candidate proposal that receives the least number of votes shall be eliminated from consideration. In the event of a tie for the least number of votes, a separate vote shall be held to select which of the candidates receiving the least votes shall be eliminated in the current round. The other candidate(s) shall remain for the next round. Between rounds of voting, presenters will again have the opportunity to merge proposals and/or make technical changes to their proposals. If a merger occurs or if technical changes are made to a proposal, all presenters shall have the opportunity to present the details of their proposal again. If two or more proposals are left, time permitting and at the discretion of the TGn Chair there may be a Panel Discussion with all the remaining Presenters. The rounds of voting will continue until only one candidate proposal remains. The order in which the proposals are eliminated will be recorded in the minutes. This ordering will serve as the ranking of the eliminated proposals needed in step 18.**

# Selection Procedure (continued)

11. During steps 9, 16 and 18, mergers will be allowed between remaining proposals, and between remaining proposals and proposals that have been eliminated. Mergers will not be allowed between eliminated proposals only. The TGn chair will provide an opportunity for the task group to decide by simple majority whether proposals that have merged or that have technical changes require normal time for consideration prior to a down-selection vote (4 meeting hours) or require extended time. **Time extension beyond 24 hours shall require support of 2/3 of the voting members present.**

# TGn - July Schedule – Meeting room:Grand A or B

| | Jul 18 | Jul 19 | Jul 20 | Jul 21 |
|---|---|---|---|---|
| Time | Monday | Tuesday | Wednesday | Thursday |
| 8:00-10:00 | ⊘ | Recess | ⊘ | Recess |
| 10:30-12:30 | ⊘ | Recess | ⊘ | Recess |
| 1:30-3:30 | ⊘ | UCLA Presentation<br>Proposal Updates | ⊘ | CA status<br>Merger Status |
| 4:00-6:00 | Opening, Agenda<br>Minutes,<br>Merger Status<br>CA & SS status | Single Stream<br>(if needed) | ⊘ | Sept plans |
| 7:30-9:30 | ⊘ | ⊘ | ⊘ | ⊘ |

# Merger Status

**Collaborative status presentations from proposal groups:**

- **WWiSE- Sean**
- **TGnSync – Aon**
- **MITMOT - Marc**

# TGn - July Schedule – Meeting room:Grand A or B

| | Jul 18 | Jul 19 | Jul 20 | Jul 21 |
|---|---|---|---|---|
| Time | Monday | Tuesday | Wednesday | Thursday |
| 8:00-10:00 | ⊘ | Recess | ⊘ | Recess |
| 10:30-12:30 | ⊘ | Recess | ⊘ | Recess |
| 1:30-3:30 | ⊘ | UCLA Presentation<br>Proposal Updates | ⊘ | CA status<br>Merger Status<br>Q&A |
| 4:00-6:00 | Opening, Agenda<br>Minutes,<br>Merger Status<br>CA & SS status & plans | Single Stream<br>(if needed) | ⊘ | Sept plans |
| 7:30-9:30 | ⊘ | ⊘ | ⊘ | ⊘ |

# Approve Agenda

- **Motion to approve agenda as outlined in slide 28.**

- **Move:**
- **Second:**

# End of Opening Report

# APPENDIX O

# TGn Closing Report – July '05

**Date:** 2005-07-16

## Authors:


| Name | Company | Address | Phone | email |
|---|---|---|---|---|
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# Plans for July

**Reuse Agenda for January as a place holder for now**

- **Which in rough outline form will be:**

**Now to July**

- **Update technical proposals posted by 10 days prior to July meeting**
- **Email questions**

**Single Stream adhoc teleconferences every 2 weeks beginning June 6**

**In Session July 18-22**

- **Proposal presentations**
- **Q&A**
- **Elimination vote**

# Motion:

**Moved: Because the TGn selection process allows proposals to ask for time to complete mergers prior to consideration, M&T&W are granted time to complete a merged Joint Proposal (JP) that will replace the current three remaining TGn proposals.**

**The time line is:**

**July 2005:**

- Provide time this week (ref 5557R0 Bruce's opening report) for these groups to go work on this effort.

**Sept 2005**

- JP draft will be provided to TGn; Q&A sessions on JP to that time.

**November 2005:**

- JP replaces current 3 proposals; Confirmation vote on JP.

Vote: 195/2/3

# TGn - January Schedule

| | Jul 18 | Jul 19 | Jul 20 | Jul 21 |
|---|---|---|---|---|
| Time | Monday | Tuesday | Wednesday | Thursday |
| 8:00-10:00 | ⊘ | Recess | ⊘ | Recess |
| 10:30-12:30 | ⊘ | Recess | ⊘ | Recess |
| 1:30-3:30 | ⊘ | UCLA Presentation<br>Proposal Updates | ⊘ | Single stream<br>CA status<br>Merger Status |
| 4:00-6:00 | Opening, Agenda<br>Minutes,<br>Merger Status<br>CA & SS status | Single Stream<br>(if needed) | ⊘ | Sept plans<br>Utah<br>Presentation |
| 7:30-9:30 | ⊘ | ⊘ | ⊘ | ⊘ |

# Motion on adding FR10 and FR11

- **Motion: adopt new revision of document 11-03-0813-13-000n-functional-requirements containing the following changes: addition of FR10 and FR11.**
  - FR10: Existence of single spatial stream transmission modes
    - **Requirement:**
      - Proposal shall define single spatial stream transmission modes that provide at least one mode of operation that supports a maximum throughput of at least 50 Mbps in a 20MHz channel as measured at the MAC data SAP.
  - FR11: Interoperability with single spatial stream non AP stations
    - **Requirement:**
      - A .11n AP or STA shall interoperate with a single spatial stream entity defined as a non-AP STA that complies with the .11n proposal with the exception of only supporting single spatial stream transmission modes as required by FR10.




Vote: 110/0/7

# September Agenda Plan

**Between now and September**

- No teleconference calls for SS or CA will be needed
- Partial merged proposal draft posted to server & announced on reflector by Monday Sept 12
- Question submission via email Thursday Sept 15
- Responses will be presented beginning Monday Sept 19

**September Meeting Plan (Monday = September 19)**

- Merged proposal  Presentation & Discussion
- Coexistence Assurance status update
- Review Document linkage for changed FR
- Formulate and Consider WFA liaison request

# Technical Proposal Documents

**Submissions**

- 05-0416 r2 Garth Hillman "TGn May Minutes"
- 05-0550 r2 Single stream ad hoc telecon minutes
- 05-0149 r5 WWiSE Proposal 05-0735 r0 MitMot Proposal Update Presentation
- 05-0737 r0 WWiSE Complete Proposal Presentation
- 04-1372 r5 MITMOT TGn Complete Proposal Detailed Description
- 04-0891 r7 TGnSync Proposal "PHY results"
- 04-0888 r13 TGnSync Proposal "Presentation"
- 04-0889 r7 TGnSync Proposal "Technical Specification"
- 04-0893 r6 TGnSync Proposal "MAC1 simulation results"
- 04-0894 r6 TGnSync Proposal "MAC2 simulation results"s
- 04-0895 r6 TGnSync Proposal "MAC simulation results"
- 04-0889 r5 TGnSync Proposal "Technical Specification"
- 04-0892 r7 TGnSync Proposal "MAC Results"
- 05-0415 r1 Security aspects of MAC aggregation

# New Documents posted during July '05 meeting

**Submissions**

- **05-0688 r0 TGn Sync, WWiSE, MitMot Opening Report**
- **05-0786 r0 TGn Sync, WWiSE, MitMot Closing Report**

- **05-0706 r0 Single Stream ad hoc minutes of July 18**
- **05-0559 r5 Single Stream ad hoc group**

- **05-0701r2 Experiments with an 11n radio test bed**
- **05-0790 r1 Soft Detector for 802.11n**

- **05-0557 r1 TGn Opening Report**
- **05-0665 r0 TGn July Minutes**
- **05-0760 r0 TGn Closing Report**

# End of Closing Report

# APPENDIX P

# IEEE P802.11
# Wireless LANs

## [Minutes of High Throughput Task Group .11n Session]

**Date:** 2005-07-18


**Author(s):**

| Name | Company | Address | Phone | email |
|---|---|---|---|---|
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| | | | | |


## Abstract


Cumulative minutes of the High Throughput Task Group meetings held during the IEEE 802.11 Interim session in San Francisco from July 18 through 22, 2005. The session was chaired by chair person elect Bruce Kraemer from Conexant.



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**Executive Summary (also see Chairs' meeting doc 11-05-0557r1 and closing report doc. 11-05-0760r0):**

1. **Proposal Updates were received from MITMOT (11-05-0735r0), TGn Sync (11-03-0888r13) and WWiSE (11-05-0737r1).**
2. **Formal announcement to merge by MITMOT-TGn Sync-WWiSE (MTW) was made.**
3. **MTW opening report (11-05-0688r0) gave their time line goal as:**
    a. **July – Formal announcement of Joint Proposal (JP) team and activities**
    b. **Sept. – Draft JP**
    c. **Nov. – JP for Confirmation Vote**
4. **MTW closing report (11-05-0786r0) updated progress and process.**
5. **Coexistence Assurance ad hoc committee gave a verbal update and will not be having CCs between July and Sept. meetings.**
6. **Single Spatial Stream Devices (S3D) ad hoc committee completed its work (see 11-05-0599r5) and will not be having CCs between July and Sept. meetings.**
7. **One of the alternatives to modify the FRs proposed by S3D was adopted namely - FR10 and FR11 were created to reflect the requirements of S3Ds and facilitate interoperability testing by WFA.**
8. **The Functional Requirements (doc. 11-03-0813r13) were updated.**
9. **Two technical presentations were received:**
    a. **"802.11n Radio Test Bed" from UCLA (doc. 11-05-701r2)**
    b. **"Novel Soft MIMO-OFDM (802.11n) Receivers" from Un. of Utah (doc. 11-05-790r1)**
10. **Agenda for September will include a progress report from MTW (to be put on .11n reflector Sept.12) and time for Q&A. Also, in Sept. a motion will be made to form a liaison with WFA to facilitate interoperability testing of .11n devices.**

**Note: 1) Relative to presentations, these minutes are intended to offer a brief summary (including document number) of each of the presentations to facilitate review and recall without having to read each of the presentations. Most of the 'presentation related' minutes are built directly from selected slides and therefore are not subjective. An effort was made to note obscure acronyms.**

**********

**Detailed cumulative minutes follow:**

**Monday; July 18, 2005; 4:00 AM – 6:00 PM [~ 170 attendees];**

1. Meeting was called to order by Task Group chairperson at 4:03 PM
2. Chairs' Meeting Doc 11-05-0557r0
3. Chair read IEEE-SA Standards Board Bylaws on Patent Policy and additional Pat Com Guidance
4. Chair reviewed topics NOT to be discussed during the meeting – licensing, pricing, litigation, market share

5. Attendance reminder – for this meeting attendance will be manual and on an honour system
6. Chair reviewed May-July progress up to the start of this meeting in order to provide the background to set the agenda for this meeting:
   6.1. from May meeting in Cairns and interim period; slides 9, 10, 12, 13
   6.2. selection procedure reviewed as a result of failure of confirmation vote #2
   6.3. Technical editor election postponed until single proposal passes 75% hurdle
   6.4. Initial version of July agenda would be a repeat of January agenda
   6.5. Single Spatial Stream ad hoc conference calls held
   6.6. Coexistence Assurance CCs held
7. **Motion by Jon Rosdahl to approve May minutes, 11-05-0416r2, was seconded by Aon Mujtaba approved unanimously**
8. Chair discussed agenda for this meeting (granted 18 hours total):
   8.1. Reviewed selection criteria and suggested we focus on step 11 re: mergers
   8.2. Suggested agenda as follows:
      8.2.1. Monday 4-6 PM establish agenda
      8.2.2. Tuesday recess for two morning sessions
      8.2.3. Tuesday 1:30-3:30 PM – UCLA presentations and Proposal Updates
      8.2.4. Tuesday 4:00-6:00 PM – Proposal Updates and Single Stream Update
9. Chair invited spokespersons for each of the proposal teams to give their updates
10. Representatives spoke on behalf of the three proposal teams (Mitmot, Tgn Sync and WWiSE – MTW) 11-05-0688r0
    10.1. Aon Mujtaba - Have held four F2F meetings since May meeting - June 13, 30, July 15, 17 and intermediate conference calls
    10.2. Sean Coffey – Tentative mechanics will be a mixture of global design guidelines and detailed draft text
    10.3. Marc de Courville – merger team would like the TG to grant the team 'closed' time at this meeting to work on the merged proposal
    10.4. Time Line Goal – draft Joint Proposal for Sept meeting and confirmation proposal for confirmation vote in November
11. **Motion by Aon Mujtaba and seconded by Amer Hassan as follows – Because the TGn selection process allows proposals to ask for time to complete mergers prior to consideration, M&T&W *request* time to complete a merged Joint Proposal (JP) that will replace the current three remaining TGn proposals.**
    ***Anticipated* Time Line –**
    ***July 2005 – provide time this week (11-05-557r0; Bruce's opening report) for these groups to go work on this effort**
    ***Sept 2005 – JP draft will be provided to TGn; Q&A sessions on JP to that time**
    ***Nov 2005 – JP replaces current 3 proposals; confirmation vote on JP**
12. Questions:
    12.1. Will the meetings be closed? A – yes, just as they have been up to now in that the three teams met individually
    12.2. Are there tasks the TG could contribute to now to help the process and conserve time? A – will consider
    12.3. Motion should be made tighter wrt times and language by eliminating the words in italics in the original motion?
13. **Motion Amended by Ken Clements and seconded by Johnny Zweig to change the italicized words in the main motion so that the motion now reads:**

**Because the TGn selection process allows proposals to ask for time to complete mergers prior to consideration, M&T&W are granted time to complete a merged a Joint Proposal (JP) that will replace the current three remaining TGn proposals.**

**Time Line –**

***July 2005 – provide time this week (11-05-557r0; Bruce's opening report) for these groups to go work on this effort**

***Sept 2005 – JP draft will be provided to TGn; Q&A sessions on JP to that time**

***Nov 2005 – JP replaces current 3 proposals; confirmation vote on JP**

**14. Motion to amend Passed unanimously**

15. Back to Questions/Comments:

15.1.1. This proposed process is not out of scope and input has been requested

15.1.2. Updated proposals from each of the teams have been put on server but no comments have been received

15.1.3. Proposers have made significant progress; let them continue

15.1.4. In fact holding 'off-line' meetings is the most efficient use of our time

15.1.5. Must balance public and private; for last year it has been an extremely public process, we now need time for some private time

15.1.6. Recall, all 3 of the original proposals were created in private and the group of three is now asking for private time

15.1.7. Will the group of 3 represent 75%? A – no guarantees but odds are good given the membership of MTW.

15.1.8. What happens if group cannot reach consensus on some issues? A – many options are available including restart or disbanding and asking for help from the TG.

15.1.9. The process will not be perfect but this is a good one

15.1.10. Question was called without objection

15.2. Chair noted the motion not procedural and therefore will require a 67% majority (per the selection procedure)

**16. Main Motion as amended passed (195,2,3) the 75% hurdle as defined in our selection procedure**

17. Back to the agenda creation discussion:

17.1.1. Thursday recess for two AM sessions

17.1.2. Thursday 1:30-3:30 PM – CA status, Merger Status

17.1.3. Thursday 4-6 PM – Planning for September meeting

**17.2. Motion to accept the agenda by Jim Petronovich and seconded by Aon Mujtaba passed without discussion and unanimously**

17.3. Sheung Li gave a verbal report on the CA ad hoc committee:

17.3.1. .19 has voted against a .15 move to Sponsor Ballot because it did not have a CA document

17.3.2. Two .11 SGs have been delayed from Excom consideration because they did not file a CA doc

17.3.3. Bottom line - 802 is taking Coexistence seriously

17.3.4. .19 Tues 8-10 and Wed 8 – 6 PM meetings in Pacific K room will be devoted to Coexistence Assurance and in particular tutorials on radios from outside .11; you are invited to attend

17.4. Single Stream ad hoc committee update by Marc de Courville (11-05-0559r4)

17.4.1. Recall goal was to investigate making modifications to the Functional Requirements (FRs) to reflect existence and importance of one-stream devices and vote on the modifications

17.4.2. Conference calls were held on 6/1,15 and 7/7

17.4.3. Methodology:
- 17.4.3.1. find a global and generic definition describing devices in this class
- 17.4.3.2. identify necessary and feasible changes to the functional requirements
- 17.4.3.3. check consistency with the PAR

17.4.4. Classes of devices included Handhelds and printers (rough definition - non APs which support single streams)

17.4.5. Alternatives to discuss:
- 17.4.5.1. Add a new FR entitled "Compatibility with single spatial stream devices"
- 17.4.5.2. Modify FR1 & FR2
- 17.4.5.3. Form another SG

17.4.6. Chair reviewed Current PAR for reference

17.4.7. Marc identified FRs that could be affected – FR1, 2, 9

17.4.8. Marc recommended adding a new FR

17.4.9. Marc reviewed the pros and cons of each alternative

17.5. Questions:

17.5.1. Who participated in the ad hoc? A – Samsung, Motorola etc

17.5.2. Will it be part of the merger discussions? A – yes

17.5.3. Will satisfying handset req'ts impact the merger? A – all the ingredients are there now so it should not have an impact

17.5.4. What will WFA do? A – outside scope of IEEE

17.5.5. Advantage of doing this in TGn, i.e., option 1 or 2.

17.5.6. If we select option 1 we should formalize a WFA liaison on this topic

17.5.7. More discussion? A- yes Tuesday afternoon

17.5.8. Chair recessed the meeting until Tuesday at 1:30 PM

**Tuesday; 7-19-05; 1:30-6:00 PM**

1. Chair called the session to order at 1:30 PM
2. Presentation: Experiments with an 802.11n Radio Test Bed; UCLA UnWired Lab (11-05-0701r2); David Browne
   a. MIMO-OFDM test bed
   b. Demo – real time using IP; test bed was in LA lab
   c. Method: simultaneous channel sounding and data transmission during super frames
   d. Uses robots to span 'space' at each measurement co-ordinate
   e. Metrics: FER vs capacity
   f. Matlab on Linux issue co-ordinate commands
   g. Showed images of test equipment
   h. Performed real time demonstration
   i. Common Channel Sounder Alternatives
      i. Delay domain to measure impulse response
      ii. Swept frequency
   j. Disadvantages:
      i. Requires Time Synchronization
      ii. Difficult to detect co-channel interference (CCI)
      iii. Not based in .11n radios
   k. Proposed Method
      i. Space-frequency Orthogonalization
   l. Advantages:

i. Does not require time sync of TX and RX
ii. Able to detect CCI during measurement
iii. Integrated into test bed
iv. Per packet
v. Watch out for PAPR issue (use circular buffer)

m. At RX
i. Use 2K point FFT
ii. RX signal and noise separated
iii. Explained CCI when interferers were .11b and BT

n. Calibration scheme use known channels
i. Fully correlated channels
ii. Uncorrelated channels

o. Results (Weijun Zhu); Parameters
i. Indoor
ii. LOS and non LOS
iii. Variable TX power
iv. Linear array of dipole antennas w/.5 lambda separation
v. 10 time separated measurements at each grid point

p. SISO – capacity proportional to SNR (averaged over frequency domain)
q. MIMO – capacity depends on eigen values of channel
r. Capacity is better characterization of performance (error rate profile) since accounts for both SNR and Channel Structure
s. Parameters for Experiment (Close to WWiSE)
i. WWiSE LDPC and BCC
ii. 2x2 and 2x3 data signaling
iii. 4x4 Channel Sounding
iv. Rate ½, 2/3, 5/6
v. 16 QAM and 64 QAM
vi. MIMO Preamble based on Hadamard Sequence
vii. Orthogonal Pilot Tones
viii. 1000 info Bytes per data packet

t. Results (FER vs Capacity)
i. LDPC vs BCC – LDPC is clear winner especially at high rates and non-LOS
ii. LOS vs non-LOS – LOS suffers at high SNR (some results confusing; explanation not obvious)
iii. 2RX vs 3RX antennas – 3 antennas much better wrt SNR but wrt Capacity little difference!! Capacity is better measure
iv. Modulation (16 QAM and 64 QAM)
v. Power – track until RX non-linearity dominates

u. Conclusions
i. Use Capacity instead of SNR as comparison metric
ii. LDPC better than BCC
iii. LOS degradation (need more investigation)
iv. Tracks theory

v. Questions
i. What was receiver architecture? A – MMSE

3. Proposal Updates:

a. TGn Sync; Aon Mujtaba; 11-04-0888r13; PHY [see glossary in presentation for acronyms]
    i. Mandatory features:
        1. Support for 1 and 2 spatial streams in 20MHz
        2. Channel coding rates: 1/2, 2/3, 3/4, and 5/6
        3. Modulations: BPSK, QPSK, 16QAM, 64QAM
        4. Support for Rx assisted Rate Control
        5. Guard Interval: 800ns
    ii. Optional features:
        1. 40 MHz channelizations
        2. STBC
        3. Transmit beamforming (Tx BF) - beamsteering
        4. Guard Interval: 400ns
        5. Advanced coding (LDPC)
        6. Support for 3 and 4 spatial streams
        7. 256-QAM
    iii. Modifications since May
        1. Introduced STBC
        2. Created MCS capability classes
        3. Made BF optional for both transmit and receive
b. TGn Sync; Adrian Stephens; 11-04-0888r13; MAC [see glossary in presentation for acronyms]
    i. Simplified
    ii. Changes since May
        1. Simplified Reverse Direction data
            a. Remove RDL/RDR/RDG signaling
            b. Single additional bit to grant RDG, re-use of existing Duration field
        2. Simplified Protection
            a. Pairwise spoofing replaced by simpler Extended PHY Protection (EPP) rules
            b. No additional signaling required
        3. Simplified and Improved Block Ack
            a. Two fixed sizes for BA bitmap depending on fragmentation
            b. Partial state bitmap option reduces implementation cost while providing benefits of immediate response
        4. Simplified Coexistence Management
            a. Removed modal behavior except for 20MHz-base operation
            b. Removed ICB/DCB frames and use existing frames to provide 20MHz-base operation
            c. Simplified text significantly
        5. Reduced number of and simplified control frames
            a. Removed ICB/DCB
            b. Most of functionality of IAC/RAC removed. IAC/RAC replaced by LAC
        6. EDCA performance now approaching HCCA performance
c. Mitmot Update; Marc de Courville; 11-05-0735r0
    i. Skewed focus on handhelds, hot spots, out doors

ii. MAC – orthogonal to nSync and WWiSE so will not elaborate
iii. PHY – exploit hybrid combination of SDM and STBC
iv. Dual-Binary Turbo Code particularly good for small block code sizes
    1. issue – SIFS constraint
    2. PAPR reduction based on pilot rotation can yield a 1.5 dB improvement in performance
v. Differentiators
    1. Capture wide range of environments/devices/applications:
        a. (full) home/enterprise/limited outdoor, handhelds/laptops, from VoIP to multimedia streaming
        b. Build in support for asymmetric TX/RX antenna configurations to accommodate various terminal sizes (PDA/Phone) offering a scalable and evolutionary solution
        c. Hotspot support: dedicated 128 carrier with double length cyclic prefix OFDM modulation, longer range achieved through hybrid STBC robust and SDM high peak rates modes
        d. .11n specific robust beacon enables materialization of new PHY mode range prediction
    2. Enhanced QoS using "Extended Centralized Coordination Function"
        a. Inherent clean split between legacy and .11n devices at MAC level
            i. with no need for mixed-modes transmission mode definition
        b. Resource allocation mechanism is highly dynamic
            i. QoS provided without use of traffic profiles (TSPECS)
        c. High Efficiency independent of application packet size through segmentation
        d. Robustness to error through retransmission mechanism on segmented packets
    3. Lower power operation:
        a. PHY power saving: PAPR reduction based on simple pilot rotation
        b. Enhanced transparency and predictability through broadcast grouped resource announcement
            i. yields clean low power implementation and low overhead
    4. New preamble definition: for simple & accurate AGC, time sync and easier quality/complexity tradeoff for CSI estimation
    5. Improved link adaptation: efficient interoperability through calibration and support of accurate link quality metrics

4. Chair recessed the meeting at 3:25 PM

5. Chair called the meeting to order at 4:00 PM
6. Sean Coffey gave the TGn WWiSE PHY update and Matt Fischer gave the MAC update; 11-05-0737r1;
    a. Summary of Proposed Changes

i. Power save mechanism
ii. HT Block Ack
iii. Coexistence of Extended Range (ER) devices with Non-extended Range (NR) devices
iv. Secondary Channel Element
v. Allowance and rules for zero-length PPDUs
vi. New LDPC code design
vii. Further beacon refinement

b. Summary
   i. High-performance PHY and MAC
   ii. Modularity and simplicity in PHY design
      1. Eases interoperability and verification, enables faster time to market and provides true scalability
   iii. Efficient, streamlined MAC extensions
      1. High performance, no unnecessary complexity
   iv. Well defined, stable technical specification
      1. Suitable for immediate use as Draft 1.0

7. Chair reopened agenda topic of Single Stream as lead by Marc de Courville
   a. Marc summarized the three Options:
      i. Add new FR10 to enable WFA mapping for S3D (single spatial stream devices)
      ii. Modify FR1 and FR2 to allow full materialization of S3D but would require a PAR change
      iii. Defer to another SG/TG
   b. What would a PAR modification entail?
   c. Chair responded:
      i. PAR would have to change to deal with relaxation of 100 Mbps requirement for S3Ds
      ii. Vote on PAR change this week in TG and WG would require 75% approval
      iii. Time line:
         1. Excom approval at November meeting
         2. Place on NEScom agenda in October
         3. NEScom could approve in December
   d. Questions:
      i. Was there impact in .11m when its PAR was changed? A – absolutely none
      ii. Would September work for TG/WG approvals instead of this meeting? A – yes, no impact on time line since October for NEScom agenda is gating item
8. Results from ad hoc group straw votes were:
   a. #1 (37,0,17)
   b. #2 (23,29,9)
   c. #3 (11,21,24)
9. Straw Poll was held in this session with the results as follows:
   a. Option 1 - Add a new FR10 to enable easier WFA mapping for S3D (67,9)
   b. Option 2 - Propose a change to the PAR in addition to modifying FR1 and FR2 in order allow full materialization of S3D in 11n (18,43) and eliminate dependency on WFA

c. Option 3 – Do nothing in .11n (3,31)

**10. Motion by Marc de Courville and seconded by Jim Petronovich to**
**Add a new FR10 to enable easier WFA mapping for S3D**
**Name: Compatibility with single spatial stream non-AP stations (S3Ds)**
**Requirement: 11n APs or STAs shall support and be compatible with non-AP stations complying with the .11n standard with the exception of only supporting the single spatial stream transmission modes of the .11n standard and shall demonstrate at least one mode of operation that provides a throughput at least 50 Mbps (at the MAC Data SAP).**

a. Discussion:
   i. Against motion since S3Ds will be accommodated in any case – if it ain't broke don't fix it!
   ii. Wording not appropriate

**11. Motion by Jon Rosdahl to postpone the motion until 1:30 block on Thursday was seconded by Joseph Levy**

a. No discussion
b. No objection to postpone

12. Chair recessed until 1:30 PM on Thursday

**Thursday; 7-21-05; 1:30 – 6:00 PM**

1. Chair reconvened the meeting at 1:32 PM
2. Marc de Courville continued with Single Stream Decision; (11-05-559r5)
   a. Proposed to split into two new FRs:
      i. New FR10 Proposed:
         1. **Name:** *Existence* of single spatial stream transmission modes
         2. **Requirement:**
            a. Proposal shall define single spatial stream transmission modes that provide at least one mode of operation that supports a maximum throughput of at least 50 Mbps in a 20MHz channel as measured at the MAC data SAP.
      ii. New FR11 Proposed:
         1. **Name:** *Interoperability* with single spatial stream non AP stations
         2. **Requirement:**
            a. An .11n AP or STA shall interoperate with a single spatial stream entity defined as a non-AP STA that complies with the .11n proposal with the exception of only supporting single spatial stream transmission modes as required by FR10.

**3. Motion by Marc de Courville (Motorola) and seconded by Eric Tokubo (Symbol Technologies) to: adopt new revision of document 11-03-0813-13-000n-Functional-Requirements containing the following changes: addition of FR10 and FR11 where:**

**i. FR10: Existence of single spatial stream transmission modes**
**ii. Requirement:**
   **1. Proposal shall define single spatial stream transmission modes that provide at least one mode of operation that supports a maximum throughput of at least 50 Mbps in a 20MHz channel as measured at the MAC data SAP.**
**iii. FR11: Interoperability with single spatial stream non-AP stations**

iv. **Requirement:**
1. **An .11n AP or STA shall interoperate with a single spatial stream entity defined as a non-AP STA that complies with the .11n proposal with the exception of only supporting single spatial stream transmission modes as required by FR10.**

b. Discussion:
i. Is this 50 Mbps Over-the-Air (OTA)? A – no; it is at the MAC Data SAP and therefore the OTA rate would be greater than .11a/g
ii. In favor because two years ago this opportunity was not as high profile but now it is and so it is good we are recognizing it at this time
iii. In favor because not much extra development work
iv. Consistent with definitions in current FR document per Adrian Stephens

**c. Motion passed: (110, 0, 7) as it meant the 75% threshold**

4. Adrian Stephens said he would update the FR doc and post it to the server as doc 11-03-0813r13
5. Coexistence Assurance (CA) status update by Sheung Li; he noted three important .19 documents 19-05-018 on BT and 19-05-025 on WiMax and 19-05-026 on Cordless Phones
    a. The CA group meeting minutes are in doc 11-05-792r0
6. Merger update by Aon Mujtaba, Chris Hansen and Marc de Courville (doc. 11-05-0786r0)
    a. Process to update has been adopted
    b. Agreed on tools (dates and locations for meetings and web tools)
    c. Agreed on firm time line
    d. MAC and Phy
    e. Next Steps – weekly conference calls for Mac and separately for Phy
    f. F2F in Japan in early August
    g. F2F in Europe in October
7. Chair discussed planning for September meeting (see doc 11-05-0557r1)
    a. No CCs need to be authorized for CA or Single Stream ad hoc committees
    b. Monday Sept 12 posting date for updated merged proposal
    c. Email question submissions by Thursday Sept. 15
    d. Responses on Monday Sept. 19 at the IEEE meeting
    e. Merged Proposal Presentation & Discussion in Sept.
    f. CA status update in September
    g. Single Spatial Stream Devices (S3D) ad hoc group would like to form a liaison with WFA
    h. Marc de Courville will lead a team to work on the wording of a motion to form a WFA liaison to the WG at the Sept meeting
8. Presentation: Behrouz Farhang; Un. Utah; A Novel Soft MIMO Detector for MIMO-OFDM (802.11n) Receivers (doc. 11-05-0790r1)
    a. Outline
        i. Introduction
        ii. Channel model
        iii. Soft Information: Log-likelihood ratio, LLR values
            1. what is the problem?
        iv. Zero-forcing / MMSE / VBLAST detectors
            1. computation of LLR values
        v. Our solution to LLR computation

vi. Simulation results
vii. Conclusions

b. SIC = successive interference canceller
c. Conclusions:
   i. The problem of soft estimation of information bits in a MIMO setup was addressed.
   ii. Using Markov chain Monte Carlo (MCMC) simulation technique, in the Wireless Communications lab of Un. of Utah, we have developed a very efficient detector for this task.
   iii. The proposed method could be *used along with any conventional detector* (ZF/MMSE/VBLAST-SIC) to improve its performance.
   iv. Gains in the order of *6 dB or more* have been observed.
   v. The proposed method is an excellent choice in systems that employ advanced channel coding, i.e., *turbo and LDPC codes.*
   vi. The proposed technology is *extremely hardware friendly*. The complexity of the MCMC simulator is *not greater than a 16 bit-by-16 bit multiplier*. Therefore, in a MIMO-OFDM where many subcarrier channels have to be examined in parallel, a number of MCMC simulators can be run in parallel at a minimum cost.
d. Questions:
   i. Frame size on FER plots? A – three symbol size
   ii. Channel? A – frequency selective
   iii. Show MSE? A – no
   iv. Initialization? A – ZF; ZF into Markov Chain and then generate LLR value and iterate
   v. Even after only 1 iteration shows much improvement? A – yes
   vi. Intuitive explanation? A – sorry don't have one yet
   vii. Guaranteed to converge? A – to be studied

9. Chair - any other business?
10. Adrian Stephens – updated Functional Requirement has been posted; doc 11-03-0813r13
11. **Motion to adjourn by Larry Arnett was seconded by Adrian Stephens passed unanimously**

# APPENDIX Q

27-Jun-2023 22:13:21 ET

# Documents

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Everything | 2004 | TGn (inactive)

889

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|---|---|---|---|---|---|---|---|---|
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# APPENDIX R

**IEEE P802.11**
**Wireless LANs**

# TGn Sync Proposal Technical Specification

**Date: 2005-01-18**


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## Abstract


This document presents the technical specification for the
MAC and the PHY layer of the TGn Sync proposal to IEEE 802.11 TGn



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# 1 Executive Summary

The TGn Sync team respectfully submits its complete proposal. The team is comprised of 802.11 WG participants whose companies represent a broad range of markets, including, PC, Enterprise, Consumer Electronics, Handset, Semiconductor and Public Access. Since these companies are based in the US, Europe and Asia Pacific, the team has had the benefit of a worldwide perspective, both in terms of perceived market demand as well as regulatory concerns (including channel bandwidth limitations, limited channel access, restricted transmission times, etc.).

Our goal has been to align (or "sync" with) 802.11n members to a single set of core positions prior to the TGn down selection phase. By aligning before entrenched positions form, we hope to increase the possibility of a more rapid introduction of an 802.11n standard.

The team has worked as a technical group for many months to develop a TGn proposal, recognizing that whatever decisions were made had to ultimately survive the TGn process and therefore be based solely on technical merit. There were no signed agreements involved in joining the TGn Sync team. There was no attempt to develop joint IP and each company was expected to abide by the same reasonable and non-discriminatory terms that the IEEE bylaws require.

The technical approach balances market expectations with design practicality. The solution is a robust, scalable architecture targeting the least amount of complexity. In fact, the basic configuration delivers a maximum mandatory rate of 243 Mbps using only two antennas. This rate is consistent with the historical trend of 5x with each generation of 802.11 (802.11/2Mbps, 802.11b/11Mbps, and finally 802.11a/ 54Mbps). The proposal also incorporates options for higher rates beyond 600 Mbps. This choice of higher peak data rates was seen as critical for future proofing this next generation of WLAN.

The PHY techniques used to achieve the higher data rates involve a MIMO evolution of 802.11 OFDM PHY with spatial division multiplexing of spatial streams, wider bandwidth options (either 20MHz or 40MHz, but not required in regulatory domains where prohibited) and an optimized interleaver for both the 20 MHz and 40MHz channelizations. Additionally, optional enhancements include advanced FEC coding techniques (LDPC), transmit beamforming with negligible additional cost in the receiving client device and/or additional RF chains. These options provide extra scalability if additional robustness and/or throughput is required.

The TGn Sync proposal also offers seamless interoperability with 802.11 legacy devices. This interoperability is achieved with an enhanced 802.11 preamble design and efficient PHY and MAC level mechanisms, which also provide robustness and cost-effectiveness.

The features added to improve MAC efficiency – for higher throughput and overall system performance – include aggregation, bi-directional data flow, enhanced Block Ack, power management (to reduce power consumption), channel management (including a receiver assisted channel training protocol) and feedback mechanisms that enable rate adaptation. Protection mechanisms are also added to achieve the seamless interoperability and coexistence with legacy

devices mentioned above. The approach supports 802.11e and proposes new features for further enhancement.

## 1.1 Proposal Structure

The TGn Sync complete proposal meets the IEEE 802.11n PAR, meets all functional requirements, and addresses all mandatory requirements of the comparison criteria.

This document contains a technical specification of the proposed MAC and PHY enhancements.

[5] contains the presentation of the proposal in powerpoint format. (Please note that the summary presentation [4] is no longer up to date).

[6] contains a statement of compliance to the IEEE 802.11 TGn FRCC requirements.

[7] and [8] contain FRCC results (and others) for the PHY and MAC respectively.

[9] and [10] are Excel spreadsheets containing detailed FRCC results from MAC simulations, and [11] describes the methodology used in these simulations.

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[11] IEEE 802.11-04/895, "TGnSync Proposal MAC Simulation Methodology"

# 3 Definitions

**Aggregate:** A PSDU transported by the PHY with an aggregate attribute indicating that it contains multiple MPDUs.

**Initiator:** A STA that holds a TXOP and transmits the first frame in a frame exchange sequence including aggregate PPDUs and/or aggregate control frames (IAC/RAC/MRAD).

**LongNAV:** A MAC-layer protection mechanism that protects multiple PPDUs exchanged within a TXOP

**Mixed Mode:** A mode of operation of an HT BSS in which there are co-channel legacy devices present.

**OFDM Format:** Definition of subcarrier frequencies relative to the channel center frequency, and specification of data bearing and pilot subcarriers.

**Originator:** A QSTA that sends data using the Block ACK mechanism.

**Pairwise Spoofing:** A PHY layer protection mechanism described in 7.1.7.2.1.

**Preamble: short and long:** Portions of the 802.11 HT PPDU used for PHY synchronization and channel estimation.

**Pure Mode:** A mode of operation of a BSS in which there are no legacy devices.

**Receiver:** Any STA receiving the current PPDU.

**Recipient:** A QSTA that receives data using the Block ACK mechanism.

**Responder:** A STA that responds to an initiator in a frame exchange sequence including aggregate PPDUs and/or aggregate control frames (IAC/RAC/MRAD).

**SIGNAL FIELD:** Portion of the 802.11 HT PHY PPDU that contains “Rate” and “Duration”, part of the PLCP header.

**Symbol:** Typically refers to an OFDM symbol, which is a collection of sub-carriers (or tones)

# 4 Abbreviations and acronyms

| Term | Description |
|---|---|
| ABF-MIMO | Advanced Beamforming MIMO (Transmit Beamforming with Spatial water filling techniques on Multiple Spatial Streams) |
| ACK | Acknowledgement |
| AGC | Automatic Gain Control |
| AP | Access Point |
| ATOC | Aggregate Table Of Contents |
| BF-MIMO | Beamforming MIMO (Basic Transmit Beamforming on Multiple Spatial Streams) |
| CAP | Controlled Access Phase |
| CDD | Cyclic Delay Diversity |
| CHDATA | Compressed Header Data MPDU |
| CRC | Cyclic Redundancy Check |
| CSI | Channel State Information |
| CSIT | Channel State Information at the Transmitter |
| CTS | Clear to Send |
| DLP | Direct Link Protocol |
| DCB | Decrease Channel Bandwidth MPDU |
| ERP | Extended Rate PHY |
| FCS | Frame Check Sequence |
| FPD | Following Packet Descriptor |
| HC | Hybrid Controller |
| HID | Header Identity |
| HT | High Throughput |
| HT-LTF | High Throughput Long Training Field |
| HT-SIG | High Throughput Signal Field |
| HT-STF | High Throughput Short Training Field |
| IAC | Initiator Aggregate Control |
| ICB | Increase Channel Bandwidth MPDU |
| IE | Information Element |
| LLC | Logical Link Control |
| L-LTF | Legacy Long Training Field |

| | |
|---|---|
| L-SIG | Legacy Signal Field |
| L-STF | Legacy Short Training Field |
| MAC | Medium Access Controller |
| MCS | Modulation Coding Scheme – includes modulation order (BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM) and FEC code rate (1/2, 2/3, 3/4, 7/8) |
| MFB | MCS Feedback |
| MHDR | MAC Header MPDU |
| MIMO | Multiple input, multiple output (Both transmitter and receiver have multiple antennas for signaling over a point-to-point link) |
| MISO | Multiple input, single output (transmitter has multiple antennas but receiver has a single antenna) |
| MPDU | MAC protocol data unit |
| MRA | Multiple Receiver Aggregate – an aggregate that contains MPDUs for multiple receiver addresses. |
| MRAD | Multiple Receiver Aggregate Descriptor |
| MRC | Maximum Ratio Combining (a technique to maximize received SNR using antenna signal combining). |
| MRMRA | Multi-response Aggregate – an MRA with multiple responses from its multiple receivers |
| MRQ | MCS Request |
| MSDU | MAC service data unit |
| NAV | Network Allocation Vector (a MAC-level carrier-sense) |
| $N_{SD}$ | Number of Data Subcarriers |
| $N_{SS}$ | Number of Spatial Streams |
| $N_{RX}$ | Number of Receive Antennas |
| $N_{TX}$ | Number of Transmit Antennas |
| OFDM | Orthogonal Frequency Division Multiplexing |
| PHY | Physical Layer |
| PLCP | PHY layer convergence protocol |
| PPDU | PHY protocol data unit |
| PSDU | PHY service data unit |
| Pure Mode | A mode of operation of a BSS in which there are no legacy devices |
| QAP | QoS access point |
| QoS | Quality of service |

| | |
|---|---|
| QSTA | QoS station |
| RAC | Royal Automobile Club |
| RDG | Reverse Direction Grant |
| RDL | Reverse Direction Limit |
| RDR | Reverse Direction Request |
| RDTID | Reverse Direction Traffic Identifier |
| RPO | Response Period Offset |
| RR | Rate Recommendation |
| RSSI | Receive Signal Strength Indicator |
| RTS | Request to send |
| RX | Receiver |
| SAP | Service Access Point |
| SF | Signal Field |
| SIFS | Short inter-frame spacing |
| SIMO | Single input, multiple output (transmitter has a single antenna, receiver has multiple antennas) |
| SISO | Single input, single output (both transmitter and receiver have a single antenna) |
| SoP | Start of Packet (i.e. PPDU Packet) |
| SRA | Single Receiver Aggregate – an aggregate that contains MPDUs for a single receiver address. |
| STA | Station |
| SVD | Singular Value Decomposition: For an arbitrary matrix A = $USV^H$ |
| TBD | To be determined |
| TC | Traffic Category |
| TGe | 802.11 Task Group e - Quality of Service |
| TGn | 802.11 Task Group n - Enhancements for Higher Throughput |
| TRMS | Timed Receive Mode Switching |
| TRQ | Training Request |
| TS | Traffic Stream |
| TSID | Traffic Stream Identifier |
| TSPEC | Traffic specification |
| TX | Transmitter |
| TXOP | Transmission opportunity |

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2

# 5 Introduction

## 5.1 Purpose

This document defines proposed Enhancements for Higher Throughput within the scope of the Project Authorization Request (PAR) [3] formulated for IEEE 802.11 Task Group n.

## 5.2 General description of MAC enhancements

The proposed MAC enhancements assume a baseline specification defined by IEEE 802.11 standard [1] and its later amendments, including the draft IEEE 802.11e amendment [2]. The purpose of the enhancements is to significantly improve throughput, providing a maximum throughput of at least 100Mbps, as measured at the MAC data service access point (SAP).

The features supported by this TGn Sync MAC proposal are as follows:

- A Frame Aggregation format that allows aggregation of multiple Data and Control MPDUs in one PPDU. Note, an aggregate can also include a single management frame, in addition to multiple data and control frames per unicast receiver address.

- New Control MPDUs and (aggregate) frame exchange rules that control the exchange of multiple MPDUs per PPDU between a single initiating STA and potentially multiple responding STAs.

- MAC header compression that allows more efficient medium usage when multiple Data MPDUs are aggregated in a single PPDU.

- A receiver assisted channel training protocol.

- A reverse direction data protocol that allows efficient channel access for single and multiple responders within a frame exchange sequence.

- Protection of the new frame exchange sequences may be provided through one of two mechanisms: a MAC-level mechanism based on NAV reservations, and a PHY-level mechanism based on spoofing the legacy PLCP rate/length information.

- QoS enhancements for TSPEC renegotiation and prioritized discarding of QoS MSDUs according to an application-defined loss priority labeling.

- Mechanisms to manage coexistence of legacy and HT devices.

- Channel management and channel selection methods.

- Power saving mechanism to reduce power consumption by only enabling a single receive chain during periods of inactivity.

## 5.3 General description of PHY enhancements

With the aim to increase the maximum PHY layer data rate, we have introduced two primary techniques that are mandatory in our proposal:

- Transmission of Multiple Spatial Streams via Multiple Transmit Antennas. Our recommendation is to make 2 spatial streams mandatory, with the option to scale to 4 spatial streams.

- Extended Bandwidth signaling. 20MHz channelization shall be mandatory worldwide. Our recommendation is to support 40MHz channelization as mandatory in regulatory domains that will permit wider bandwidth operation

We have also introduced several secondary techniques for increasing throughput. These include:

- A reduced guard interval of 400ns (i.e. half-GI), channel dispersion permitting (e.g. TGn channel model B). Support for half-GI is mandatory in 20MHz.

- Higher channel coding rate of 7/8. Support for 7/8 is mandatory in 20MHz.

- Support for 256-QAM is optional in our proposal.

Due to the susceptibility of a wireless link to multipath fading, especially in a MIMO channel, our proposal introduces two optional techniques for improving the robustness of the link between the transmitter and the receiver, with the aim to keep the client (station) configuration low-cost and low-power:

- Transmitter beamforming, with the understanding that Access Points will be able to support more than 2 antennas, while the client stations would be restricted to 2 antennas.

- Advanced channel coding. Our proposal includes LDPC as an option. LDPC codes exhibit a larger minimum free distance compared to the existing 802.11a convolutional code, and hence are able to better exploit the frequency and spatial diversity in the channel.

Our proposal support full backwards compatibility with existing 802.11a/b/g standards. Our preamble design support PHY layer interoperability with the OFDM preamble from 802.11a/g, while providing a robust mechanism for synchronization of the high throughput data.

# 6 Frame Formats

This clause specifies the format of new HT frames.

Reserved fields and subfields shall be transmitted as zeroes and shall be ignored by an HT receiver

## 6.1 Control frames

This section defines new control frame subtypes as listed below:

| Control Frame **Subtype** | **Name** |
|---|---|
| IAC | Initiator aggregate control |
| RAC | Responder aggregate control |
| MRAD | Multiple receiver aggregate descriptor |
| ICB | Increase channel bandwidth |
| DCB | Decrease channel bandwidth |
| Calibration Training | Calibration Training frame |

### 6.1.1 Initiator Aggregation Control (IAC) MPDU

#### 6.1.1.1 Introduction

This MPDU provides control of the MCS, size, duration, training and any reverse flow of aggregates in an exchange of aggregates between STAs. It is sent by the initiator STA of an aggregate exchange.

There are a number of groups of fields (IAC elements), which perform specific purposes within the MPDU as described below:

| **Element Name** | **Purpose of item** |
|---|---|
| RTS – Request to Send | Detects collisions at the receiver<br>Tests state of NAV in the receiver<br>Sets NAV reservation near Transmitter (LongNAV) |
| TRQ – MIMO training request | Request to train the channel<br>Used for MIMO with implicit Feedback. |
| MRQ – MCS request | Request for MCS feedback |
| MFB – MCS Feedback | Closed loop channel adaptation feedback<br>Contains values from which the MCS, which will be used for the next PPDU, may be derived deterministically.<br>Note, when combined with an RDG, the RDG duration is adjusted as appropriate to this MCS value. |
| FPD – Following packet descriptor | Provides size and default MCS for the next PPDU to be sent by this STA so that its peer can properly set a Pairwise Spoofing value |

| | |
|---|---|
| RDL – Reverse direction limit | Indicates a duration that is a limit on the amount of reverse direction that will be granted<br>Used for Bi-directional frame transfer as defined in section 7.1.10 |
| RDG – Reverse direction grant | Grants a specified duration to be used for a reverse direction PPDU<br>Used for Bi-directional frame transfer as defined in section 7.1.10 |

Note, although described as "elements", the structure of the IAC MPDU containing these elements is fixed.

### 6.1.1.2 Format of IAC MPDU

This section defines the format of the IAC MPDU.
The IAC MPDU has a fixed structure. Fields that are not used are present, but reserved.

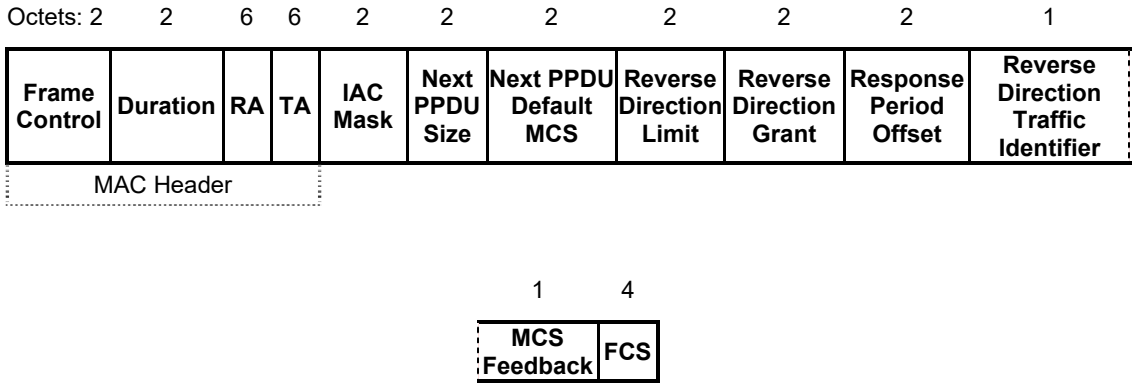



**Figure 1 – IAC MPDU**

| Field | Size (bytes) | Purpose |
|---|---|---|
| Frame Control | 2 | Type is control, subtype is IAC |
| Duration | 2 | |
| Receiver Address | 6 | |
| Transmitter Address | 6 | |
| IAC Mask | 2 | A bitmask indicating which IAC elements are present in the packet. |
| Next PPDU Size | 2 | Size in bytes of following PPDU that will be sent by this STA (FPD).<br>This is interpreted along with the Next PPDU default MCS to determine the duration of the next |

| | | |
|---|---|---|
| | | PPDU.<br>Present when FPD is indicated, otherwise undefined. |
| Next PPDU Default MCS | 2 | Default MCS that will be used in the absence of any updated training information to send next PPDU.<br>Present when FPD is indicated, otherwise undefined. |
| Reverse direction limit | 2 | Indicates the amount of time in microseconds that is the maximum amount of time that will be granted in a RDG.<br>Present when RDL is indicated the IAC mask field, otherwise undefined. |
| Reverse direction grant | 2 | Indicates the amount of time in microseconds that is available for a reverse direction PPDU including any expected response MPDUs and an RAC MPDU.<br>Present when RDG is indicated, otherwise undefined. |
| Response Period Offset (RPO) | 2 | Indicates the delay in microseconds between the end of the PPDU containing the IAC MPDU and the start of the response PPDU.<br>This value shall be no less than SIFS.<br>Present when RDG is indicated, otherwise undefined. |
| Reverse Direction Traffic Identifier<br>(RDTID) | 1 | Indicates one of:<br>• An AC for which reverse direction grant is valid<br>• A TSID indicating a specific TS for which the reverse direction grant is valid<br>• Unconstrained<br>Present when RDG is indicated, otherwise undefined. |
| MCS Feedback | 1 | Contains a recommended MCS value.<br>Present when MFB is indicated, otherwise undefined. |
| FCS | 4 | |

1

#### 6.1.1.2.1 IAC Mask Field

This field indicates which logical elements are carried in the MPDU.

| IAC Mask Field bit | Position | Description |
|---|---|---|
| RTS | B0 | When set, indicates this is an RTS. The receiver should not generate any response if its NAV is non-zero. |
| TRQ | B1 | When set, indicates a request to train the channel.<br>Used for MIMO with implicit Feedback. |
| MRQ | B2 | When set, indicates a request for MCS feedback. |
| MFB | B3 | When set, indicates an MFB training response is present as defined by the MCS Feedback field. |
| FPD | B4 | When set, indicates that the next PPDU duration may be determined from the next PPDU length and default MCS fields. FPD is set only when using Pairwise Spoofing rules. |
| RDG | B5 | When set, indicates a reverse direction grant is present. |
| RDL | B6 | When set, indicates that a reverse direction limit is present |

#### 6.1.1.2.2 MCS Feedback Field

This contains an MCS value containing a recommended MCS value.
MCS values are defined in section 11.2.1.4.2.2.

### 6.1.1.3 Use of IAC elements according to context

This section defines what IAC elements are valid in the following three contexts:

- Within an SRA
- Within an MRA, when a response is permitted for that receiver
- Within an MRA, when no response is permitted for that receiver

| Element Name | SRA Context | MRA Context (response) | MRA Context (non-response) |
|---|---|---|---|
| RTS – Request | Valid | Valid (see note | Not Valid |

| | | | |
|---|---|---|---|
| to Send | | below) | |
| TRQ – MIMO training request | Valid | Valid | Not Valid |
| MRQ – MCS request | Valid | Valid | Not Valid |
| MFB – Use this MCS selection | Valid | Valid | Valid |
| FPD – Following packet descriptor | Valid – implies Pairwise Spoofing rules | Not Valid | Not Valid |
| RDL – Reverse direction limit | Valid | Valid | Not Valid |
| RDG – Reverse direction grant | Valid | Valid | Not Valid |

Note – the RTS element may be included in an MRA. For this to be useful, the initiator should aggregate together an IAC (RTS) for each responder and send these as an aggregate. These IACs should contain a short RDG to collect RAC (CTS) responses. The responder will interpret this as a request to check its NAV is idle during its scheduled response period. If the NAV is idle, a response is sent. Using this method, the initiator can test the NAV state of multiple STAs.

### 6.1.2 Responder Aggregation Control (RAC) MPDU

#### 6.1.2.1 Introduction

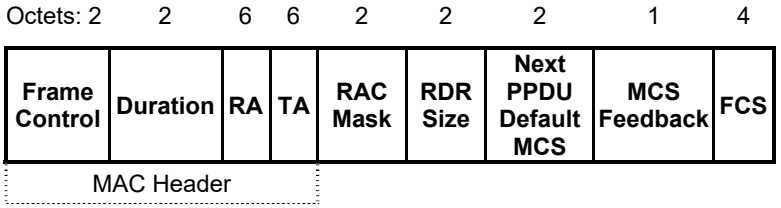
This MPDU provides control of the MCS, size, duration, training and any reverse flow of aggregates in an exchange of aggregates between STAs. It is sent by the responder STA of an aggregate exchange.
There are a number of groups of fields (RAC elements), which perform specific purposes within the MPDU as described below:

| RAC Element Name | Purpose of item |
|---|---|
| CTS – Clear-to-Send | Response to RTS indicates that the medium is clear |
| TRQ – MIMO training request | Request to train the channel<br>Used for MIMO with implicit Feedback. |
| MRQ – MCS request | Indicates a request for MCS feedback |
| MFB –MCS Feedback | Closed loop channel adaptation feedback<br>Contains values from which the MCS, which will be used for the next PPDU, may be derived deterministically.<br>Note, when combined with an RDG, the RDG duration is adjusted appropriate to this MCS value. |
| RDR – Reverse direction request | Request for a reverse direction data flow<br>Contains requested total data MPDU length (bytes) and default MCS |

1

2 **6.1.2.2 Format of RAC MPDU**

3 This section defines the format of the RAC MPDU.
4 The RAC MPDU has a fixed structure. Fields that are not used are present, but reserved.
5




6 **Figure 2 – RAC MPDU**

7

| Field | Size (bytes) | Purpose |
|---|---|---|
| Frame Control | 2 | Type is control, subtype is RAC |
| Duration | 2 | |
| Receiver Address | 6 | |
| Transmitter Address | 6 | |
| RAC Mask | 2 | A bitmask indicating which RAC elements are present in the packet. |
| RDR Size | 2 | Size in bytes of requested reverse direction flow.<br>This is interpreted along with the Next PPDU default MCS to determine the duration of the next PPDU.<br>Present when RDR is indicated, otherwise undefined. |
| Next PPDU Default MCS | 2 | Default MCS that will be used in the absence of any updated training information to send next PPDU<br>Present when RDR is indicated, otherwise undefined. |
| MCS Feedback | 1 | Contains a recommended RCS value..<br>Present when MFB is indicated, otherwise undefined. |
| FCS | 4 | |

#### 6.1.2.2.1 RAC Mask Field

This field indicates which logical RAC elements are carried in the MPDU.

| RAC Mask Field bit | Position | Description |
|---|---|---|
| CTS | B0 | When set, indicates this is a CTS. |
| TRQ | B1 | When set, indicates a request to train the channel.<br>Used for MIMO with implicit Feedback. |
| MRQ | B2 | When set, indicates a request for MCS feedback. |
| MFB | B3 | When set, indicates an MFB training response is present as defined by the MCS Feedback field. |
| RDR | B4 | When set, indicates a request for reverse direction data-flow is present as described by the RDR Size |

| | | |
|---|---|---|
| | | and Next PPDU Default MCS fields. |

#### 6.1.2.2.2 MCS Feedback Field

As defined in IAC MPDU.

### 6.1.3 Multiple Receiver Aggregate Descriptor (MRAD) MPDU

#### 6.1.3.1 Introduction

The MRAD MPDU is the first frame inside a MRA aggregate. It defines the contents of the aggregate. The MRAD may be used by a receiving STA to save power. Based on the contents of the MRAD, the receiving STA may disable its receiver after it has received any broadcast frames or frames addressed to its MAC address.

#### 6.1.3.2 Format of MRAD MPDU

This section defines the format of the MRAD MPDU.

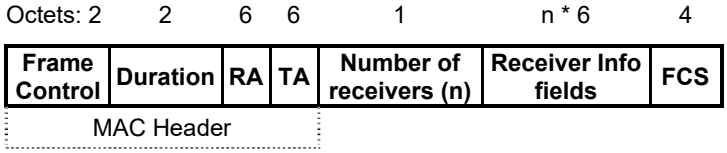



**Figure 3 – MRAD MPDU**

| Field | Size (bytes) | Purpose |
|---|---|---|
| Frame Control | 2 | Frame type is Control, subtype MRAD |
| Duration | 2 | |
| Receiver Address | 6 | The RA field is the broadcast group address. |
| Transmitter Address | 6 | The TA field is the address of the STA transmitting the MRA aggregate. |
| Number of receivers | 1 | The number of receivers (n) for which MPDUs are included inside the MRA aggregate. |
| Receiver Info fields | n * 6 | n Receiver Info fields, one for each Receiver Address in the MRA aggregate. |
| FCS | 4 | |

The order of the Receiver Info fields is equal to the order in which MPDUs for the corresponding receivers appear in the MRA aggregate.

#### 6.1.3.2.1 Receiver Info field

The format of the Receiver Info field is as described below.

| Field | Size (bytes) | Description |
|---|---|---|
| Receiver Address | 6 | Contains the receiver's MAC address |

### 6.1.4 Increase Channel Bandwidth (ICB) MPDU

#### 6.1.4.1 Introduction

The ICB frame is sent by an HT AP to start a 40 MHz period in 20 MHz-base managed mixed mode. When 40 MHz HT STAs operating in 20 MHz receive this frame, they shift to 40 MHz analogue mode.

#### 6.1.4.2 Format of ICB MPDU

The frame format for the ICB frame is defined as is in Figure 4.

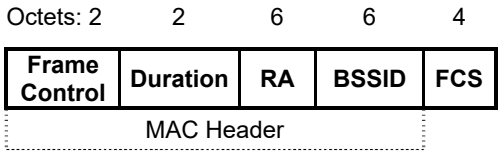



**Figure 4 – ICB MPDU**

| Field | Size (bytes) | Purpose |
|---|---|---|
| Frame Control | 2 | Frame type is Control, subtype ICB |
| Duration | 2 | Duration of the 40MHz phase plus transition periods |
| Receiver Address | 6 | The RA field is the broadcast group address. |
| BSSID | 6 | |
| FCS | 4 | |

This frame is used in the 20 MHz-base managed mixed mode and sent by the HT AP. When switching to 40 MHz channel, the Duration field will be set to cover the 40 MHz phase plus the transition periods between 20 and 40 MHz operation. This is to have HT STAs switch back to 20 MHz channel even if they do not receive the DCB frame at the end of the 40 MHz period.

### 6.1.5 Decrease Channel Bandwidth (DCB) MPDU

#### 6.1.5.1 Introduction

The DCB frame is sent by an HT AP to end a 40 MHz period in 20 MHz-base managed mixed mode. When 40 MHz HT STAs operating in 40 MHz receive this frame, they shift to 20 MHz analogue mode.

#### 6.1.5.2 Format of DCB MPDU

The frame format for the DCB frame is defined as is in Figure 4.

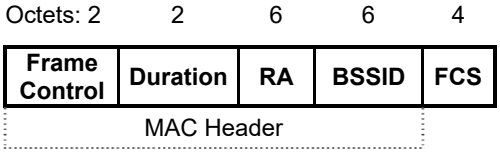



**Figure 5 – DCB MPDU**

| Field | Size (bytes) | Purpose |
|---|---|---|
| Frame Control | 2 | Frame type is Control, subtype DCB |
| Duration | 2 | Duration of the 20MHz period, in TU. |
| Receiver Address | 6 | The RA field is the broadcast group address. |
| BSSID | 6 | The BSSID field is the address of the STA contained in the AP. |
| FCS | 4 | |

This frame is used in the 20 MHz-base managed mixed mode and sent by the HT AP.
When switching back to the 20 MHz channel, the Duration field will at least cover up to the start of the next 40 MHz period. The Duration field in the DCB frame contains this duration in TUs.

### 6.1.6 Block Ack (BA) MPDU

This section defines modifications to the BA frame introduced in 802.11e.

#### 6.1.6.1 Introduction

This section defines a compressed variant of the 802.11e BA MPDU. The variant is distinguished by setting the "Compressed" field of the BA Control field to 1.
Two compression mechanisms exist:

- Support for non-fragmented BA. This reduces the bitmap size to 1 bit per MSDU.
- Truncation of the bitmap to reduce the number of MSDUs acknowledged in the bitmap.

The use of these mechanisms is negotiated when the BA agreement is created through the exchange of ADDBA frames, and is constant for a BA agreement throughout its lifetime. This means that a BA for a particular BA agreement is always the same size.

### 6.1.6.2 Format of BA MPDU

The frame format for the BA frame is defined as in Figure 6.

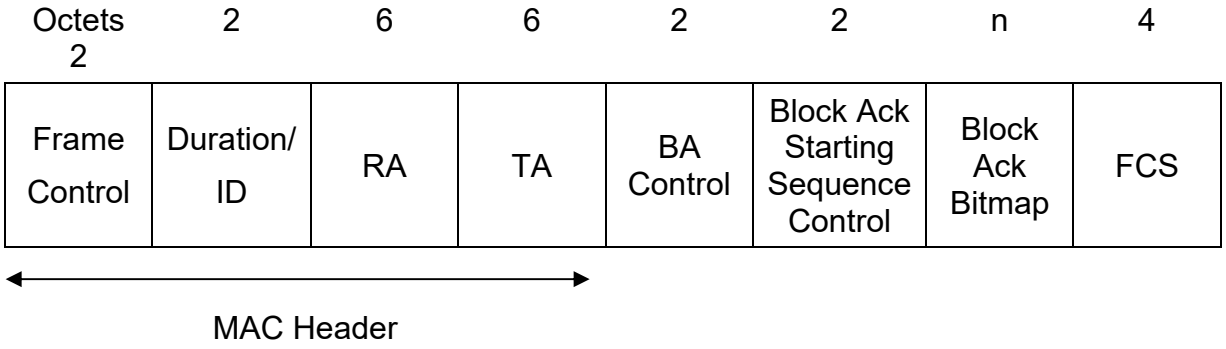



**Figure 6 - Compressed BA MPDU**

Only the BA control and Block Ack Bitmap fields are modified.

The BA Control Field is shown in Figure 7.

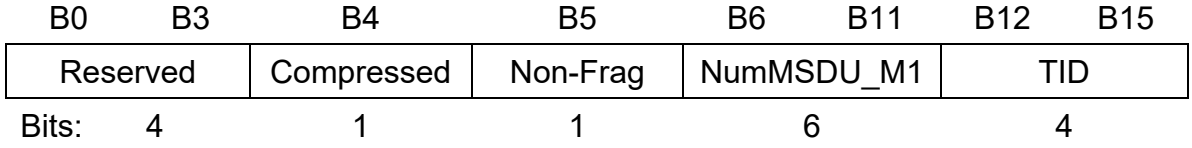



**Figure 7 - BA Control field**

The Compressed, Non-Frag and NumMSDU_M1 are new fields.

The Compressed field selects between legacy 802.11e format and compressed format. When Compressed is set to 0, the BA is interpreted according to legacy 802.11e. The Compressed field is always set to 1 when the BA is set up between HT STAs.

The Non-Frag bit indicates whether acknowledgement is per MSDU or per MPDU. It affects the interpretation of the bitmap field as defined below.

The NumMSDU_M1 field defines the number of MSDUs that are acknowledged by the present bitmap, less one. The NumMSDU_M1 field set as 0 indicates 1 MSDU is acknowledged by the bitmap and when it is 63, 64 MSDUs are acknowledged.

The maximum value of NumMSDU_M1 and the length of the Block Ack Bitmap is defined by the BA agreement, and is fixed for the lifetime of the BA agreement. They are derived from the ADDBA parameters, Non-Frag and Buffer Size, as defined below

**Table 1 - Interpretation of the ADDBA Parameters**

| Non-Frag subfield value | Maximum value of NumMSDU_M1 | Bitmap length n (octets) |
|---|---|---|
| 1 | Buffer Size – 1 | ceil (Buffer Size/8) |
| 0 | Min (Buffer Size, 64) – 1 | Buffer Size x 2 |

The bitmap is interpreted according to the setting of the Compressed, Non-Frag and NumMSDU_M1 fields as defined in the following table.

**Table 2 - Interpretation of the BA Bitmap**

| Compressed | Non-Frag | NumMSDU_M1 | Bitmap interpretation |
|---|---|---|---|
| 0 | 0 | 0 | Legacy 802.11e interpretation |
| 1 | 1 | 0 to 63 | Each bit set acknowledges the successful reception of a single MSDU in order of sequence number |
| 1 | 0 | 0 to 63 | Each bit set acknowledges reception of a single MPDU. The bitmap is interpreted as in legacy 802.11e except that only the first (NumMSDU_M1+1) x 16 bits are significant. |

Other combinations of these fields are reserved.

### 6.1.7 Calibration Training MPDU

The frame format of the Calibration Training MPDU is defined in Figure 8.

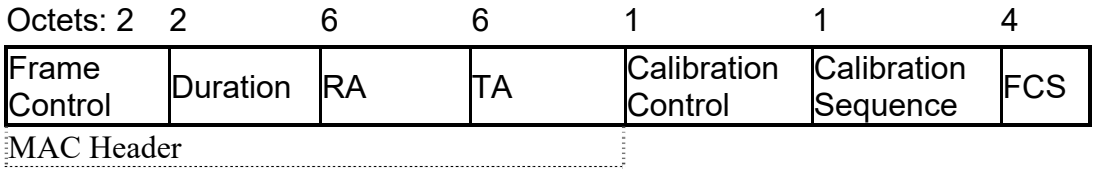



**Figure 8 – Calibration Training MPDU**

The Calibration Control field contains:

- Number of antennas at the initiating STA *Ni* (2 bits)
- Number of antennas at the responding STA *Nr* (2 bits)
- Position (2 bits). This field is set to '0' by the STA transmitting the first frame that initiates the calibration training frame exchange sequence. The field is incremented in

subsequent Calibration Training frame transmissions in the calibration training frame exchange sequence.

- *Reserved* (2 bits)

The Calibration Sequence field is incremented at the transmission of the Calibration Training frame that initiates the calibration procedure. The remaining frames in the same calibration procedure use the same Calibration Sequence value.

The Calibration Traning frame is carried in a PPDU of attributes defined in according to the value of the position field.

| Position Field | PPDU | TXVECTOR NLTF |
|---|---|---|
| 0 | Non-Aggregate | |
| 1 | Non-Aggregate, Sounding | *Ni* |
| 2 | Non-Aggregate, Sounding | *Nr* |

**Figure 9 – PPDU attributes for Calibration Training MPDUs**

The Calibration Training frame shall be transmitted in a non-aggregate PPDU as part of the calibration training exchange defined in 8.3.4.sounding PPDU that includes an HT-LTF of appropriate length.

## 6.2 Data frames

To allow for MAC header compression two new MPDUs are defined: MAC Header (MHDR) MPDU and Compressed Header Data (CHDATA) MPDU.
These MPDUs are present only in aggregates. Because the space of Data Subtypes is fully used, the unused MPDU type with value "11" is defined to be the Extended Data (EDATA) type. The MAC header (MHDR) and Compressed Header Data (CHDATA) MPDUs defined here are subtypes of EDATA.

### 6.2.1 MAC Header (MHDR) MPDU

#### 6.2.1.1 Introduction

This MPDU provides the MAC header for subsequent CHDATA MPDUs.

#### 6.2.1.2 Format of MHDR MPDU

This section defines the format of the MHDR MPDU.

| Octets: 2 | 2 | 6 | 6 | 6 | 1 | 1 | 2 | 4 |
|---|---|---|---|---|---|---|---|---|
| Frame Control | Duration | Address 1 | Address 2 | Address 3 | HID | Reserved | QoS Control | FCS |




**Figure 10 – MHDR MPDU**

Note, the MHDR MPDU contains no data.

| Field | Size (bytes) | Purpose |
|---|---|---|
| Frame Control | 2 | Frame type is Data. |
| Duration | 2 | |
| Address 1 | 6 | |
| Address 2 | 6 | |
| Address 3 | 6 | |
| HID | 1 | The Header ID field that links the MHDR MPDU with corresponding CHDATA MPDUs |
| Reserved | 1 | |
| QoS Control | 2 | |
| FCS | 4 | |

### 6.2.2 Compressed Header Data (CHDATA) MPDU

#### 6.2.2.1 Introduction

This MPDU contains the actual data and a (compressed) header that refers to a MHDR MPDU for full MAC header information.

#### 6.2.2.2 Format of CHDATA MPDU

This section defines the format of the CHDATA MPDU.

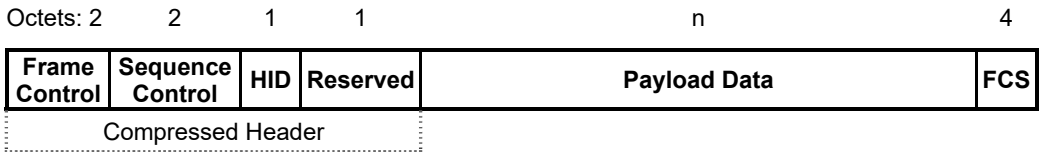



**Figure 11 – CHDATA MPDU**

| Field | Size (bytes) | Purpose |
|---|---|---|
| Frame Control | 2 | Frame type is EDATA, subtype is CHDATA |

| | | |
|---|---|---|
| Sequence Control | 2 | |
| HID | 1 | The Header ID field that links the CHDATA MPDU with corresponding MHDR MPDU |
| Reserved | 1 | |
| FCS | 4 | |

## 6.3 Management frame formats

### 6.3.1 HT Capabilities

Support for any optional features or behavior will be declared through a STA's capabilities or management elements.

**Table 3 –HT Capabilities**

| Capability | Contents |
|---|---|
| HT Supported | Indicates that the device is an HT device, supporting all the mandatory features of this document.<br>This capability is indicated by the presence of the HT capability element. |
| Number of Rx Antennas | Indicates the number of Rx Antennas |
| Max number of Rx spatial channels | Max number of spatial channels the device can receive: in the range 1 to 4. |
| Supported MCS set | Defines the MCS values supported by a STA. An MCS set contains a bitmap of size 128 bits. Bit 0 maps to MCS 0. A bit is set to indicate support for that MCS.<br>See section **11.2.1.4.2.2** for a list of MCSs. |
| Advanced Coding Capability | Advanced Coding Capability Indicates support for advanced coding.<br>This field has the same format as the advanced coding field defined in section **10.1.1.8**, where a bit set as one indicates that that coding type is supported. |
| Supported Channel Width Set | Contains:<br>{20} for a device only capable of 20MHz operation<br>{20, 40} for a device capable of both 20MHz and 40MHz operation. |

#### 6.3.1.1 HT Capability element

The HT Capability element contains a number of subfields that are used to advertise optional HT capabilities at an HT device. The HT Capability element is present in beacons, association and re-association request frames and in probe response frames. The presence of the HT Capability element indicates that the device is an HT device. The HT Capability element is defined in Figure 12.

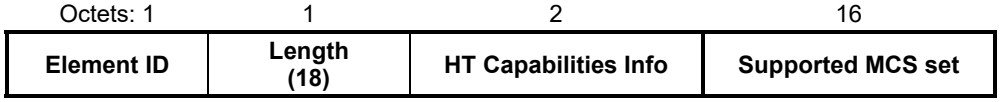



**Figure 12 – HT Capability element format**

The HT Capabilities Info field is 2 octets in length, and contains capability information bits as defined in Figure 13.

| B0 B1 | B2 B3 | B4 | B5 |
|---|---|---|---|
| **Number of rx Antennas** | **Max number of Rx spatial channels** | **Advanced coding capability** | **Supported channel width set** |

**Figure 13 – HT Capabilities Info field**

The Number of rx antennas field contains the number of rx antennas supported, minus 1.
The max number of rx spatial channels filed contains the maximum number of rx spatial channels supported, minus 1.
The advanced coding capability field indicates support for advanced coding if its value is 1.
The supported channel width set indicates {20} if its value is 0, and {20, 40} if its value is 1.
Note: All APs and STAs support TRMS operation in other STAs with a zero hold-on time.

### 6.3.2 Additional HT Information Elements

The AP will signal information in new information elements to manage the BSS.
This information is defined in the table below.

**Table 4 – Additional HT Information Elements**

| Name | Description | Use |
|---|---|---|
| Control Channel | Channel number of the control 20MHz channel | In a mixed mode, all broadcast and non-aggregated control frames are sent so that they can be received by a legacy device operating on the control channel. |
| Extension Channel Offset | Values: –1, 1 indicate offset of the extension channel from the control channel.<br>Value of 0 indicates no extension channel is present. | To locate the 40MHz channel in combination with the control channel |
| Permitted Width | Defines the channel widths | A STA can use any channel |

| | | |
|---|---|---|
| Set | that may be used in the BSS.<br>Values: {20} or {20,40} | width in transmitting a unicast non-control frame supported by the destination STA, and present in the permitted width set. |
| Operating Mode | Either:<br>Mixed: (there are legacy devices co-channel)<br>Pure: (there are no legacy devices co-channel or the AP is operating internally in managed mixed mode)<br>Base-20 Managed mixed: (there may be legacy devices in both the control and the extension channel, see section 8.1.3.4)<br>Mixed-Capable IBSS | Used to control the use of protection mechanisms (see section7.1.7).<br>Also selects between legacy beacon and HT beacon generation in an IBSS network (see section 8.1.3.2). |
| Channel Extension Indication | Values: 0,1<br>1 means that 40 MHz capable HT STAs in the BSS should extend their channel bandwidth to 40 MHz according to the information from the Extension Channel Offset information element. | Present in Beacon frames in CFP when 20 MHz-base managed mixed mode is used. It indicates that transition to a 40 MHz period will start in the current CFP after the reception of the Beacon. |
| Extension Channel Access Timeout | Integer >=1<br>Specifies a time limit (in TU) after which the AP gives up the transition to 40 MHz and the 40 MHz capable HT STA switches back to 20 MHz if it has not received CTS-to-self or Beacon on the extension channel. | Present in Beacon/Probe Response frames when 20 MHz-base managed mixed mode is used.<br>Note: The AP sets the local extension channel access timer to the Extension Channel Access Timeout minus the duration of CTS-to-self or Beacon frame. |
| Basic MCS set | An MCS set contains a bitmap of size 128 bits. Bit 0 maps to MCS 0. A bit is set to indicate support for that MCS. | Present in Beacon/Probe Response frames to indicate what MCS values shall be supported by all devices in the BSS. |
| Duplicate Legacy | Indicates that this beacon is a duplicate transmitted as | Present in legacy beacons transmitted by a HT AP during |

| | | |
|---|---|---|
| Beacon | part of managed mixed mode operation.<br>HT STAs should ignore duplicate legacy beacons regardless of BSSID. | managed mixed mode operation.<br>(See section 8.1.3.3.) |

### 6.3.2.1 TRMS Information Element

The TRMS feature is managed by the TRMS information element defined below.
The TRMS Information Element (IE) may be included in association and reassociation request frames, DLP request and response frames and TRMS Update action frames. This IE includes the following fields:

| Field | Description | Use |
|---|---|---|
| TRMS active | Indicates whether or not TRMS operation is active | If TRMS is active, a STA transmitting to this STA shall operate the procedures defined in section 8.3. |
| Hold-on time | The amount of time in 100s of milliseconds that the STA operates with full receive capability after transmitting a frame. A value of zero indicates that it retains full receive capability for 1 slot time (+ SIFS) after transmitting a frame for which a response is expected. | A hold-on time of zero indicates that the STA wishes to reduce receive capability on completing a sequence exchange.<br>All APs and STAs support TRMS operation in other STAs with a hold-on time of zero.<br>It is an option of a STA to support TRMS tracking for non-zero values of the hold-in time. |

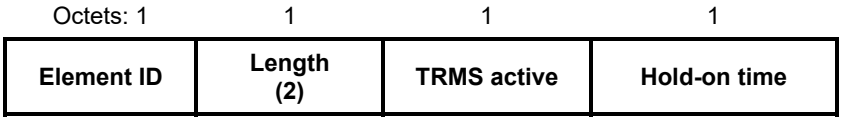



**Figure 14 – TRMS element format**

The TRMS active field indicates that TRMS is active when it takes the value 1, and TRMS is inactive when it takes the value 0.

### 6.3.3 Management Action Frames

These frame are defined to be action frames using the 802.11e Action frame format.
They share a common category code "HT".

The frames using the "HT" category code are defined in Figure 15.

| Action Code | Meaning |
|---|---|
| 1 | TRMS Update |
| 2 | Calibration Measurement |
| 3 | Calibration Correction |

**Figure 15 – Action codes for the HT action category**

#### 6.3.3.1 TRMS Update Action Frame

The TRMS Update Action frame provides a mechanism for the STA to notify the AP and its peers of changes in its operating mode. This frame includes the TRMS IE defined in section 6.3.2.1.

The frame body of the TRMS update contains the information shown in the table below:

| Order | Information |
|---|---|
| 1 | Category |
| 2 | Action |
| 3 | Dialog Token |
| 4 | Status Code |
| 5 | TRMS IE |

All fields except the TRMS IE are defined in 802.11e **[2]**.

#### 6.3.3.2 Calibration Measurement Action Frame

Calibration Measurement frame is a management action frame of category Calibration. It contains the following fields.

| Order | Information | Size |
|---|---|---|
| 1 | Calibration Control | 1 |
| 2 | Calibration Sequence | 1 |
| 3 | MCMR Segment Sequence | 1 |
| 4 | MIMO Channel Measurement Report | 3 × *Ns* × *Ni* × *Nr* |

Where:

- *Ns* = Number of subcarriers in the Calibration Training symbols
- *Ni* = Number of antennas at the STA that transmitted the Calibration Request
- *Nr* = Number of antennas at the STA that is transmitting the Calibration Response

All messages in the same calibration procedure use the same Calibration Sequence value.
The Calibration Control field (1 octet) consists of:

- Number of antennas at the initiating STA *Ni* (2 bits)
- Number of antennas at the responding STA *Nr* (2 bits)
- Calibration Complete (1 bit). The Calibration Complete bit is set to '1' if the STA transmitting the Calibration Measurement frame declares the calibration procedure complete without requiring the other STA to transmit a Calibration Correction Vector frame.
- Reserved (3 bits)

The MCMR Segment Sequence (1 octet) contains the segment sequence number when the MIMO Channel Measurement Report has been segmented. The MCMR Segment Sequence of the first segment is 0. The complete MIMO Channel Measurement Report contains $Ns \times Ni \times Nr$ complex coefficients.

Each complex coefficient (3 octets) is represented by its 12-bit real and 12-bit imaginary parts. Hence the total length of the complete MIMO Channel Measurement Report is $3 \times Ns \times Ni \times Nr$ octets.

The complete MIMO Channel Measurement Report may need to be transmitted using more than one MAC frame. In the mandatory configuration with $Ns = 114$, $Ni = 2$, $Nr = 2$, there will be 1368 octets (456 coefficients) in a single MIMO Channel Measurement Report element. The maximum length of the MIMO Channel Measurement Report field is 5472 octets (1824 coefficients) for the case with $Ns = 114$, $Ni = 4$, and $Nr = 4$. If the MIMO Channel Measurement Report is longer than 1368 octets, the first 1368 octets are included in the first frame (MCMR Segment Sequence = 0) and the remaining octets are included in subsequent frames (MCMR Segment Sequence = 1, 2, etc.).

#### 6.3.3.3 Calibration Correction Action Frame

Calibration Correction frame is a management action frame of category Calibration Correction. It contains the following fields.

| Order | Information | Size |
|---|---|---|
| 1 | Calibration Control | 1 |
| 2 | Calibration Sequence | 1 |
| 3 | MIMO Correction Vector | $3 \times Ns \times Nr$ |
| Where:<br>• *Ns* = Number of subcarriers in the Calibration Training symbols<br>• *Nr* = Number of antennas at the STA that transmitted the Calibration Response | | |

All frames in the same calibration procedure use the same Calibration Sequence value.

The Calibration Control field (1 octet) consists of:

- Number of antennas at the initiating STA *Ni* (2 bits)
- Number of antennas at the responding STA *Nr* (2 bits)
- Reserved (4 bits)

The MIMO Correction Vector contains *Ns* × *Nr* complex coefficients.
Each complex coefficient (3 octets) is represented by its 12-bit real and 12-bit imaginary parts.
Hence the total length of the MIMO Correction Vector field is 3 × *Ns* × *Nr* octets. The maximum length of the Correction Vector field corresponds to *Ns* = 114, *Nr* = 4 is 1368 octets.

### 6.3.4 TSPEC Modification to support Periodic RDR

This section defines modifications to the 802.11e TSPEC structure in support of Periodic reverse direction data.
A new 1-bit field is added to the TSPEC Info Field called "Periodic RDR".
This field takes values 0 and 1.
When "Periodic RDR" is 1, the TSID is associated with a Periodic RDR. This is valid only with TSPECs indicating periodic uplink. This is interpreted by the HC to mean that, instead of transmitting a QoS CF-Poll to the STA to satisfy its TSPEC, the HC periodically transmits an IAC containing an RDG for the specified TSID to satisfy the TSPEC.
See also section 7.4.2.

### 6.3.5 Block Ack Parameter Set field

This section defines changes to the 802.11e Block Ack Parameter set field of the ADDBA frame.

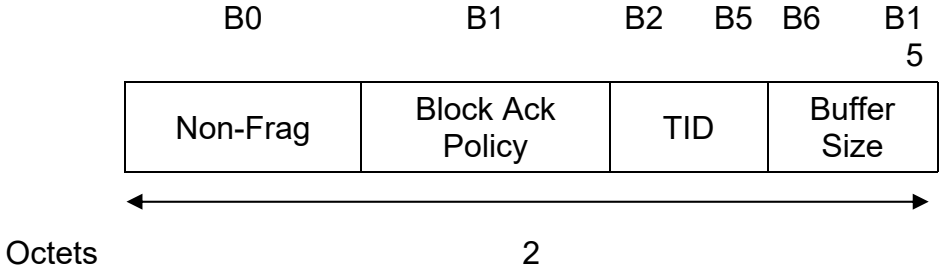



**Figure 16 - Block Ack Parameter Set fixed field**

The Non-Frag subfield is set to 1 if fragmentation is not used.
The compressed BA format is used whenever the Block Ack negotiation is set up between the HT STAs.
The Buffer Size subfield contains the number of buffers at the receiver. Its interpretation depends on the setting of the Non-Frag subfield. The maximum value of the NumMSDU_M1 parameter used in the compressed BA is also derived from the Buffer Size and Non-Frag fields as specified in the following table.

**Table 5 - Interpretation of the Buffer Size parameter**

| Non-Frag subfield | Buffer Size interpretation | NumMSDU_M1 |
|---|---|---|

| value | | |
|---|---|---|
| 1 | Buffer size contains the maximum number of MSDUs that can be sent within the BA window.<br>Maximum value is 64 | NumMSDU_M1 = Buffer Size – 1 |
| 0 | Buffer size contains the maximum number of MPDUs that can be sent within the BA window.<br>Maximum value is 1024 (i.e., 64 x 16) | NumMSDU_M1 = min (Buffer Size, 64) - 1 |

In an ADDBA request frame, the Buffer Size subfield is advisory and the recipient selects a value equal to or smaller than the initial value.

## 6.4 A-MPDU and A-MSDU aggregation formats

### 6.4.1 Introduction to Aggregation (Informative)

There are two types of aggregation defined in this specification: A-MPDU aggregation and A-MSDU aggregation.

A-MPDU aggregation joins multiple MPDUs together and transports them in a single PSDU. A-MPDU aggregation is defined in this section. A-MPDU aggregation can be considered to be a layer that operates at the bottom of the MAC.

A-MSDU aggregation joins together multiple MSDUs and creates a single larger MSDU that is transported in MPDUs. A-MSDU aggregation is defined in 6.4.5. A-MSDU aggregation can be considered to be a layer that operates at the top of the MAC.

Note, the term "aggregate" used elsewhere in this document refers to A-MPDU aggregation, unless specifically referring to A-MSDU aggregation.

The MAC interprets the PSDU as a single MPDU, or as an A-MPDU according to the *Aggregate* TXVECTOR/RXVECTOR parameter, that is robustly transported in the PLCP header.
The MAC separates the MPDUs of an A-MPDU using a robust MPDU delimiter. It is robust in the sense that loss of a single delimiter does not necessarily cause loss of multiple MPDUs in an aggregate.
Note, MPDUs are separately protected by a CRC. Loss of an individual MPDU does not imply loss of all MPDUs in a PPDU.
The Duration fields in the MAC Headers of all MPDUs in an aggregate carry the same value.

### 6.4.2 Aggregated MPDU format (A-MPDU)

An A-MPDU consists of a number of MPDU delimiters each followed by an MPDU.

Except when it is the last MPDU, padding octets are appended (if needed) to make each section a multiple of 4 octets in length.

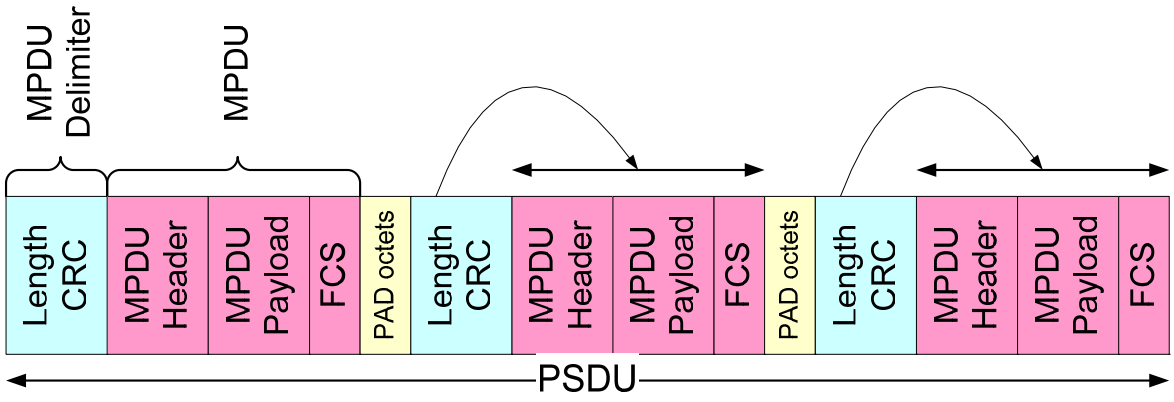



**Figure 17 – A-MPDU format**

The MPDU delimiter is 4 octets in length and contains the fields defined below:

**Table 6 – MPDU delimiter Fields**

| MPDU delimiter Field | Size (bits) | Description |
|---|---|---|
| Reserved | 4 | - |
| MPDU length | 12 | Length of the MPDU in octets |
| CRC | 8 | 8-bit CRC of the preceding 16-bits.<br>As defined in IEEE 802.11 section 14.3.2.2.3 |
| Unique pattern | 8 | Unique pattern that may be used to detect an MPDU delimiter when scanning for a delimiter.<br>The unique pattern is set to the ASCII value for character 'N'. |

The purpose of the MPDU delimiter is to robustly delimit the MPDUs within the aggregate. Robust in this case means that the structure of the aggregate can usually be recovered when one or more MPDU delimiters are received with errors. Individual delimiters have the same BER as the surrounding MPDUs, and so can be lost.

Note, a delimiter with MPDU length zero is valid. This can be used to introduce padding between MPDUs, or at the end of the A-MPDU.

#### 6.4.2.1 Deaggregation (Informative)

The receiver checks the MPDU delimiter for validity based on the CRC. It may also check that the length indicated is within the PSDU HT-LENGTH indicated in RXVECTOR.
If the MPDU delimiter is valid, the MPDU is extracted from the aggregate. The next MPDU delimiter is expected at the first multiple of 4 octets immediately after the current MPDU. This process is continued until the end of the PPDU is reached.
If the MPDU delimiter is not valid, the deaggregation skips forward 4 octets and checks to see if the new location contains a valid MPDU delimiter. It continues searching until either a valid

delimiter is found, or the end of the PSDU is reached based on the RXVECTOR PSDU HT length field. [1]
This algorithm is expressed in the following pseudo-code (note, this is not optimized for efficiency):

```
ParseA-MPDU(length)
{
      Int offset = 0;   /* Byte offset from start of PPDU */
      While (offset+4 < length)
      {
            If valid_MPDU_delimiter(offset) &&
                  get_MPDU_length(offset) <= 2346 &&
                  get_MPDU_length(offset) <= (length – (offset+4))
            {
                  /* Valid delimiter */
                  Receive_MPDU(offset+4, get_MPDU_length(offset));
                  /* advance multiple of 4 bytes */
                  offset += 4 + 4*((get_MPDU_length(offset)+3)/4);
            }
            Else
            {
                  /* delimiter invalid, advance 4 bytes and try again */
                  offset += 4;
            }
      }
}
```

Note: the unique pattern is used to reduce computation required while scanning for a valid delimiter. In this case the receiver tests each possible delimiter for a matching unique pattern. Only when a match is discovered does it then check the CRC.

### 6.4.3 Single receiver frame aggregation format

An aggregate is a sequence of MPDUs carried in a single PPDU carrying the aggregate attribute. In a single-receiver aggregate, all MPDUs are addressed to the same receiver address. The aggregate contains MPDUs in the order defined below.

**Table 7 Single Receiver Aggregation MPDUs**

| MPDU | Multiplicity | Description |
|---|---|---|
| IAC or RAC | At most one | Initiator or responder aggregate control.<br>Used when it is necessary to include a logical element as described in sections 6.1.1 and 6.1.2 |
| ACK | At most one | Contains an acknowledgement of at most one MPDU in the previous aggregate that required immediate acknowledgement. |

[1] This procedure will occasionally wrongly interpret a random bit-pattern as a valid delimiter. When this happens, the MAC will attempt to interpret a random MPDU. The MAC will discard it based on a bad MAC CRC check. The overall effect may be to lose one or more MPDUs from the aggregate very infrequently.

| | | |
|---|---|---|
| BA | At most one per Block ACK agreement in the appropriate direction | Block ACK MPDUs |
| QoS Data, MHDR or CHDATA | No limit, except as constrained by Block ACK protocol and TXOP duration<br>When MAC Header compression is applied the aggregate shall include at least one MHDR MPDU per TC and receiver. | Data MPDUs sent under Block-ACK policy.<br>These MPDUs can come from multiple TCs, provided that they comply with the TC policy of the current TXOP.<br>Apart from QoS Data MPDUs the aggregate may also contain MHDR- and CHDATA MPDUs (both of Type 'EDATA'). |
| BAR | At most one per Block ACK agreement (immediate Block ACK policy). | Immediate Block ACK Requests |
| Any MPDU requiring an immediate response | At most one | At most one MPDU that requires an Ack MPDU response may be transmitted.<br>This includes BAR sent under delayed Block ACK policy, Data MPDU (including non-QoS), Management MPDU. |

At most one single Block ACK Request using the delayed Block ACK policy is permitted. This is acknowledged by an acknowledgement MPDU in the following aggregate.

### 6.4.4 Multiple receiver frame aggregation format

A multiple-receiver aggregate contains MPDUs that are addressed to multiple receivers. The multiple receiver aggregate (MRA) is distinguished by the presence of the MRAD MPDU that lists the receiver addresses referenced in the aggregate. The MRA contains a MRAD MPDU, followed by one or more groups of MPDUs organized by receiver address.
Each group is either a response group or a non-response group. The rules for contents of the two groups are similar, except that the response group contains an IAC that defines a response period.
A Broadcast/Multicast Data Group contains MPDUs in the order defined below.

**Table 8 - Broadcast/Multicast Receiver Group MPDUs**

| MPDU | Multiplicity | Description |
|---|---|---|
| Data or management MPDU | No limit, except as constrained TXOP duration | Data or management MPDUs with the broadcast or the same multicast destination address. |

A Scheduled Response Receiver Group shall contain the same MPDUs as a Single Receiver Aggregate (see section 6.4.3), addressed to the same receiver, in the order defined in Table 7.

A No Response Receiver Group shall contain the following MPDUs, addressed to the same receiver, in the order defined below.

**Table 9 - No Response Receiver Group MPDUs**

| MPDU | Multiplicity | Description |
|---|---|---|
| IAC | At most one | Initiator aggregate control MPDU<br>Note this cannot contain an RDG. |
| ACK | At most one | Contains an acknowledgement of at most one MPDU in the previous aggregate that required immediate acknowledgement. |
| BA | At most one per Block ACK agreement in the appropriate direction | Block ACK MPDUs |
| QoS Data, MHDR or CHDATA | No limit, except as constrained by Block ACK protocol and TXOP duration<br>When MAC Header compression is applied the aggregate shall include at least one MHDR MPDU per TC and receiver. | Data MPDUs sent under Block-ACK policy.<br>These MPDUs can come from multiple TCs, provided that they comply with the TC policy of the current TXOP.<br>Apart from QoS Data MPDUs the aggregate may also contain MHDR- and CHDATA MPDUs (both of Type 'EDATA'). |

The MRA aggregate shall contain the following (groups of) MPDUs in the order defined below.

**Table 10 - MRA Aggregate MPDUs**

| MPDU | Multiplicity |
|---|---|
| MRAD | One |
| Broadcast/Multicast Data Group | One per broadcast or multicast destination address.<br>Only permitted when the BSS is operating in pure mode. |
| Scheduled Response Receiver Group<br>or<br>No Response Receiver Group | One per receiver address. |

Scheduled Response Receiver Groups and No Response Receiver Groups may be mixed in any order.
Data MPDUs can come from multiple TCs, provided that they comply with the TC policy of the current TXOP.
Data MPDUs with the same receiver address are included in consecutive locations in the MRA aggregate. The order of (groups of) Data MPDUs for different receiver addresses is equal to the order of the Receiver Info fields in the MRAD MPDU.

### 6.4.5 Aggregated MSDU Format (A-MSDU)

This section describes the format of Aggregated MSDU (A-MSDU). The purpose of the A-MSDU is to allow multiple MSDUs being sent to the same receiver to be aggregated and sent in a single MPDU, which improves the efficiency of the MAC layer, particularly when there are many small MSDUs such as TCP acks. Support for A-MSDU is mandatory at the receiver. However, the transmitter is free to use A-MSDU or not based on information such as traffic characteristics and link conditions. The maximum length of an A-MSDU is limited so that the length of an MPDU containing an (unfragmented) A-MSDU shall not exceed 4095 bytes.

Figure 18 shows the structure of a Data MPDU containing an A-MSDU, which is a sequence of *n* MSDU sub-frames. Each sub-frame consists of a sub-frame header followed by an MSDU and 0-3 bytes of padding. The MSDU shall not exceed 2304 byes in length. A sub-frame (except the last) is padded so that its length is a multiple of 4 bytes. The last sub-frame has no padding.

The sub-frame header contains three fields: Destination Address (DA), Source Address (SA), and Length. [2] The DA and SA fields are interpreted as described in Table 12 and Table 13 below. The length field contains the length in bytes of the MSDU.

[2] Note, these fields are arranged in the same order as the 802.3 frame format.

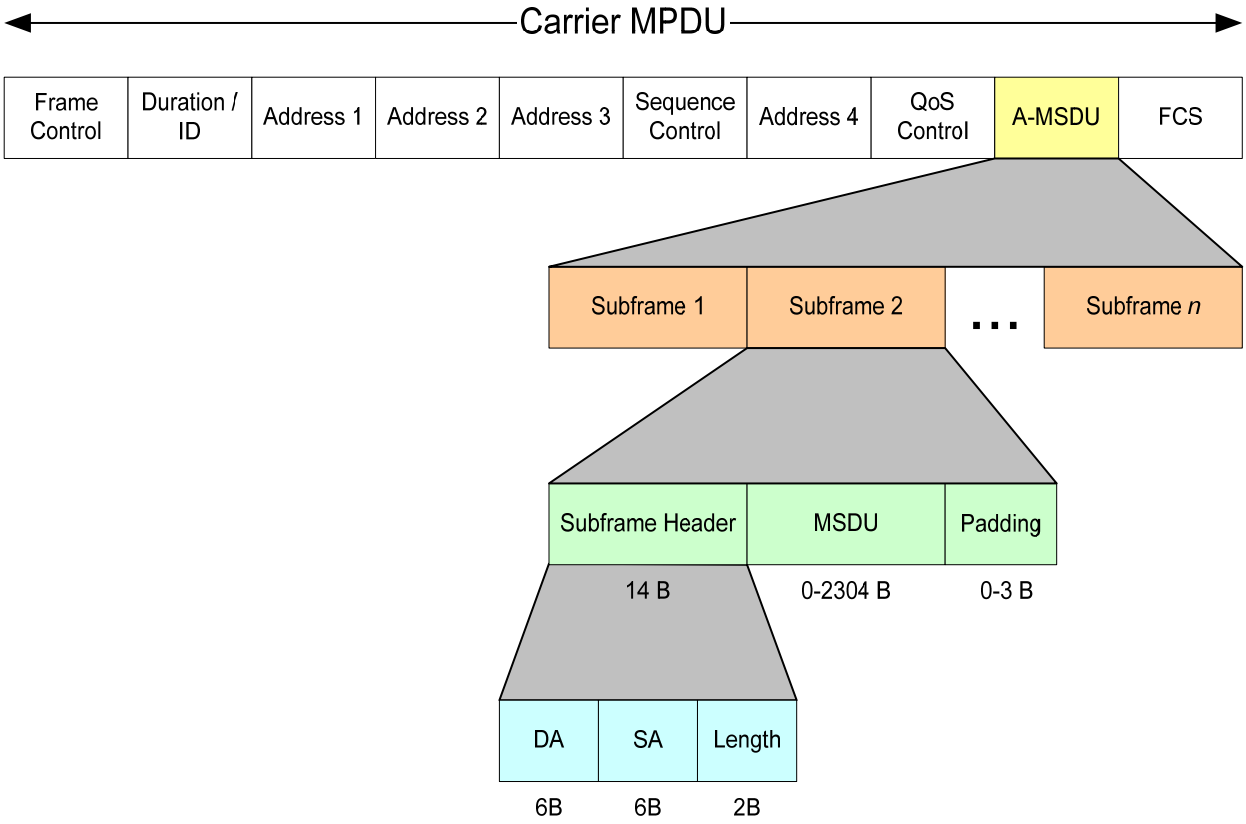



**Figure 18 – A-MSDU Structure**

The MPDU containing the A-MSDU is one of the QoS data subtypes. The presence of the A-MSDU is signaled by a bit in the QoS control field, whose contents are described in the table Table 11.

**Table 11 – QoS Control Field**

| Applicable Frame (sub) Types | Bits 0-3 | Bit 4 | Bit 5-6 | Bit 7 | Bits 8-15 |
|---|---|---|---|---|---|
| QoS CF-Poll and QoS CF-Ack+CF-Poll frames sent by HC | TID | EOSP | Ack Policy | Reserved | TXOP limit |
| QoS Data+CF-Poll and QoS Data+CF-Ack+CF-Poll frames sent by HC | TID | EOSP | Ack Policy | A-MSDU Present | TXOP limit |
| QoS Data and QoS Data+CF-Ack frames sent by HC | TID | EOSP | Ack Policy | A-MSDU Present | QAP PS Buffer State |
| QoS Null and QoS CF-Ack frames sent by HC | TID | EOSP | Ack Policy | Reserved | QAP PS Buffer State |
| QoS Data and QoS Data+CF-Ack frames sent by non-AP QSTAs | TID | 0 | Ack Policy | A-MSDU Present | TXOP duration requested |
| | TID | 1 | Ack Policy | A-MSDU Present | Queue size |

| | | | | | |
|---|---|---|---|---|---|
| QoS Null and QoS CF-Ack frames sent by non-AP QSTAs | TID | 0 | Ack Policy | Reserved | TXOP duration requested |
| | TID | 1 | Ack Policy | Reserved | Queue size |

The DA and SA are passed between the MAC and its service client in the MAC service primitives. The mapping of DA, SA to the addresses in the MPDU header is described by the following tables. It is possible to have different DA and SA in the same A-MSDU as long as they all map to the same receiver address.

**Table 12 – Address field contents for unicast MPDUs**

| To DS | From DS | Address 1 | Address 2 | Address 3 | Address 4 | DA | SA |
|---|---|---|---|---|---|---|---|
| 0 | 0 | DA | SA | BSSID | X | - | - |
| 0 | 1 | DA | BSSID | - | X | - | SA |
| 1 | 0 | BSSID | SA | - | X | DA | - |
| 1 | 1 | RA | TA | - | - | DA | SA |

**Table 13 - Address field contents for broadcast/multicast MPDUs**

| To DS | From DS | Address 1 | Address 2 | Address 3 | Address 4 | DA | SA |
|---|---|---|---|---|---|---|---|
| 0 | 0 | Bcast Addr. | SA | BSSID | X | DA | - |
| 0 | 1 | Bcast Addr. | BSSID | - | X | DA | SA |
| 1 | 0 | BSSID | SA | - | X | DA | - |
| 1 | 1 | RA | TA | - | - | DA | SA |

Notes:
1. Fields marked with X are not present
2. Fields marked with "–" are present but their contents are reserved
3. Broadcast/multicast MPDU transfer follows the procedure described in Section 9.2.7 of IEEE 802.11-2003. Thus broadcast/multicast frames sent by non-AP stations are directed at the AP and are ACKed by the AP. In this case, a STA may aggregate both broadcast/multicast frames and unicast frames. The same is not true for frames sent by AP, since broadcast/multicast and unicast frames are mapped to different receiver address (Address 1).

After A-MSDU aggregation, the A-MSDU is treated like any other MSDU. It be be transported using either QoS Data or CHDATA MPDUs. It may be fragmented.

# 7 MAC sublayer functional description

## 7.1 Aggregation Exchange Sequences and related rules

### 7.1.1 IAC/RAC Exchange Rules

This section describes how IAC/RAC MPDUs are used in a bi-directional exchange.
An exchange protected using LongNAV rules shall start with the exchange of non-aggregate IAC and RAC MPDUs at a basic rate. An RTS/CTS exchange may be substituted for an IAC/RAC exchange if none of the features of the IAC/RAC are required by the initiator. Control frames intended to modify the NAV (IAC, RAC, CF-End and SCB) are sent at a basic rate.
A STA shall respond to a PPDU carrying a non-aggregate IAC MPDU with a non-aggregate RAC response MPDU. Note, in this case the IAC MPDU does not include an RDG value. The response RAC is generated regardless of the absence of the RDG.
Following the initial exchange, for all PPDUs for which a response is permitted, the initiator may include an IAC in the aggregate containing the permitted response grant.
When the initiator schedules a response, the initiator shall allow enough RDG time for a response RAC and any requested BAs. The responder does not need to include an RAC if no elements of the RAC need to be transmitted. If the response is a single MPDU (i.e. a Block Ack), the responder may send this as an aggregate or non-aggregate.
Note: under LongNAV rules, the initiator can re-use any time not used by the responder in its response. Under pairwise spoofing rules, this is not the case.

### 7.1.2 Non-aggregate IAC/RAC Rate selection Rules

An initiator that needs to set the NAV in its locality (i.e. LongNAV rules for initial exchange) shall use a basic rate. In a mixed BSS, it shall use a basic legacy rate and PPDU format.
A responder responding to an IAC with an RAC MPDU assumes that it is required to set the NAV in its locality. It shall use a basic rate. In a mixed BSS, it shall use a basic legacy rate and legacy compatible PPDU format.

### 7.1.3 Response Period Scheduling

The initiator may grant reverse direction to:

- Respond to an RDR contained in the previous PPDU received from this STA
- Respond to a periodic RDR TSPEC at the start of its service period
- Respond to a transmission failure in the previous PPDU received from this STA
- Allow for an RAC MPDU
- Allow for a BA response to any BAR it is transmitting to the STA in its current PPDU.
- Allow for an Ack response to any MPDU it is transmitting that requires an ACK response.

The grant is in units of time and should use the latest MCS value for that STA to convert the known amount of data to grant value. This MCS value is the latest value either sent to the STA (as an MFB element, including one in the current PPDU) or received from the STA (as a default MCS).

#### 7.1.3.1 Retransmission Rules

When transmitting an MRA containing periodic RDR, or when transmitting a SRA under the Pairwise Spoofing rules, the initiator shall allocate in its next RDG sent to a responder during the current frame exchange sequence, a grant for MPDUs transmitted by the responder that were not received successfully at the initiator.

### 7.1.4 Responder Rules

An HT STA that receives an IAC containing an RDG shall, in response, transmit a single non-aggregate MPDU or a single receiver aggregate PPDU addressed to the initiating HT STA. This response shall begin no earlier than the scheduled response period and end no later than the end of the scheduled response period. If the IAC contains an RTS element, the responder shall generate no response if its NAV is non-zero at the start of the response period, otherwise the responder shall respond with an RAC containing a CTS element.
A responder should respond to the MRA initiator at the starting time of its granted response period, regardless of whether it is receiving frames or is physically sensing the medium busy at the starting time of its RDG.

### 7.1.5 Response PPDU Contents

When sending a response PPDU, the IAC's Reverse Direction Traffic Identifier (RDTID) identifies what Data MPDUs are eligible to be transmitted, as follows.

When the RDTID contains a TSID, only MPDUs of this traffic stream may be transmitted. This is typically used with a periodic TSPEC to gather uplink MPDUs for that TSPEC.

When the RDTID contains an AC, only MPDUs of the specified access category may be transmitted. This is typically used by an initiator that gained access to the channel using EDCA to ensure that only MPDUs of that AC are sent by a responder.

When the RDTID contains the value "unconstrained", MPDUs of any traffic stream or user priority may be transmitted. This may be used by an initiator during a TXOP gained through HCCA.

### 7.1.6 Power-saving at the receiver of an aggregate PPDU

An HT STA may sleep through part of the aggregate PPDU under the following conditions:

- It correctly received an initial MPDU that was not a MRAD, and was addressed to another receiver
- It correctly received an initial MPDU that was a MRAD that did not contain its receiver address or broadcast address

If the HT STA correctly receives a MRAD that caused it to remain awake because it contained the broadcast address, the HT STA may sleep as soon as it decodes a unicast receiver address in the aggregate.
If the HT STA correctly receives a MRAD that caused it to remain awake because it contained its address, the HT STA may sleep once it has decoded an MPDU containing its receiver address followed by one that contains a different receiver address.

### 7.1.7 Protection mechanisms

#### 7.1.7.1 MAC layer protection

The following techniques may be used to achieve protection using a MAC layer technique:

- A contention-free-period of a beacon containing a CF parameter set.
- The HC may deliver a polled TXOP to an HT STA. The whole of the TXOP may be protected by the duration field in the QoS CF-poll.
- The HC uses its privileged channel access (after a PIFS) and starts a CAP with transmission of a CTS-to-self MPDU.
- A TXOP may be started with an RTS/CTS or IAC/RAC exchange, providing NAV protection of the duration specified in these control MPDUs.

##### 7.1.7.1.1 Long NAV

When a STA has a TXOP, it may set a long NAV to protect multiple PPDUs using a single protection MAC layer protection exchange, e.g., RTS/CTS.
The STA may be able to accurately predict the duration of these PPDUs, in which case it can set the duration values in the preceding protection exchange accurately.
However, it may not be able to predict the duration accurately. Setting a longer NAV allows it to respond to the following events:

- Retries of failed transmissions in the current exchange
- Adaptation of transmit parameters by training feedback during the current exchange
- Transmission of MSDUs arriving at the MAC Data SAP during the current exchange
- Reverse direction grants

LongNAV protection is defined as selecting a duration value, limited by the remaining duration in the current TXOP and setting the NAV to this value using one of the MAC layer protection techniques.

##### 7.1.7.1.2 Truncation of TXOP

In the case that a STA gains access to the channel using EDCA and uses LongNAV to protect a duration value, and then runs out of MPDUs to transmit, the STA may transmit a CF-End provided that the remaining duration is long enough to transmit this MPDU.
This shall be interpreted by HT STAs and is interpreted by legacy STAs as a NAV reset – i.e. they reset their NAV timer to zero at the end of the PPDU containing this MPDU. [3].

[3] Note, the transmission of a single CF-End MPDU by the initiator resets the NAV of devices hearing the initiator. There may be devices that could hear the responder that had set their NAV that do not hear this NAV reset. Those devices will be prevented from contending for the medium until the original NAV reservation expires

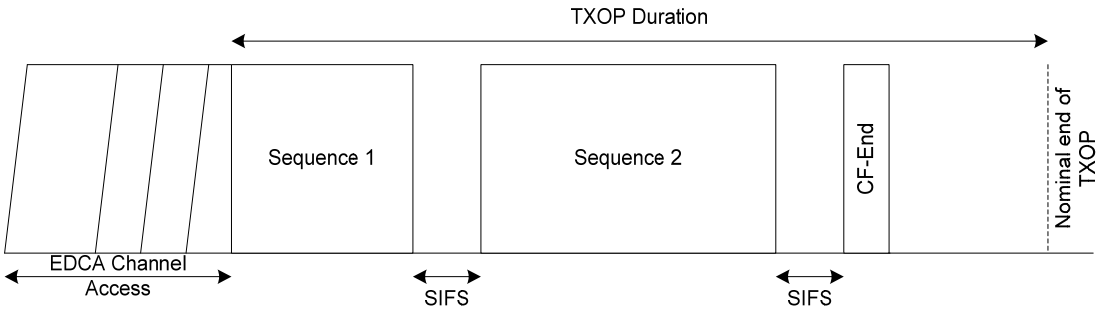



**Figure 19 – Example of TXOP Truncation**

In the example above the device accesses the medium using EDCA channel access and then engages in two sequences of PPDUs in the initiator role (these could be to the same receiver address, or different receiver addresses). Each sequence may include multiple PPDUs sent and received.
At the end of the second sequence, the initiator has no more data that it can send that fits within the TXOP, so it truncates the TXOP by transmitting a CF-End MPDU.
HT STAs and legacy STAs that receive this MPDU reset their NAV and can start contending for the medium immediately after this MPDU.

### 7.1.7.2 PHY layer protection – Spoofing

The Spoofed NAV Duration is virtually set in the PHY Header by using the Length and Rate Field of the legacy SIGNAL Field.
Previously, the Rate field declares the Rate that the packet is coded in after the PHY Header, and the Length field declares the Length of the packet (after the PHY header) in Bytes. When a legacy node receives this SIGNAL Field, it starts to decode the rest of the packet in the specified rate and will continue to do so until the end of Length / Rate time.
The Spoofed NAV uses this characteristic of the Length and Rate Fields, so that the (Length / Rate) – (EIFS – DIFS) is equivalent to the intended NAV Duration. A legacy node that is spoofed by these two fields will continue reception for that (Length / Rate) – (EIFS – DIFS) time, preventing it to start transmission during that period. This way transmission protection can be achieved without requiring that legacy nodes can receive the MPDU contents.

#### 7.1.7.2.1 Pairwise Spoofing

Pairwise spoofing is a method of providing protection for an SRA aggregate exchange using the spoofing mechanism at both initiator and responder.

Pairwise Spoofing works as follows.

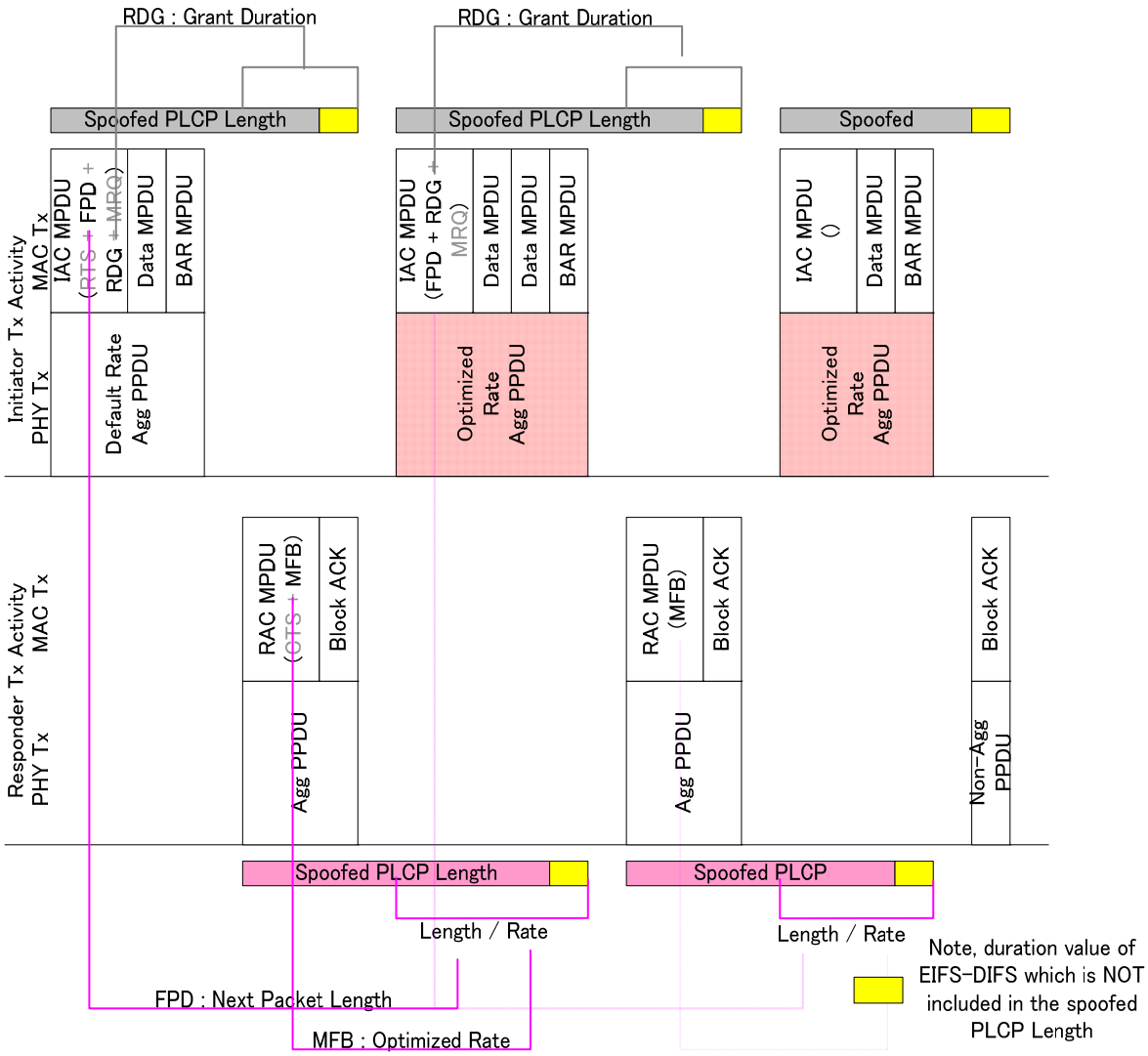



**Figure 20 – Basic Operation of Pairwise Spoofing**

The transmitter of a Data packet informs the recipient of the length of the packet it intends to transmit by indicating the FPD (Following Packet Descriptor) or RDR (Reverse Direction Request) field. When a STA receives an FPD or an RDR, it calculates the length, in time, it will take to receive that packet by dividing the length by the rate that the packet will be sent at. The MCS of the packet may be specified by the recipient using an MFB (MCS Feed Back) field for optimization purposes, otherwise it uses the default MCS notified in the FPD / RDR Field. The STA shall add to the length of the packet indicated in the FPD or RDR the length of any response MPDUs (e.g. RAC, BA, Ack) implied by its own transmission in determining the duration to spoof.

#### 7.1.7.2.2 Single Ended Spoofing

Single ended spoofing provides protection of MRA aggregate exchanges using the spoofing mechanism at the initiator.

Single Ended Spoofing works as follows.

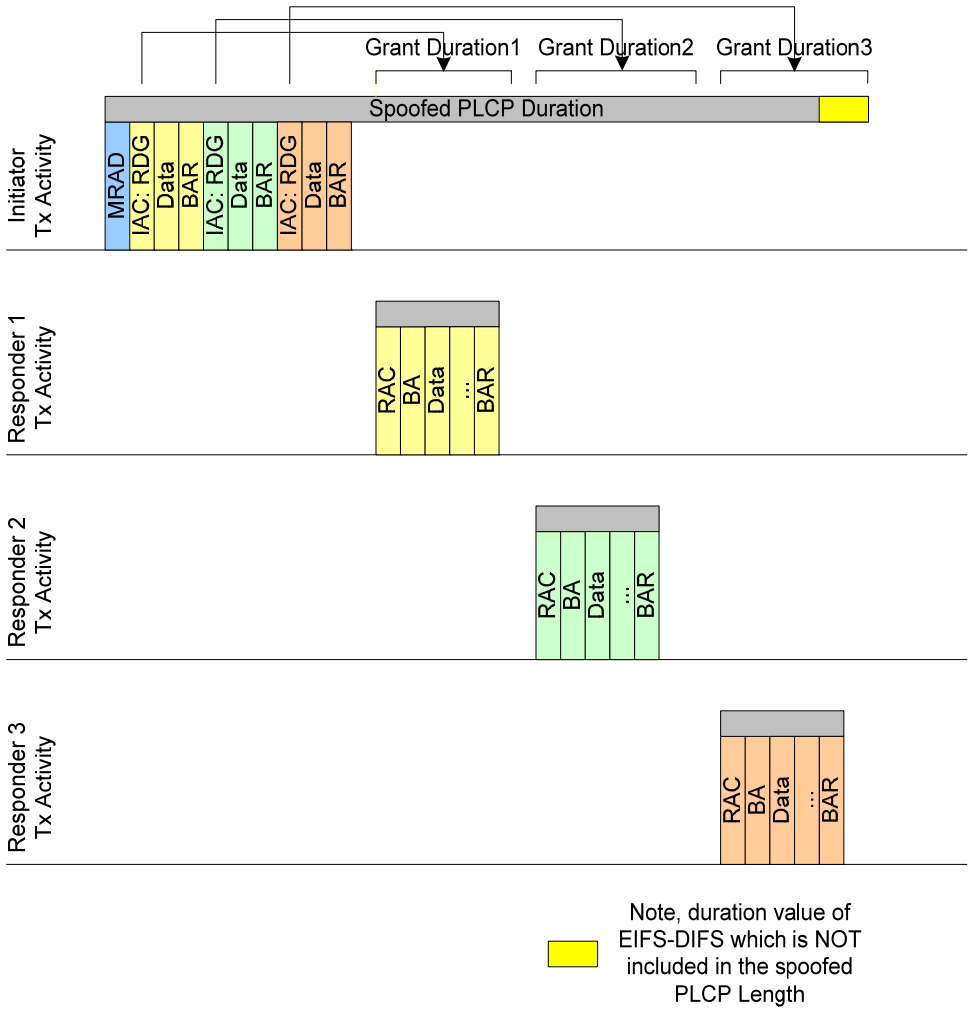



**Figure 21 – Basic Operation of Single Ended Spoofing**

In the case where single ended spoofing is used, an initiator should set its spoofed duration according to the duration it grants to reponses using the RDG field. The spoofed duration should be set so that it covers from the start of the initiator's frame to the end of the last grant duration minus (EIFS – DIFS).
In the figure above, single ended spoofing is used to protect responses to an MRMRA packet. The use of single ended spoofing is not limited to just MRMRA but may also be used for protection of an SRA sequence.

### 7.1.7.3 HT Device NAV and EIFS Rules

An HT device that receives a PPDU examines the legacy and HT rate and length fields from which it calculates legacy and HT durations.
It determines that spoofing is in operation if the legacy duration is not equal to the HT duration.
If spoofing is in operation, it shall set its NAV to the value of legacy duration + (EIFS – DIFS) – HT duration at the end of the received PPDU, unless the NAV has been set by reception of a duration field value within the PPDU. (See section 9.3.5 for a explanation of why this is necessary).
Note: EIFS is of less value in an HT network than a legacy network. It is difficult to define exactly what duration should be protected. Also use of spoofing and LongNAV provides NAV protection throughout aggregate exchanges containing MPDUs that a 3rd party HT STA is

unlikely to be able to hear. 3rd party HT STAs should not use EIFS at the end of an aggregate exchange because that would unfairly benefit the two peer STAs involved in the exchange.
The following rule defines EIFS selection for an HT STA:
An HT STA that receives an MPDU with a bad CRC shall only use EIFS if its NAV is zero at the start of the PPDU containing the MPDU. The condition is never true during an aggregate exchange, but is true for isolated Data/ACK.

### 7.1.8 MAC support for closed loop modes

#### 7.1.8.1 Closed-loop MCS training

Support for closed-loop MCS adaptation is provided by the exchange of MRQ (MCS Request) and MFB (MCS Feedback) elements carried in IAC/RAC control frames.
An MCS Request can be included in any IAC or RAC. Its purpose is to request the peer STA to measure the characteristics of the link and return information in an MFB that allows the link to be used more effectively.
There are three types of MCS training exchange: normal, unsolicited and unanswered.
There is no negotiation or indication about which type of training exchange will take place. The peer initiating the exchange shall be prepared for a normal or missing response. It shall also respect unsolicited MFB.
A STA receiving an MFB should use the information contained in it to adapt its transmission parameters. A STA using the Pairwise Spoofing mechanism shall use the information received in the MFB to define the transmission parameters of the next PPDU to be transmitted in the current exchange sequence to that peer.

##### 7.1.8.1.1 Normal Adaptation

In a normal training exchange, an MFB element is present in the next aggregate sent by the receiver of the MRQ element, and the aggregates are separated by a SIFS interval.

##### 7.1.8.1.2 Unsolicited Adaptation

In an unsolicited exchange, a STA may send an MFB element without any matching MRQ element at any stage of an exchange.

##### 7.1.8.1.3 Unanswered Training Exchange

In an unanswered training exchange, a STA ignores an MRQ element and refuses to provide an MFB element. In the case of pairwise spoofing, the STA that has sent the ignored MRQ element, shall use the default MCS defined in the FPD / RDR element.

#### 7.1.8.2 Closed-loop MIMO training

Support for closed-loop MIMO adaptation is provided by the exchange of a TRQ (MIMO Training Request) element carried in IAC/RAC control frames and an HT sounding PPDU.
A TRQ can be included in any IAC or RAC. Its purpose is to request the peer STA to return an HT sounding PPDU that allows the requesting STA to use better parameters for subsequent transmissions to the peer STA.
Use of Closed-loop MIMO training is an option of the STA sending the TRQ. A STA that does not support closed-loop MIMO will never send an IAC or RAC with the TRQ flag set. All STAs support the creation of an HT sounding PPDU.

A STA that receives a PPDU carrying a TRQ element should ensure that its response PPDU is sent with the TXVECTOR SOUNDING parameter set to 1.

### 7.1.9 Aggregated Single Directional frame transfer

This section contains examples of aggregate exchanges for a single receiver address and for data transfer from the initiator to the responder.
In order to use aggregation, protection or legacy protection is required as defined by the operating mode.
In the LongNAV case, protection is achieved through the IAC/RAC exchanged transmitted at a rate such that all devices can receive these frames. An RTS/CTS exchange may be used if none of the IAC elements (apart from RTS) is required.
This is followed by a sequence of PPDUs. The PPDUs transmitted by the initiator shall be aggregate PPDUs. The PPDUs transmitted by the responder may be aggregate or non-aggregate PPDUs and must carry only response MPDUs and training feedback. These response PPDUs must not include any Data or Block ACK Request MPDUs.
The initiator prevents reverse direction data flow by defining an RDG to be large enough only for the expected response MPDUs: an RAC, one or more BAs and up to one ACK.

#### 7.1.9.1 LongNAV examples

The first example shows use of LongNAV, unidirectional.
A pair of IAC/RAC MPDUs establishes NAV protection of the TXOP.
There then follows a sequence of transmissions of aggregates and reverse direction Block ACK responses from the responder. No RAC MPDUs are present in the response PPDUs because none of the logical elements are required to manage the exchange.

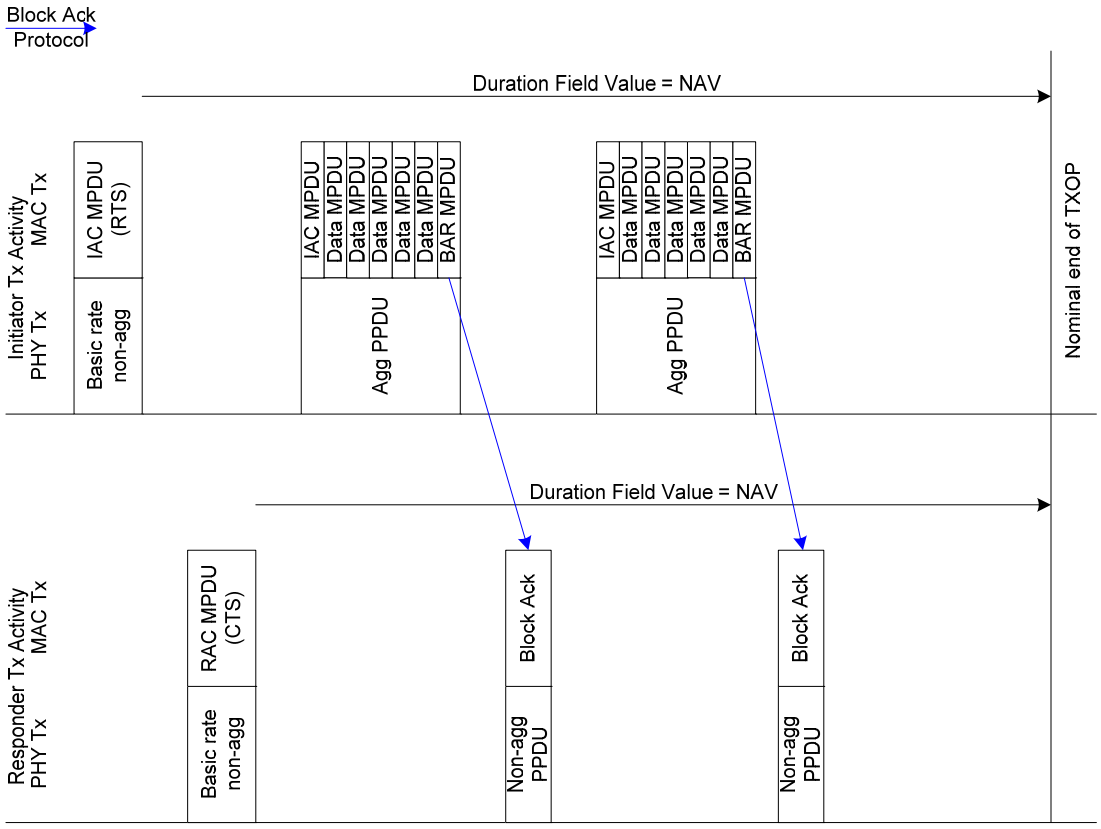



**Figure 22 – LongNAV, untrained unidirectional exchange**

The responder may want to request some reverse direction data transfer, or to send a training response in addition to sending a BA. In this case, it uses an aggregate to contain this information in its single response PPDU.

Note: The initiator does not know which of these the responder will elect to do, and so provides an RDG that supports the transmission of the longest response.

In the example below, the responder uses an aggregate to return a MFB (MCS Feedback) plus a Block ACK, in response to a MRQ (MCS Request) in the IAC and a BAR (Block ACK Request).

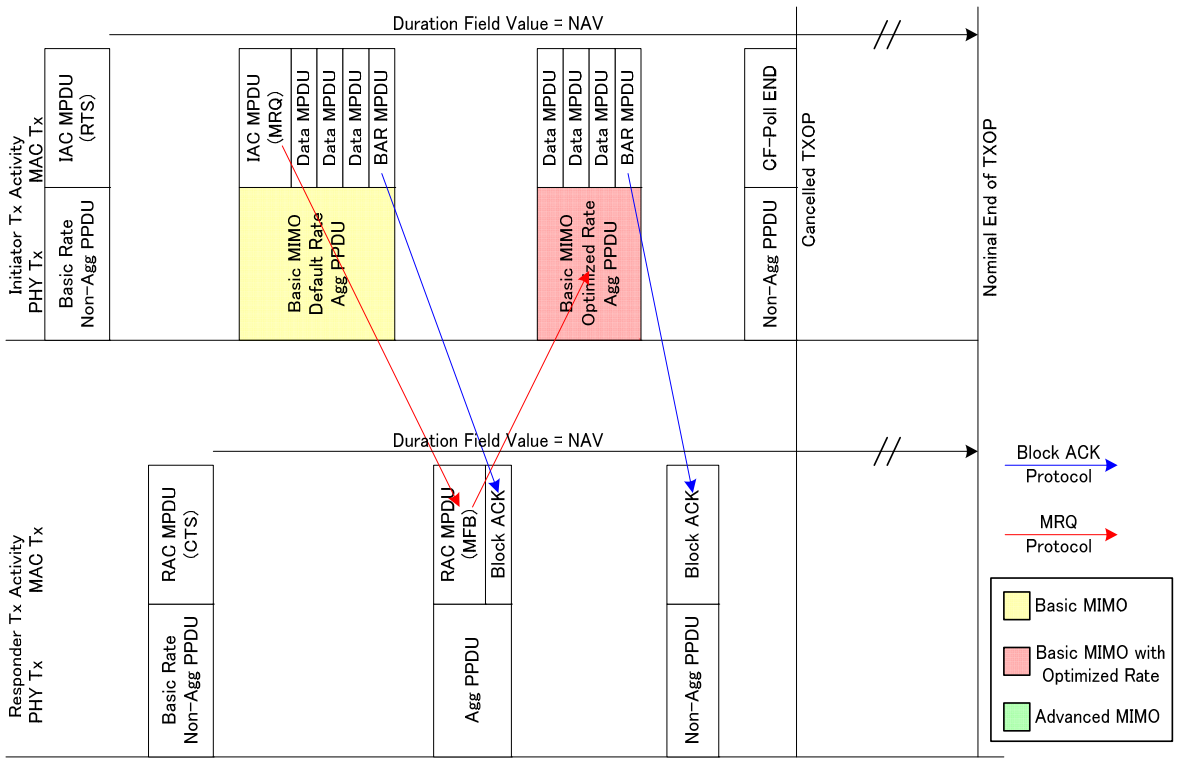



**Figure 23 – LongNAV, untrained unidirectional showing aggregate response**

The next diagram shows an example when training is involved.
First, a pair of IAC/RAC packets are sent at a basic rate (SISO mode), so that any third party nodes, including legacy nodes can set its NAV correctly. In the next IAC packet, the TRQ (Training Request) element is indicated to show that the following packet will be sent at an "Advanced MIMO Mode (MIMO with implicit Feedback)". In response to the TRQ, the responder will send its response PPDU with the TXVECTOR SOUNDING parameter set to 1. Also, in the second IAC, the MRQ (MCS Request) element is indicated to request a MCS Feedback, so that the modulation scheme may be selected by the responder.
When the initiator chooses to end the TXOP before the nominal end of the intended TXOP, it sends a CF-Poll End packet at a Basic Rate to cancel the TXOP.

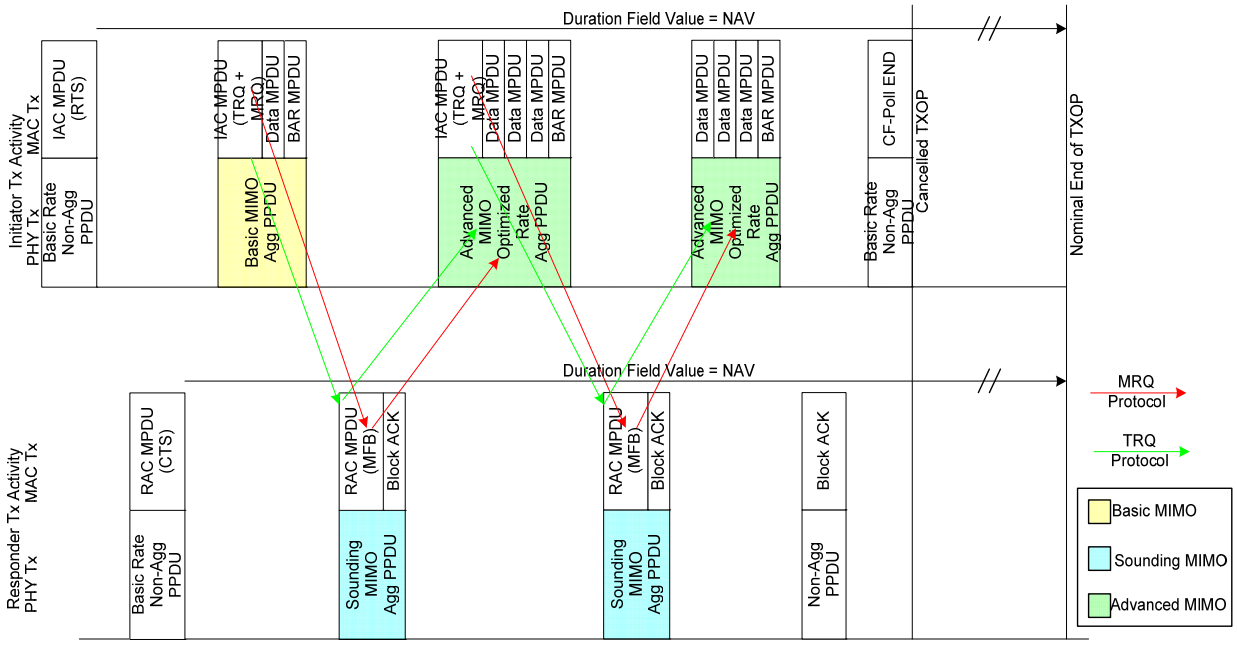



**Figure 24 – LongNAV, trained unidirectional showing aggregate response**

### 7.1.9.2 Pairwise Spoofing example

The next set of examples shows uses of Pairwise Spoofing, unidirectional.

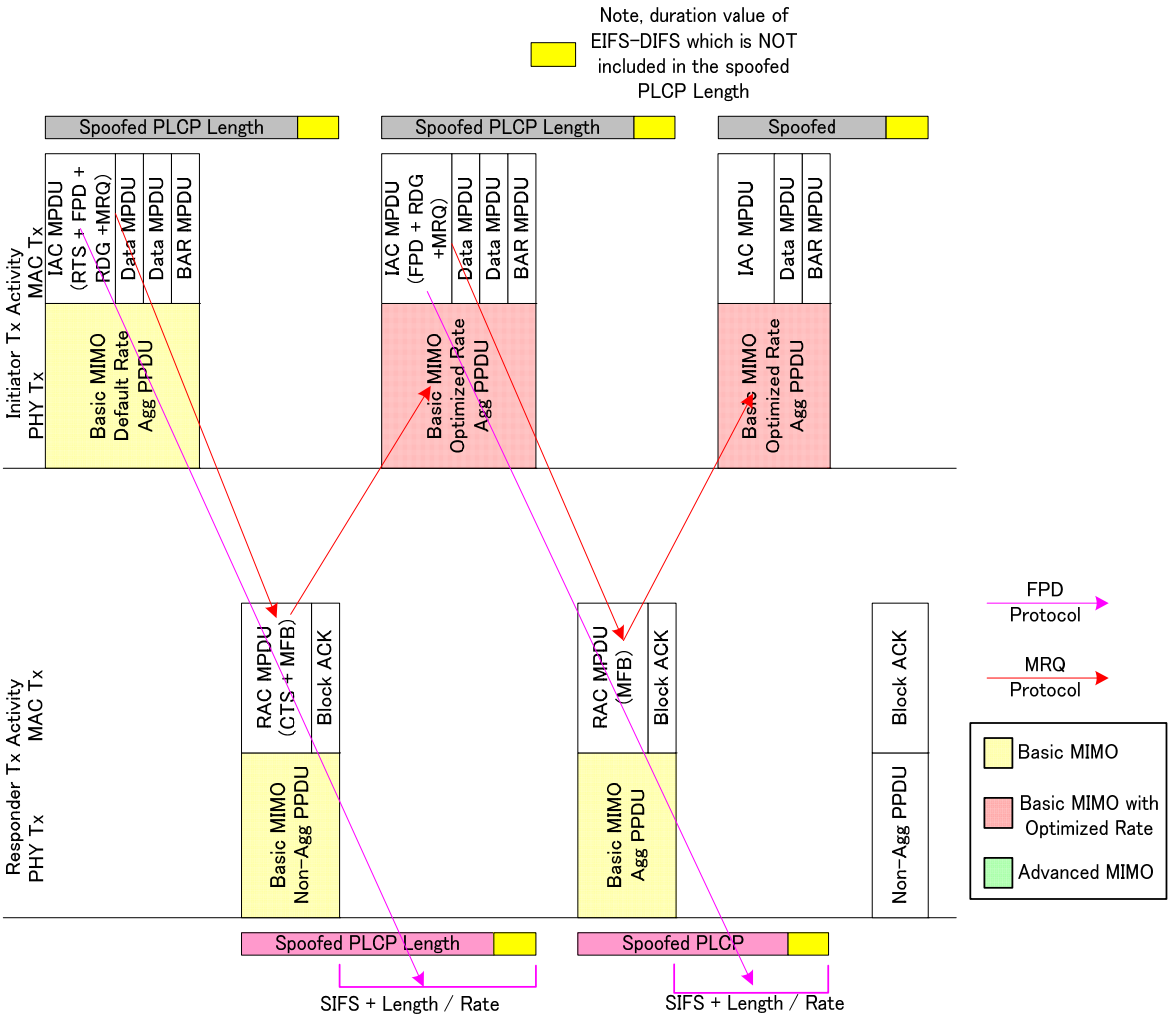



**Figure 25 – Pairwise Spoofing, Untrained Unidirectional Exchange**

An initiator starts with an IAC MPDU containing an FPD (Following Packet Descriptor) and an RDG big enough to hold the RAC response PPDU. Also, an MRQ is present to request MCS selection by the responder. The PPDU carrying the IAC MPDU will have a spoofed duration, set by the Rate and Length Field of the SIGNAL, which protects the RAC MPDU and Block ACK MPDU of known size.

The Responder answers with a RAC MPDU containing an MFB (MCS Feed Back) element. The MFB species the MCS at which it expects to receive the next PPDU from the initiator. When this MFB Field is not present, the Initiator will send its next PPDU at the default MCS specified in the FPD Field. The PPDU containing the RAC MPDU will have a spoofed duration of Length (in the FPD Field) divided by the Rate (either the default MCS or the MCS selected in the MFB) minus (EIFS – DIFS). For details on Spoofed NAV, see section 8.1.7.1.

After receiving the RAC MPDU, the initiator will send its aggregated MPDU at the MCS specified by the MFB Field. This aggregated MPDU will have a spoofed duration, which protects the fixed sized RAC MPDU and the expected response from the BAR (Block Acknowledgment Request) that it has sent.

This process will continue until the expiry of Initiator's TXOP or when the Initiator has no more packets to send.

The following example considers what happens when there is training involved.

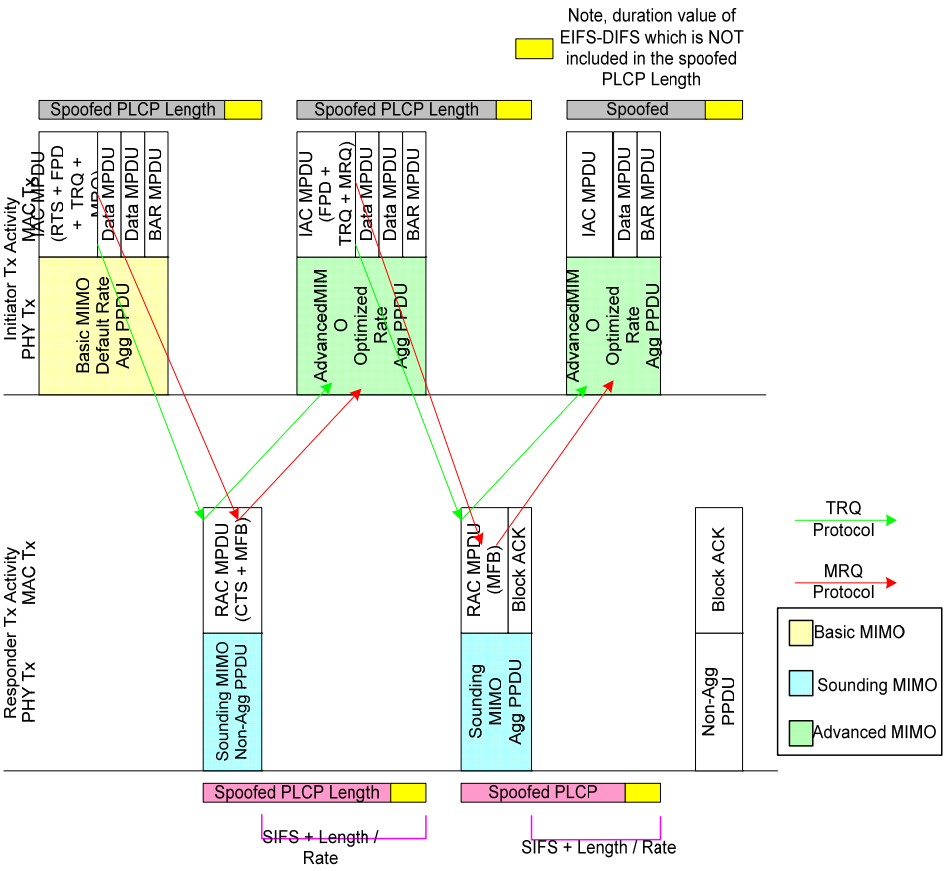



**Figure 26 – Pairwise Spoofing, Trained Unidirectional Exchange**

In Figure 26, the Initiator's MRQ element is used to optimize MCS selection at the responder. This optimized MCS is carried in the RAC MPDU.
Also, the TRQ (Training Request) element is present to show that the following packet will be sent at an "Advanced MIMO Mode (MIMO with implicit Feedback)". In response to the TRQ, the responder will send its response PPDU with the TXVECTOR SOUNDING parameter set to 1.

### 7.1.10 Bi-directional data transfer

This section defines the rules for setting of the RDL, RDR and RDG elements in order to achieve reverse direction data transfer, and then illustrates the use of these rules with example sequences.

#### 7.1.10.1 RDL/RDR/RDG Rules

A STA that is an initiator may advertise willingness to provide reverse direction data flow by including a RDL element in its IAC.

A STA that is a responder may request a reverse direction allocation from the initiator using an RDR element. The RDR element contains the length of data in the PPDU it would like to send, plus a default MCS. An MFB element may accompany the RDR, and the initiator may determine an updated MCS based on their contents.

In determining an RDR value, a STA shall only consider those MPDUs that meet any RDTID constraint contained in the previous IAC.

The initiator receiving the RDR information (and possibly augmented by the MFB) calculates a grant duration. The RDG element in the next IAC contains the allocation for reverse direction data, plus any additional grants as defined in section 7.1.3.

The initiator is free to grant any RDG it wishes (compliant with the TXOP rules) including: no duration, the exact duration implied by the RDR, or any other duration determined by the implementation. Under pairwise spoofing rules an initiator should not grant an RDG that is longer than the RDR (plus additional duration as described in section 7.1.3), otherwise it may cause the channel to be used inefficiently.

### 7.1.10.2 TXOP and RDG

An initiator that grants one or more response periods using RDG shall ensure that that its current PPDU and any scheduled response periods all fit entirely within the current TXOP.
It is up to the initiator to decide whether to also allow for any response it may have to make to the transmissions made by the responder during the allocated RDG. For example, the PPDU sent next by the responder may include multiple BAR MPDUs.
The initiator may make an allowance for BA responses to these BARs in making its RDG allocation, in which case it will have time to transmit a response before the end of the TXOP, or it may not make allowance for its own responses. In the latter case, the responder may send a BAR, but there may be no time to send the BA from the initiator in the current TXOP. The responder will assume that the BAR was not received and will retry it subsequently.

### 7.1.10.3 LongNAV Bi-Directional Example (Informative)

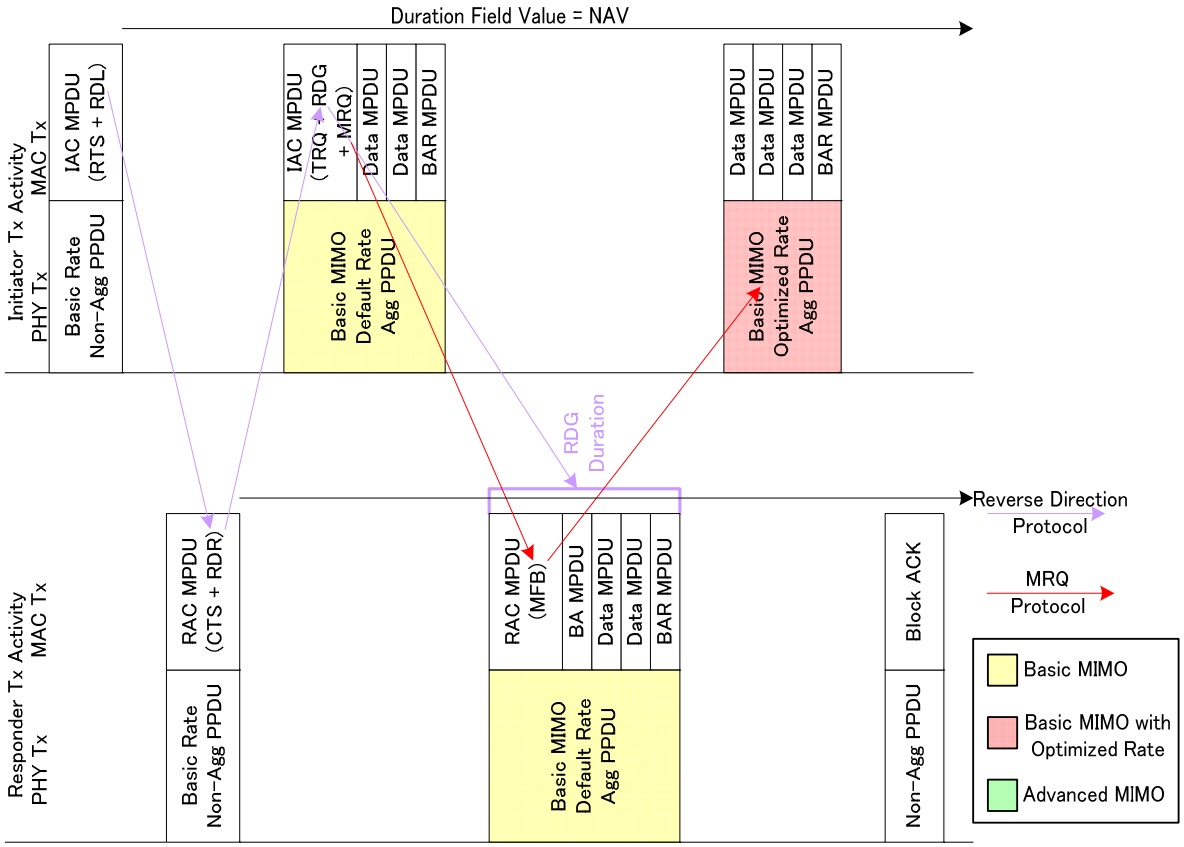



**Figure 27 – LongNAV Bi-Directional Example**

Initiator sets the granted RDG duration long enough to include the duration of reverse data plus any expected responses (RAC + BAs). The duration granted by the RDG for reverse data may be less than the requested duration, in which case the responder must reduce the amount of data it sends. The responder can also itself reduce the amount of reverse data it sends. Any response PPDU duration no longer than the RDG duration is valid.

### 7.1.10.4 Pairwise Spoofing Example (Informative)

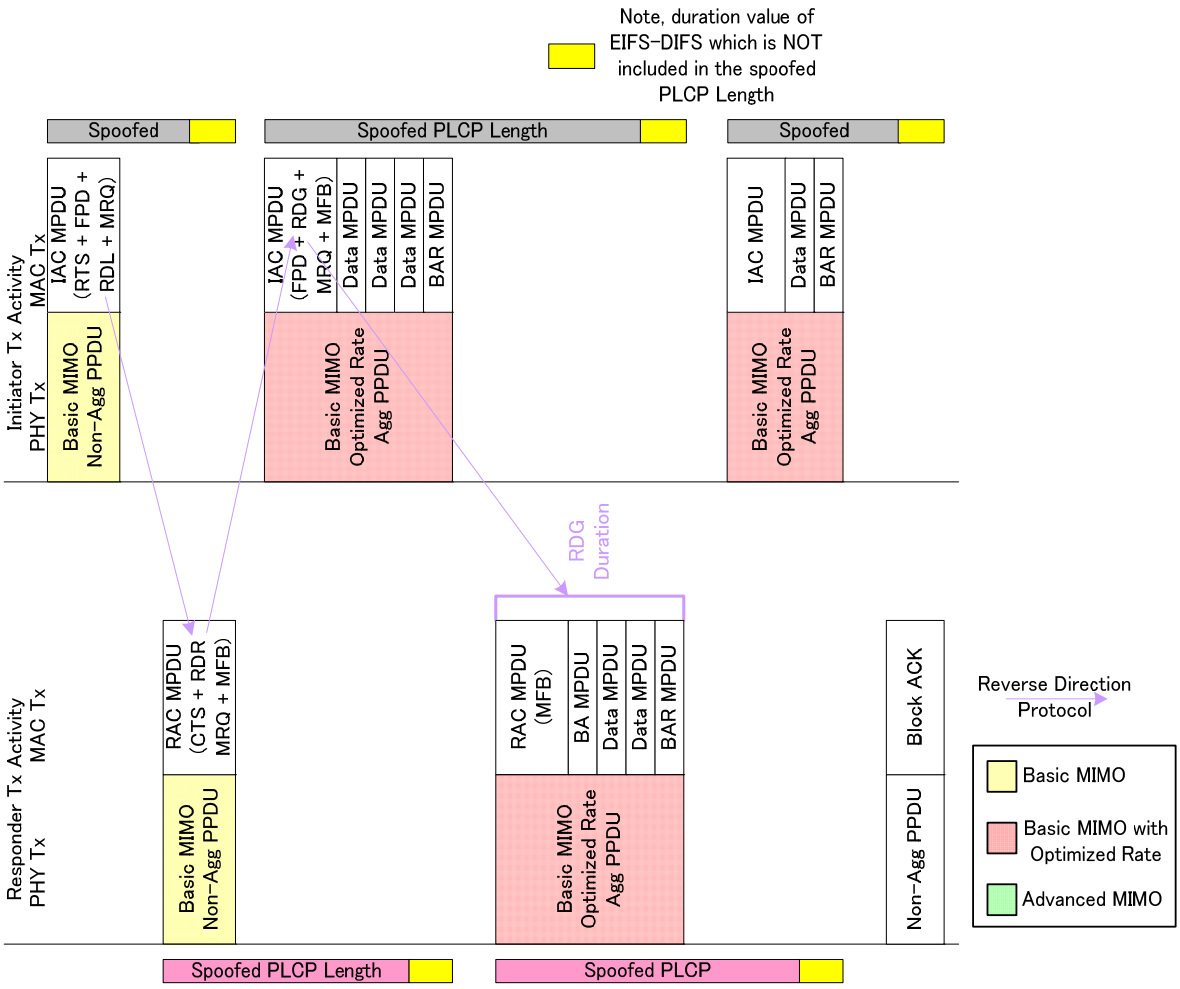



**Figure 28 – Pairwise Spoofing, Trained BiDirectional**

In Pairwise Spoofing Bi-Directional Transfer, the RDG Duration will include the duration of the reverse direction data plus any expected responses (RAC + BAs). The Spoofed NAV will include the duration of the PPDU transmission from the initiator plus the duration of reverse direction data and any expected responses (RAC + BAs).

### 7.1.11 Multiple receiver aggregation (MRA)

This section defines rules relating to the generation of multiple receiver aggregates by an initiator and relating to generation of responses to an MRA. It includes example sequences.

#### 7.1.11.1 Rules and Scheduling of MRA

Generation of MRA PPDUs is optional for an HT STA. The ability to receive an MRA and generate a response to an MRA PPDU is mandatory for all HT STAs.
The transmitter of a MRA containing a reference to a periodic RDR TS is always an HT AP. A non-AP HT STA can also generate an MRA with or without responses (see example at end).
An HT STA may send MRA aggregates addressed to multiple HT STAs and request scheduled responses from none, some or all of those HT STAs.

The initiator schedules the response periods according to local policy, except as specified here. The first response period shall start no less than a SIFS after the end of the MRA PPDU. Typically the initiator will arrange that response periods are separated by SIFS, but there is no normative requirement for this to be the case.
An example of the scheduling scheme is shown in Figure 29, where the MRA addresses 3 HT clients.

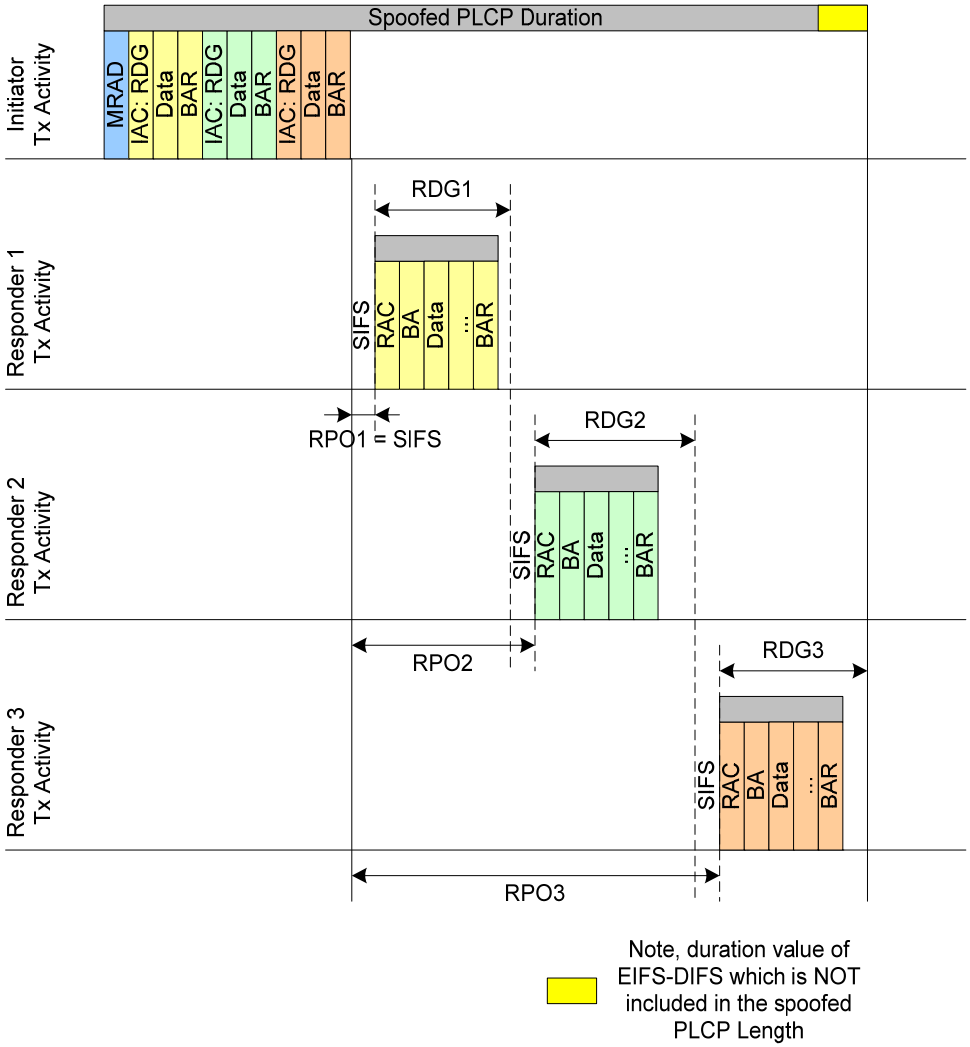



**Figure 29 – Example of MRA response scheduling with 3 responders**

#### 7.1.11.1.1 Interspersing of periodic and aperiodic traffic

The HT AP may intersperse periodic and aperiodic traffic within the same MRA. It can intersperse periodic and aperiodic transmissions but it cannot intersperse periodic and aperiodic RDG to a single HT STA in the same response period since only one RDTID value can be included in an IAC.
Within the same sequence of aggregates, the HT AP may change the RDTID type to a particular receiver. So, an HT AP could service a periodic RDR TS and transition to servicing best effort traffic to the same HT STA in a later PPDU.

#### 7.1.11.2 Protection Rules for MRA

An MRA exchange may be protected using either LongNAV or single-ended spoofing.
In the LongNAV case the NAV of all devices that can hear the initiator has already been set by transmission of a previous MPDU. In this case, the MRA PPDU should not carry a spoofed duration because it limits the ability of the initiator to recover unused RDG at the end of the response period. The single-ended spoofing case is applicable when there is no apriori NAV setting. In this case, the initiator sets the spoofed duration of the MRA PPDU to include from the start of this PPDU up to the end of the last scheduled response period as indicated by the IAC MPDUs within the aggregate.
In this spoofing case, the initiator does not generate FPD elements in its IAC MPDUs, and so the responders do not generate a spoofed duration for their response PPDUs.
In the case of LongNAV protection, the initiator may continue with a transmission a SIFS after the actual end of the last response PPDU. In the case of spoofing protection, the initiator may continue its transmission a SIFS after the end of the last response period, regardless of the actual length of the response.

#### 7.1.11.3 Rate Selection

When a STA transmits a MRA to multiple receivers, it shall ensure that the MRA is sent using transmit parameters that should make the PPDU receivable by all receivers in the MRAD.
It has to respect their receiver capabilities (e.g. supported MCS values, number of rx antennas, optional coding capabilities) and select a “lowest common” set of parameters that should be consistent with reception at all these STAs.
If it contains multicast/broadcast Data, the rate is further constrained so a rate in the basic MCS set.

#### 7.1.11.4 Interaction of MRA and TRQ+MFB (Informative)

Consider the two possible uses for MRA:

1. Periodic data
2. Best Effort data

In the periodic case, if the lifetime of the training information is longer than the interval between service periods, the initial MRA can contain training requests for multiple STAs. The STAs can generate forward direction rate feedback and a reverse direction training request in their responses. The initiator can then generate a final MRA containing the reverse direction rate feedback. So at the end of each cycle, rate feedback has been exchanged in both directions for use in the next service period.
In the best effort case, the initial MRA contains the training requests (and RDL values). The responses contain the rate feedback (and RDR). After the first MRA and responses, the forward direction is now trained, so an MRA containing data can be transmitted and also containing rate feedback and RDG for the reverse direction.

#### 7.1.11.5 Examples of MRMRA frame transfer (Informative)

### 7.1.11.5.1 Periodic Traffic

To support periodic RDR TSs, the AP periodically sends an IAC containing a response period specific to that TS. These IACs may be aggregated into an MRA.
The PPDU is then followed by one or more response periods during which the responder sends any RAC, any BA, its data for the specified TS and a BAR.
At the end of the responses, the initiator then sends an aggregate containing Block ACKs. It may also contain IACs scheduling response grants for any transmissions from responders that were not correctly received as well as retransmissions of data that were not acknowledged.
The cycle of MRA followed by responses terminates when either there is no more time in the service period, or when all data to and from the initiator has been successfully received.

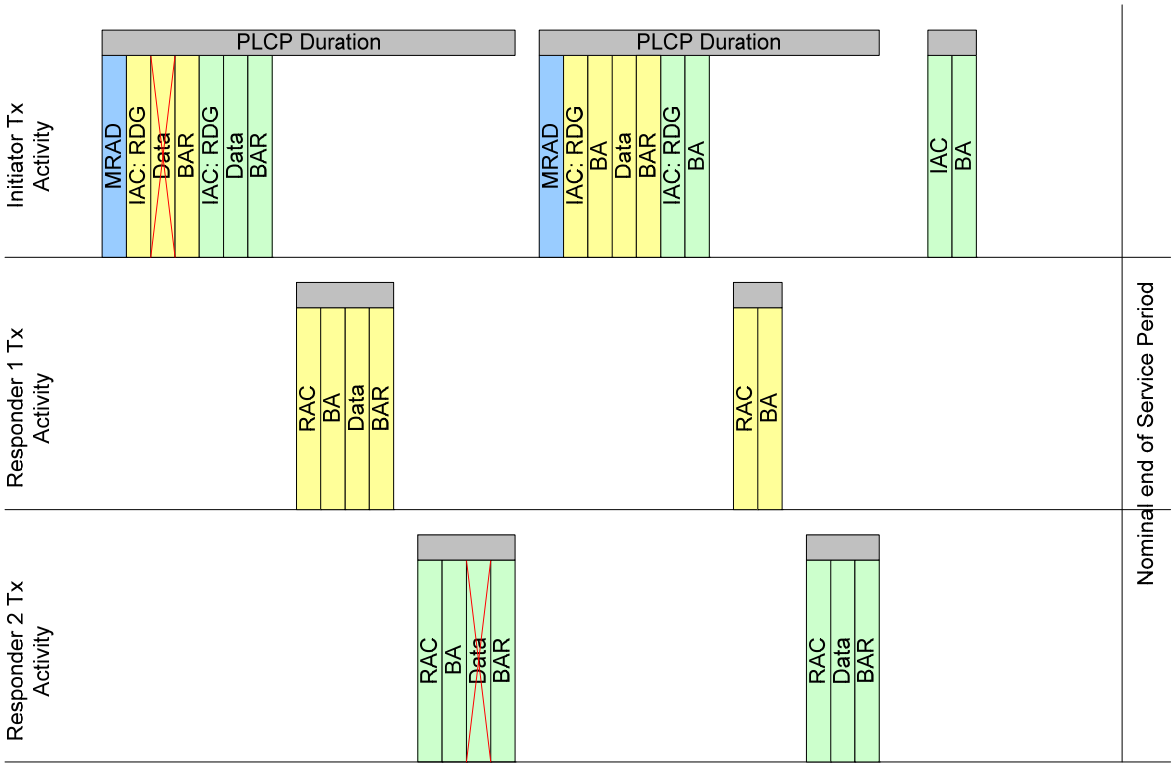



**Figure 30 – MRMRA Example for Periodic Traffic**

In the example shown above, an AP has two STAs with established periodic RDR in the uplink direction (the downlink is also periodic, and part of the same composite schedule).
The first PPDU is an MRA containing a MRAD that lists the two responders. For each responder there is an IAC containing a grant, some data and a BAR. The spoofed duration of the first PPDU includes the MRA and the two response periods.
The first responder generates a response PPDU containing an RAC (not strictly necessary), BA, Data, BAR. The BA indicates that the data from the initiator was not received correctly.
The second responder generates a response PPDU containing an RAC (not strictly necessary), BA, Data, BAR. The BA indicates that the data is received correctly.
The initiator generates a PPDU containing the retried data to responder 1 and grants to both responders. The grant to the first responder is allocated because the initiator has transmitted a BAR and expects to receive a BA in response. The grant to the second responder is allocated because the initiator did not correctly receive all of the uplink data and is scheduling an opportunity for the second responder to retransmit.
The responder 1 then sends the BA, and the responder 2 successfully transmits data and BAR.

The initiator needs to respond to the BAR and sends an aggregate containing the BA. Because this is sent to a single receiver, this aggregate need not contain a MRAD. Strictly, the IAC is not necessary, and the response could be sent in a non-aggregate PPDU.

#### 7.1.11.5.2 Aperiodic Traffic

The MRA may also be used with aperiodic traffic. Aperiodic traffic has no implicit RDR at the start of the sequence. In this case, the initiator sends an MRA containing one or more IACs containing a scheduled response period long enough to contain an RAC and any expected BA MPDUs.
The initiator advertises its willingness to allow aperiodic traffic in an MRA response by including an RDL value and specifying an RDTID that permits aperiodic traffic.
The responder can also, at this point, generate an RDR to request additional response duration for its data transmissions to the initiator.
Note, this sequence is exactly the same as for a LongNAV bidirectional single-receiver sequence – except for the absence of the initial RTS/CTS.

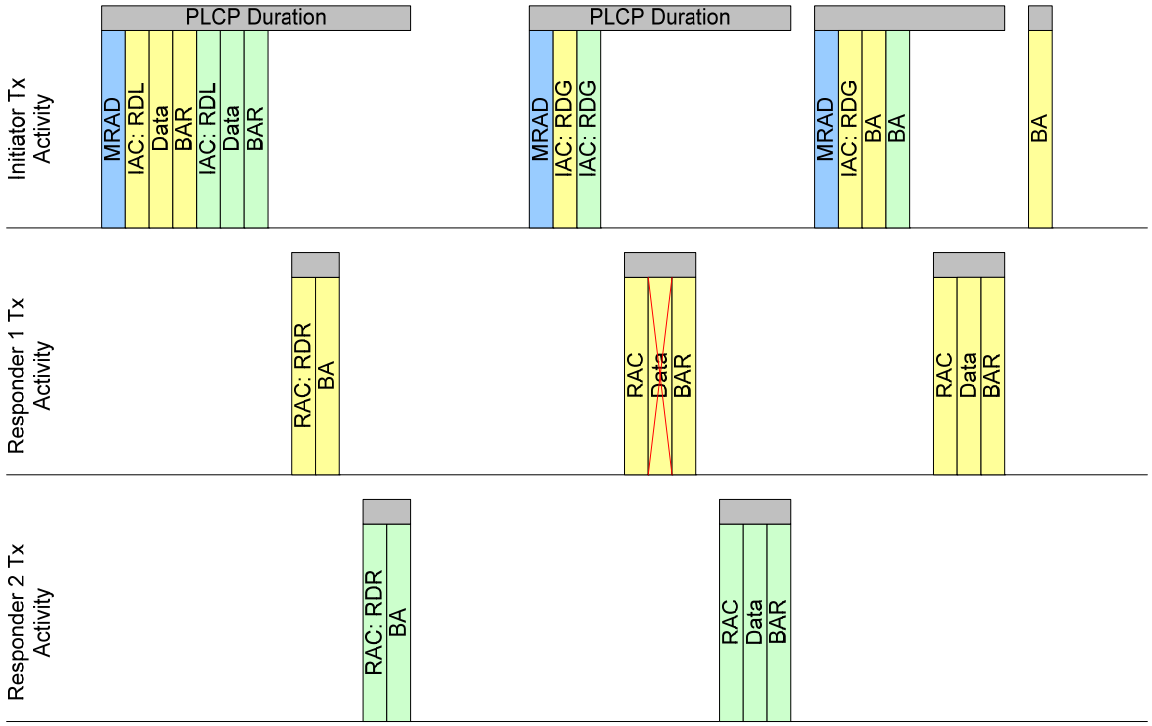



**Figure 31 – MRMRA Example for Aperiodic Traffic**

## 7.2 MAC Header Compression

### 7.2.1 Introduction (informative)

Frame aggregates can contain multiple Data MPDUs with similar MAC Headers. MAC Header Compression reduces the overhead associated with the MAC Headers of these MPDUs. The

efficiency gain of MAC Header Compression depends on the number and size of the Data MPDUs in the frame aggregate.
A transmitting STA or AP includes a MAC Header (MHDR) MPDU in an aggregate frame. This MPDU then provides MAC header information to multiple Compressed Header Data (CHDATA) MPDUs. Both MPDUs include a Header Identity (HID) to relate a CHDATA MPDU and its corresponding MHDR MPDUs.

### 7.2.2 Functional description

MAC Header compression is limited to the boundaries of a frame aggregate, i.e. only Data MPDUs within a single aggregate are compressed using MAC Header compression. As a consequence MAC Header (MHDR) MPDUs and Compressed Header Data (CHDATA) MPDUs shall not be transmitted as non-aggregate MPDUs.
The following requirements apply to a transmitting and receiving STA or AP in an 802.11n network:

- It is optional for a transmitting STA to use MAC Header compression in a frame aggregate.
- It is mandatory for a receiving STA to be able to receive frames with compressed MAC Headers in an aggregate.

#### 7.2.2.1 Transmitting side

When the transmitting STA uses MAC Header compression it includes a MAC Header (MHDR) MPDU, identified by a Header Identity (HID), in the aggregate.
The transmitting STA shall include one or multiple Compressed Header Data (CHDATA) MPDUs, each having the same HID as the corresponding MHDR MPDU.
The transmitting STA may include multiple copies of MHDR MPDUs to increase robustness in case of loss of a MHDR MPDU. These MHDR MPDUs may be located anywhere within the sequence of CHDATA MPDUs subject to the constraints specified in section 7.2.3.
The transmitting STA performs MAC Header compression per destination and per Traffic Class separately.
Retransmissions of CHDATA MPDUs may be as either uncompressed Data or CHDATA MPDUs.

#### 7.2.2.2 Receiving side

A receiving STA determines whether MAC Header compression has been used based on the Type and Subtype definitions in the received MPDUs.
A receiving STA shall use the fields from the MAC Header (MHDR) MPDU to replace the missing fields of the Compressed Header Data (CHDATA) MPDUs, having the same HID value, to recreate full Data MPDUs.
MHDR MPDUs are not acknowledged by the receiving STA or AP.
The acknowledgement policy of CHDATA MPDUs is defined in the QoS field as present in the corresponding MHDR MPDU.
Retransmissions of corrupt or non-received CHDATA MPDUs by the transmitting STA or AP are supported by the presence of sequence numbers in these MPDUs.
CHDATA MPDUs for which no corresponding MHDR MPDU is found in the frame aggregate, shall be discarded.

### 7.2.3 Ordering constraints for MHDR and CHDATA MPDUs

These constraints are designed so that only a single MHDR needs to be stored by a receiver in order to fully reconstruct an aggregate containing CHDATA MPDUs.
A CHDATA MPDU for a particular HID shall be preceded by at least one MHDR MPDU for the same HID. A MHDR for a different HID shall not occur between a CHDATA and its matching MHDR MPDU(s).
Within an aggregate, MHDR MPDUs that are not identical shall have different HID values.

### 7.2.4 Multiple receiver aggregates

The Header Identity (HID) ensures a unique link between a single MAC Header MPDU and a CHDATA MPDU. For each receiver address in a Multi Receiver Aggregate, a MHDR MPDU is included in the aggregate with a unique HID. The subsequent CHDATA MPDUs include the HID for the corresponding MHDR MPDU.

## 7.3 Multirate support

The Supported MCS Set (6.3.1) and Basic MCS Set (6.3.2) indicate MCS values for HT format PPDUs only.
The existing basic rate and supported rate sets indicate rate selections for legacy format PPDUs only.
Rate selection for control frames:
A control frame that needs to be received by legacy devices (i.e. to set the NAV) shall be selected from basic rates in the BSS's basic rate set, and transmitted using the legacy PPDU format.
Multicast/broadcast frames in pure mode and control frames that need to be received by HT devices only shall be selected from the Basic MCS set.
Control frames that need to be received by a single HT device only may be sent at any rate supported by the intended receiver. An example of this is a single Ack/BlockAck by a responder within a sequence protected by LongNAV.
Under pairwise and single-ended spoofing rules, it is not necessary for any third part HT STA to be able to receive MPDUs, so aggregate PPDUs may use any MCS supported by the intended receiver(s).

## 7.4 Quality of Service (QoS)

### 7.4.1 802.11e Requirements

An HT device shall support the mandatory features of an 802.11e QSTA.
An HT device shall support the use of the Block ACK mechanism introduced in 802.11e.

Note: this document extends the 802.11e Block Ack by defining a compressed Block Ack frame format, and rules for implicit Block Ack request in an aggregate. These are defined in section 6.1.6 and 6.3.5.

The default TXOP limit is 3.008 ms for Best Effort (BE) traffic. This value needs to be validated by simulation in order to determine the effect of this value on bandwidth differentiation between Best Effort and Video (VI) traffic. This value should be considered to be a place-holder.
A TXOP limit of zero is considered to allow an Aggregate exchange sequence containing the transfer of at most a single MSDU or MMPDU, which may be fragmented and acknowledged using the block Ack protocol.

### 7.4.2 Periodic RDR

### 7.4.3 Introduction (Informative)

Periodic RDR is a new type of traffic specification (TSPEC) that results in the HC seeing a periodic reverse direction request for data associated with that TSPEC.
In a conventional periodic uplink TXOP, the HC delivers a polled TXOP for a known duration during a known service period to a QSTA. The QSTA can then use this TXOP for any purpose it chooses. It can send MPDUs to the HC or any other QSTA using DLP. It is responsible for retrying any transmission failures.
A periodic RDR is much more constrained. The HC will deliver an RDG of duration sufficient to collect the first transmissions of data during a known service period. The HC also allows in the scheduling of the service period enough time to send a subsequent RDG to collect retransmissions of failed data.
The HC can service multiple QSTAs during the same service period. In practice it is likely to group together into a composite service period RDG for QSTAs with similar TSPECs (i.e. service interval and delay limit) and possibly PHY parameters. How it does this is outside the scope of the standard.

### 7.4.4 Meaning of Service Period with Periodic RDR

When a STA creates a TSPEC using periodic RDR, the AP shall create a service period during which the STA shall be awake to receive data and RDGs.
The AP may add TSPEC requests from multiple STAs into a composite service period during which it will service the STA. This allows it to use MRMRA.
Note, as STAs are added to or removed from the composite service period, the AP may need to update the service period notification by transmitting an updated service period element to the STAs.
The AP shall ensure that any IAC transmissions intended to service the periodic RDR traffic stream lie wholly within the service period.
A STA that receives data during an MRMRA sequence may go to sleep as soon as it has received and acknowledged all data sent to it by the initiator, and has received acknowledgement for all data it has sent.

## 7.5 Enhanced Block acknowledgment

### 7.5.1 Introduction (Informative)

The 802.11e Block Ack mechanism is enhanced with the usage of implicit Block Ack Request when using frame aggregation.
An aggregated frame need not include a BAR frame and the recipient interprets the receiving aggregation frame as though it includes a BAR frame. This is the Implicit BAR mechanism.
A compressed variant of the 802.11e Block Ack frame is also defined. The compression parameters are defined during the Block Ack set up by an ADDBA request/response frame

exchange based on whether to use fragmentation or not and the maximum number of MSDUs in the Block Ack window.
The size of the compressed BA frame is defined by the BA agreement, and is constant throughout the lifetime of the BA agreement.

### 7.5.2 Implicit BAR mechanism

The originator may omit the inclusion of a BAR frame in an aggregated frame.

An HT STA

1. that is permitted to generate a response PPDU as defined in section 7.1.4, and
2. receives directed data frames for a particular TID sent under BA acknowledgement policy as part of an SRA or MRA, and
3. For which it receives no matching BAR in the aggregate

interprets this as an implicit BAR, and shall prepare a BA for the TID for transmission in its response PPDU.

In legacy 802.11e, the Starting Sequence number in the BAR frame causes the recipient to indicate complete buffered MSDUs to its higher layer and release those buffers. The Starting Sequence number also defines the Starting Sequence number for the response BA.

For the Implicit BAR mechanism, as the BAR frame is omitted in the aggregate, these functions are determined as defined below:

| Condition | Receive Buffer Update | BAR starting sequence number |
|---|---|---|
| Aggregate received and the first data MPDU for this TID is received correctly | Update according to the first data MPDU's sequence number | Use this MPDU's sequence number |
| Aggregate received and the first data MPDU for this TID is not received correctly | Do not update the receive buffer | Use the seqence number of the first data MPDU received correctly.<br><br>In an aggregate MPDUs are strictly ordered by sequence number |
| A BAR MPDU is received | Update according to the starting sequence number contained in the BAR | Use the starting sequence number in the BAR MPDU |

For the multiple TID aggregate, the first data MPDU of a TID is distinguished if the last data MPDU of the previous TID has no error. The first data MPDU for the directed part in the MRA case can be also distinguished in the same way.

The reception buffer management for the Implicit BAR mechanism is explained in the following figures.

The basic operation of buffer management is shown in **Figure 32**. When the recipient, here as a responder receives the aggregated frame, the first MPDU is received correctly. Therefore the Starting Sequence number will be updated at the recipient. By the update of the Starting Sequence number, all the complete MSDUs with lower sequence numbers than the Starting Sequence number and also the complete sequential MSDUs after the Starting Sequence number will be indicated to the higher layer as in 802.11e. All the buffers held by preceding MPDUs are released.

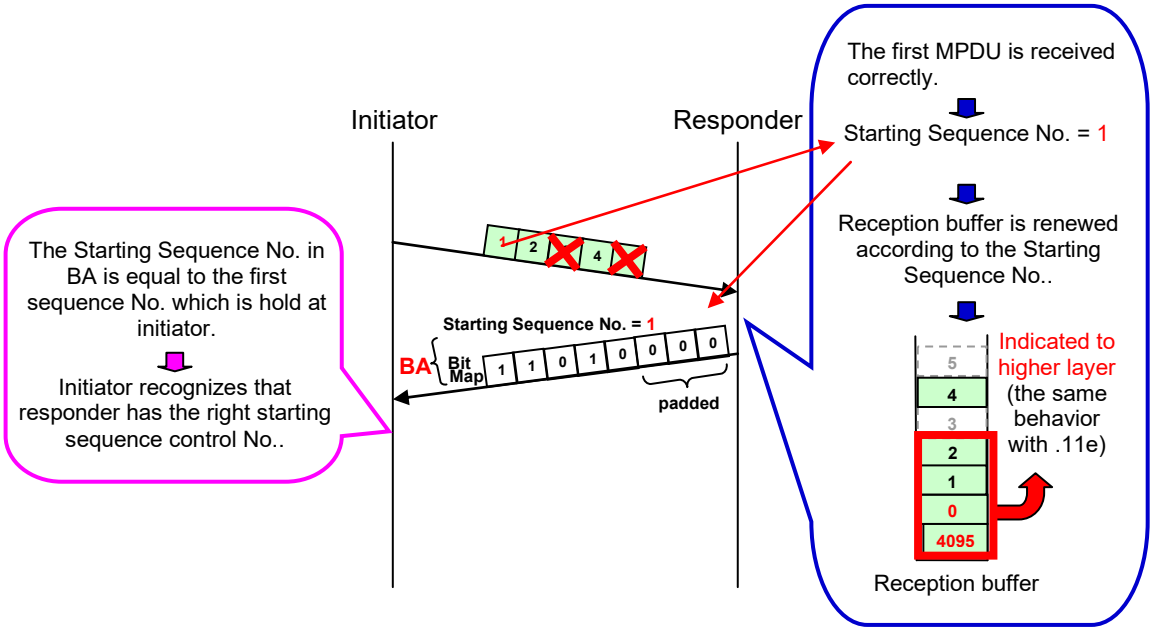



**Figure 32 - Basic buffer management in Implicit BAR**

When the first MPDU is not correctly received, the buffer management will operate as Figure 33 or Figure 34. Since the first MPDU has an error, the recipient cannot acquire the correct Starting Sequence number from the aggregation. The recipient uses sequence number of the first correct MPDU to generate the BA frame. In this case, completed MPDUs are not indicated to the higher layer and buffers are not released.

When the BA frame is received at the originator, it compares the Starting Sequence number indicated in the BA frame with the first sequence number it is holding, i.e., the real Starting Sequence number. If the values are not equal, then the originator recognizes that the recipient has failed to acquire the Starting Sequence number from the aggregation. To inform the recipient of the correct Starting Sequence number, the initiator may transmit a BAR frame as in Figure 33. Or the retransmission of the failed MPDUs in the next aggregation includes the retransmission of the right Starting Sequence number. This is shown in Figure 34. Additional MPDUs may be included in the next aggregation.

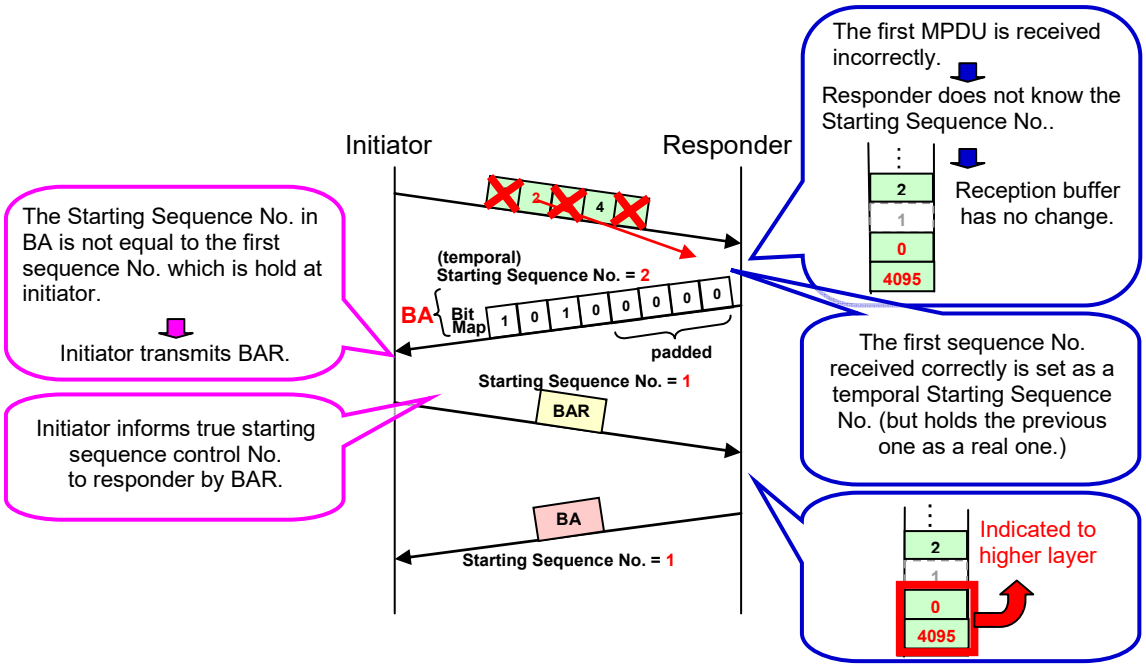



**Figure 33 - Buffer management when the first MPDU is incorrect in Implicit BAR (Case 1)**

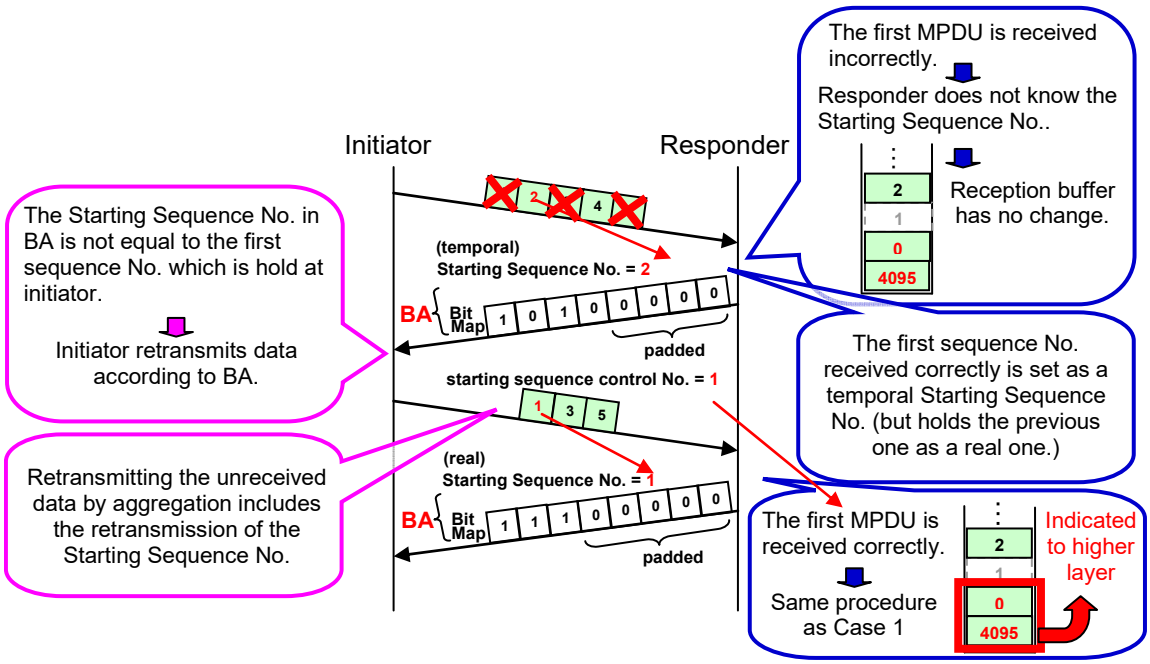



**Figure 34 - Buffer management when the first MPDU is incorrect in Implicit BAR (Case 2)**

When the originator does not receive the BA frame after the transmission of the aggregated MPDU, it shall transmit a BAR frame and obtain a BA response before transmitting any more data frames using this BA agreement. The recipient then transmits a BA frame according to the Starting Sequence number indicated by the BAR frame and the buffer status.

When all the MPDUs in the aggregate fail at the recipient, the recipient does not send a BA frame. From the originator's point of view, this is indistinguishable from the lost BA case described above, and is handled in the same way.

### 7.5.3 Maintaining Acknowledgement State for a BA agreement

The recipient shall maintain the acknowledgement bitmap of size defined by the combination of Non-Frag and NumMSDU_M1 defined in section 6.1.6.2 for each BA agreement.

This bitmap for the matching agreement shall be reset whenever a first data frame for that agreement is received in an aggregate. A STA retains this acknowledgement state in case its BA is not received by the originator, and the originator has to retry. However, once the originator has successfully received the BA, it may transmit data in an aggregate, and the receipt of a new aggregate indicates to the recipient that the previous acknowledgement state is no longer required for the matching TID.

### 7.5.4 Compressed BA

A compressed variant of the 802.11e legacy BA frame may be used according to parameters negotiated during the Block Ack setup.

The Non-Frag and NumMSDU_M1 parameters define the use of fragmentation and the maximum number of MSDUs acknowledged in the BA bitmap.
The compressed BA frame format is defined in section 6.1.6.

A STA transmitting an ADDBA MPDU shall first determine if its peer is a HT STA from an exchange of capabilities and shall not set the Non-Frag field to 1 if its peer is not a HT STA.

A HT STA shall always transmit a compressed format BA MPDU to a HT STA. A HT STA shall never transmit a compressed format BA MPDU to a non-HT STA.

The maximum value of the NumMSDU_M1 subfield is determined from the BA agreement as defined in 6.3.5. The number of MSDUs whose acknowledgment status is reported in the current BA MPDU is equal to (NumMSDU_M1+1).

The value of the Non-Frag subfield is shall match the BA agreement. This same value is present in all BA MPDUs transmitted for this agreement.

The length of the BA bitmap is determined from the ADDBA Buffer Size subfield and the Non-Frag subfield as defined in 6.3.5, and is constant for the lifetime of the BA agreement.

An HT STA shall not transmit fragmented MSDUs on a BA agreement for which Non-Frag has the value 1.

# 8 MAC sublayer management

## 8.1 Coexistence management

### 8.1.1 Operating Modes

The operating modes of an HT BSS are defined in the following table. These modes determine the format of beacon transmission and the kind of protection used for HT transmissions.

| Topology | BSS Mode Name | Definition of Mode |
|---|---|---|
| Infrastructure | Pure | No co-channel legacy devices are present |
| | Mixed Capable | No co-channel legacy devices are present, but the HT AP is able to accept association from a legacy device that discovers this BSS (e.g. through receiving its legacy beacon) and decides to associate. |
| | Managed Mixed | Legacy and HT devices are present co-channel. Access to the medium is managed by an AP.<br>Note: In this mode, time is divided between contention periods for HT and legacy stations (by selectively setting the NAV) |
| | Unmanaged Mixed | BSS contains both legacy and HT devices or there are co-channel legacy devices of a different BSS present |
| | 20 MHz-Base Managed Mixed | BSS contains both legacy and HT devices. There may be legacy devices of overlapping BSS in either or both of the channels. Legacy and HT devices associate to the AP's BSS in the control channel. The AP manages the generation of 40 MHz mode periods, during which 40 MHz HT devices are allowed to access in 40 MHz. |
| Independent (ad-hoc) | Discoverable IBSS | No co-channel legacy devices are present. The IBSS may be discovered by a legacy device. |
| | Mixed IBSS | There are legacy devices co-channel |

### 8.1.2 Receiver capabilities wrt legacy operation in the extension channel

An HT AP or IBSS STA should be able to detect activity in the extension channel without being able to receive legacy MPDUs in it. On detecting a possible legacy MPDU, the STA should enable itself to receive in that extension channel in order to determine if a legacy BSS has arrived on the extension channel. It is not necessary that this capability be available simultaneous with operation on the control channel.

### 8.1.3 Infrastructure BSS Operation

#### 8.1.3.1 At the AP

**Table 14 – AP Mode Definitions**

| AP Mode | Beacon Transmission | Indicated STA operation |
|---|---|---|
| Pure | Pure | Pure |
| Mixed Capable | Legacy | Mixed |
| Managed Mixed | Dual (see below) | Pure |
| Unmanaged Mixed | Legacy | Mixed |
| 20 MHz-Base Managed Mixed | Legacy<br>mandatory in the control channel, optional in the extension channel | Mixed |

The AP controls the operating mode of its STA through an information element in the beacon. In pure mode, the AP will ignore any probe requests sent by legacy STAs and any legacy beacons sent by overlapping co-channel legacy devices. The AP transmits its beacon using a HT PPDU type. The beacon contains an HT management element that requires pure mode operation of its STAs.

> Note, use of pure mode at the AP is only suitable for managed installations where it is not permitted that legacy APs may share the same channels as HT APs.

In the mixed-capable mode, the AP transmits its beacon using a legacy PPDU. The beacons contain an HT management element that indicates this is an HT AP [4].
In a mixed-capable BSS, an HT STA shall operate in pure mode except when communicating with a legacy STA using DLP. An HT STA shall switch to legacy mode for communication with a legacy STA using DLP.
In the mixed-capable mode, the AP may receive association and probe requests from legacy STAs. It shall respond to a legacy probe request with a legacy probe response. It shall respond to a legacy association request with a legacy association response. The AP may choose to accept or deny the association request. If the AP sends an association response with status = OK, it shall enter either managed, unmanaged or 20 MHz-base managed mixed mode operation, and stay there while it has any associated legacy STA. The AP monitors its channel for a legacy co-channel BSS, and if it detects one, transitions into mixed mode, or attempts to find an alternative channel using the procedures defined in section 8.2.
In the unmanaged mixed mode, the AP transmits its beacon using the legacy PPDU type. The beacon contains an HT management element that requires mixed mode operation of its STAs. STAs in an unmanaged mixed mode BSS may use legacy or HT transmissions.

[4] This will stop other co-channel mixed-capable APs from considering the AP to be a legacy AP.

In the 20 MHz-base managed mixed mode, the AP transmits its beacon using the legacy PPDU type. The beacon is transmitted on the control channel but for the purpose of reserving the extension channel, an AP may send beacons also in the extension channel. Beacons in the extension channel may cause legacy STAs to attempt association but the HT AP shall deny association or may ignore those requests. The beacon contains an HT management element that requires mixed mode operation of its STAs.

#### 8.1.3.2 At the STA

An infrastructure HT STA supports three possible modes of operation: legacy, mixed and pure. [5]
In pure mode, there are no overlapping legacy STAs. Protection of HT frames from legacy devices is not required.
In mixed mode, the HT STA is operating in the presence of legacy STAs co-channel on the control channel and/or the extension channel These STAs may be part of the same BSS, or may be associated with an overlapping legacy BSS. In mixed mode, use of a legacy protection mechanism is required (see section 7.1.6). An HT STA shall operate in pure mode except for communicating with a legacy STA on a Direct Link. An HT STA shall switch to legacy mode for communication with a legacy STA on a Direct Link. A 40 MHz capable HT STA, whose permitted width set is 20 and 40 MHz, shall switch to 20 MHz mode for communication with a 20 MHz HT STA.[6]
In 20 MHz-base managed mixed mode, a 40 MHz capable HT STA is enabled to communicate in 40 MHz mode during the 40 MHz period. In case a 40 MHz capable HT STA wishes to communicate with a 20 MHz mode HT STA or with a legacy STA, it shall do so in the 20 MHz period.
In legacy mode, the HT STA operates exactly as a legacy device, with the exception that it may switch from legacy mode to mixed or pure modes while scanning in order to detect an HT AP.

#### 8.1.3.3 Managed Mixed Mode Operation (Informative)

This section describes a coexistence mechanism that permits a legacy network and an 802.11 HT network to operate co-channel without requiring the 802.11 HT devices to be able to communicate directly with the legacy devices.
The mode is operated by an HT AP in managed mixed mode that has both legacy and HT STAs associated with it. Its HT STAs operate in pure mode.
In this mode, the AP manages coexistence of legacy devices in its control channel with HT devices occupying the HT channel, which may be 20 or 40MHz wide depending on the operating mode of the AP.
The case of a 40MHz channel where both 20MHz halves are overlapped by legacy devices is managed using the 20 MHz-base managed mixed mode which is described in section 8.1.3.4.

##### 8.1.3.3.1 Assumptions

It is assumed that the legacy devices cannot receive HT PPDUs and cannot interpret MAC duration values. The managed mode avoids the need for individual STA to provide legacy protection, and thereby potentially reduces overhead.

[5] The STA cannot distinguish between the AP's managed mixed mode and pure mode.

[6] A 20 MHz HT STA is the one whose permitted width set is limited to 20 MHz.

#### 8.1.3.3.2 Mechanism

The AP provides managed mixed mode operation.
This AP divides time between legacy and HT phases of operation. In the legacy phase it ensures that the NAV of all HT devices is set, and *vice versa*.
One way to do this is for the AP to periodically transmit a legacy CTS-to-self to start the HT phase and an HT CTS to start the legacy phase. Alternatively, the AP may combine setting the NAV with transmission of a beacon that contains a contention-free period element, and transmission of a matching CF-end at the end of the phase.
The legacy beacon transmitted by an HT AP in managed mixed mode contains an element which causes any HT STA scanning for a network to ignore the duplicate legacy beacon.
HT devices in pure mode should ignore legacy PPDUs they may receive, so they do not receive NAV reservations intended for legacy devices.

### 8.1.3.4 20 MHz-Base Managed Mixed Mode Operation

This section describes a coexistence mechanism where a BSS operates in 20 MHz mode and switches to a 40 MHz capable phase under the control of an HT AP. Both legacy and HT STAs may be associated in the BSS. An HT STA may be either a 40 MHz capable HT STA or a 20 MHz HT STA. STAs associate with the HT AP on the control channel.
The 20 MHz-base managed mixed mode allows overlapping BSS containing legacy STAs in both control and extension channels. Due to the protection of the 40 MHz period in both channels, it is tolerant of overlapping BSSs. If the overlapping BSS is a QBSS, access to the channel may experience longer latencies in the order of the TXOP duration of the QBSS. Similarly, channel access delays will be long when operating with an 802.11b BSS, which may use substantially lower data rates.
The AP, before it selects a control channel and extension channel and operating mode may take into account the likely performance benefits of using the 20MHz base mode operation. The AP should try to avoid overlapping 802.11e or 802.11b STA, particularly on the extension channel.

#### 8.1.3.4.1 Assumptions

Legacy STAs and HT STAs may coexist in the 20 MHz-base managed mixed mode. Two types of STAs may coexist with the 40 MHz capable HT STAs in the 20 MHz-base managed mixed mode: legacy STAs and 20 MHz HT STAs. It is assumed that the legacy STAs cannot receive HT PPDUs and cannot interpret MAC duration values. The 20 MHz HT STAs are assumed not to be able to receive 40 MHz mode HT PPDUs and to interpret their MAC duration values. An HT AP in the 20 MHz-base managed mode provides legacy protection against legacy STAs and 20 MHz HT STAs.

#### 8.1.3.4.2 Mechanism

The 40 MHz capable HT AP may operate in the 20 MHz-base managed mixed mode. It divides time into 20 MHz and 40 MHz periods. In a 20 MHz period, it ensures that the NAV of 40 MHz mode operation in 40 MHz capable HT STAs is set. In the 40 MHz period, the NAV of legacy STAs and 20 MHz HT STAs is set.

The basic period is the one in which operation is strictly in the 20 MHz control channel. To start a 40 MHz period, the HT AP first reserves the control channel by setting NAV of legacy and 20 MHz HT STAs with a legacy Beacon frame or an ICB frame. The transmission rate of the SCB frame shall be selected from the BSSBasicRateSet. Due to the range of the Duration/ID field in the MAC header, the ICB frame cannot be used to start a 40 MHz period longer than 32767 μs.

Then, the HT AP shifts to the extension channel for its reservation. The extension channel is reserved by a transmission of a CTS-to-self or a legacy Beacon frame after an appropriate channel access is performed in the extension channel.

The Beacon frame sent to reserve the control channel includes the channel extension indication information element. When a 40 MHz capable HT STA associated with the HT AP receives the Beacon frame, it extends its channel bandwidth to 40 MHz according to the information in the Extension Channel Offset information element. The 40 MHz capable HT STAs act in the same way when receiving an ICB control frame.

After setting the NAV in the extension channel is completed, the HT AP resets the NAV of 40 MHz capable HT STAs by sending a CF-end frame. Thereby the 40 MHz period is started, during which HT STAs can communicate in 40 MHz mode using EDCA.

The AP can also support operation using HCCA by polling HT STA during the 40 MHz period before allowing the 40MHz devices to contend using EDCA.

To end the 40 MHz period, the HT AP first sets the NAV of 40 MHz mode operation in 40 MHz capable HT STAs by transmitting an DCB frame. The 40 MHz capable HT STAs will switch back to the control channel in 20 MHz. Then the AP resets the NAV in the extension channel by transmitting a CF-End frame. The AP may reset the NAV in the control channel by a CF-End frame but it may also continue the CFP that was set in the last Beacon frame on the control channel. At this point the AP and all its STAs are operating on the control channel using 20MHz channel width. The process may e.g. be repeated periodically, such as related to the beacon interval. The superframe thus created is divided into a phase for communication on the 40 MHz channel and phases for communication on the 20 MHz channels. One cycle of the process is illustrated in Figure 35.

A 40 MHz capable HT STA that is attempting an EDCA channel access during a 40MHz period either freezes the backoff counter during 20MHz operation and resumes the interrupted backoff during the next 40MHz period or selects a new random backoff at the start of the 40MHz period. Likewise, if it is attempting a channel access during a 20MHz period, it either freezes the backoff counter during 40MHz operation and resumes the interrupted backoff during the next 20MHz period or it selects a new random backoff at the start of the 20MHz period.

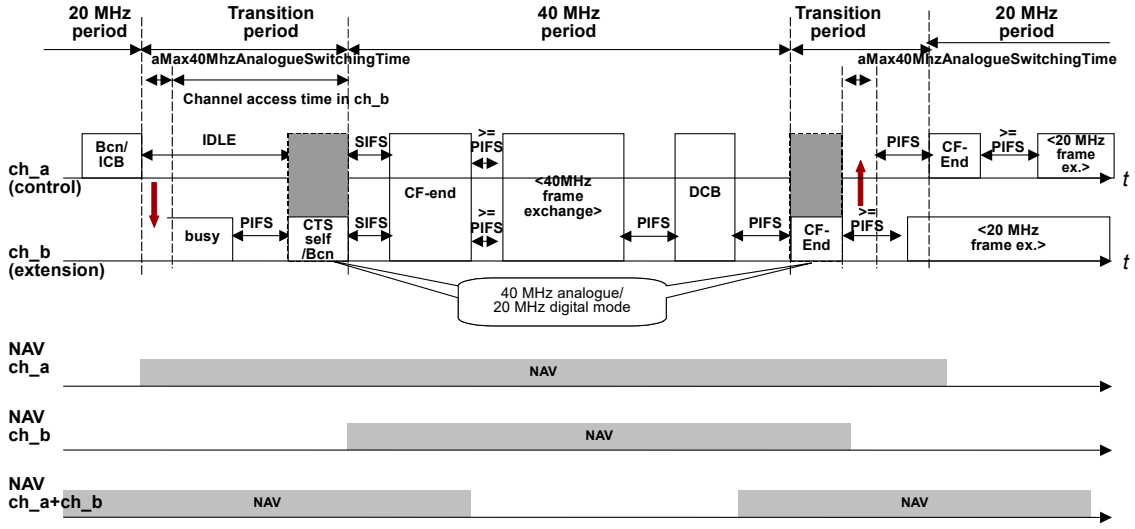



**Figure 35 – 20 MHz-Base Managed Mixed Mode**

### 8.1.3.4.3 Operation at HT AP

To start the 40 MHz period, the HT AP transmits a legacy Beacon frame or an ICB frame in the control channel to acquire the control channel and define a CAP to block the channel by setting the NAV of the legacy STAs and 20 MHz HT STAs on the control channel. The CFP of the Beacon or Duration field of the ICB frame will be set to cover the 40 MHz phase plus the transition periods between 20 and 40 MHz operation.

The HT AP announces the "extension channel access timeout" value in its Beacon and Probe Response frames to limit the maximum transition time to the 40 MHz period. When the HT AP transmits the Beacon frame or ICB frame on the control channel, it starts a timer of a duration, which is "Extension Channel Access Timeout" minus the duration of the Beacon or ICB frame. The "Extension Channel Access Timeout" is the maximum time, after which the STAs shall have received the Beacon or CTS-to-self on the extension channel. One reason why the AP might not be able to send the Beacon or CTS-to-self frame within "Extension Channel Access Timeout" time could be a busy medium on the extension channel.

After setting the NAV in the control channel, the AP may switch to 40 MHz analogue and 20 MHz digital mode and shall listen to both the control channel and the extension channel. As the control channel is supposed to be reserved by the previous operation, this phase is mainly given to wait for the extension channel to be idle. However, it shall be noted that while waiting for the extension channel to become idle, the control channel will be left without any activity and the STAs which did not receive the Beacon or ICB frame in the control channel may interfere with the reservation. The purpose of the mode transition to 40 MHz analogue and 20 MHz digital is to omit an analogue channel switch at the beginning of the transmission phase in the 40 MHz channel. If the extension channel becomes idle the AP shall transmit a CTS-to-self or legacy Beacon in the extension channel a PIFS after it has become idle. The CTS-to-self or Beacon shall block the channel by setting the NAV of the legacy STAs on the extension channel. The NAV shall cover the intended duration of the 40 MHz period and the transition times between 20 MHz period and 40 MHz period.

If the "extension channel access timeout" timer at the AP expires while attempting to transmit CTS-to-self or Beacon, the AP shall give up switching to the 40 MHz bandwidth and may try

again at a later time. The AP shall furthermore transmit a CF-end frame on the 20 MHz control channel in order to re-set the NAV of the legacy STAs on the control channel. HT STAs will have started an "Extension Channel Access Timeout" timer themselves after having received the first Beacon or ICB frame on the control channel and do therefore not have to be notified by the AP about the expiration of the timer.
The NAV setting in the extension channel is done through CTS-to-self or Beacon. CTS-to-self would give less overhead, however, the Beacon in the extension channel may avoid other BSSs being created, since other STAs will detect the presence of the HT BSS. Furthermore, the duration of the NAV that can be signaled by a CTS-to-self is limited. Therefore, for long periods setting the NAV by a Beacon frame will be required. According to this analysis, implementers may decide to send Beacons in the extension channel.
If the "Extension Channel Access Timeout" timer has not yet expired, the AP shall transmit a 40 MHz mode CF-end to signal to the HT STAs that the 40 MHz channel is available. The CF-end frame shall be transmitted at least aMax40MhzAnalogueSwitchingTime after the end of the first Beacon or ICB frame on the control channel. aMax40MhzAnalogueSwitchingTime is the maximum allowed time for the STAs and the AP to carry out an analogue channel switch from 40 MHz to 20 MHz and vice versa. The AP has to wait at least aMax40MhzAnalogueSwitchingTime before starting the 40 MHz phase in order to account for the STA with the slowest possible switching time. If aMax40MhzAnalogueSwitchingTime time has already expired since the end of the Beacon or ICB frame on the control channel, the AP shall send the CF-end or QoS CF-Poll frame a SIFS after the CTS-to-self or Beacon on the extension channel.
After the 40 MHz frame exchanges, the AP shall set the NAV of the 40 MHz HT STAs until the intended end of the 20 MHz period by means of a DCB frame. Then the AP shall free the extension channel and the control channel for communication in 20 MHz mode by transmitting CF-End frames in both channels. The CF-End frame in the control channel is not required if the AP wishes to continue the CFP. The CF-End frame on the control channel shall not be sent earlier than aMax40MhzAnalogueSwitchingTime after the CF-End on the extension channel. The first CF-End frame in the extension channel may be transmitted in 40 MHz analogue and 20 MHz digital mode in order to avoid an additional analogue channel switch. After the first CF-End frame the AP switches to the control channel in 20 MHz analogue mode and transmits the second CF-End frame.

The ratio between the 40 MHz and 20 MHz period should be adjusted according to types of traffic and priority. Whether frames are sent in the 40 MHz or 20 MHz period shall be scheduled depending on their traffic types.
Note that in scenarios with heavy interference between control and extension channel the AP may choose to switch to a different 40 MHz channel, on which no time-sharing with legacy STAs might be required. The selection of channels affects the performance and efficiency for the 20 MHz-base managed mixed mode. Not only the initial channel selection but also monitoring the channels while operating in 20MHz-base mixed mode is necessary to cope with condition changes.

#### 8.1.3.4.4 Operation at 40 MHz capable HT STAs

A 40 MHz capable HT STA is allowed to operate in 20 MHz mode on the control channel or in 40 MHz mode on both channels. It is not allowed to operate in 20 MHz mode on the extension channel.
40 MHz capable HT STAs shall store the "extension channel access timeout" value contained in Beacon or Probe Response frames sent by an HT AP.

When a HT STA receives a Beacon or ICB frame with channel extension indication information element set, it shall start an associated timer of duration "Extension Channel Access Timeout" and wait in the 40 MHz analogue mode for the HT AP to reset its NAV by a CF-End frame. Furthermore, upon reception of the Beacon or ICB frame in the control channel, a 40 MHz capable HT STA shall start the timer included in the Duration/ID field of the ICB frame or the CFP Parameter Set element in the Beacon frame. If the HT STA operates in the 20 MHz mode, it shall shift to 40 MHz analogue mode by the reception of the Beacon or the ICB frame on the control channel. A HT STA shall switch to 40 MHz analogue mode within at least aMax40MhzAnalogueSwitchingTime time.
In case the "extension channel access timeout" timer expires before receiving the CTS-to-self or Beacon on the extension channel, a 40 MHz capable HT STA leaves the waiting state. It shall switch back to 20 MHz mode on the control channel depending on the operation mode of the AP.

When a 40 MHz capable HT STA receives a CF-end frame, its NAV for the 40 MHz channel will be reset and it becomes free to access in 40 MHz mode. The 40 MHz capable HT STA switches back to 20 MHz mode on the control channel if the timer runs out before it receives the DCB frame which indicates the end of the 40 MHz period.
The HT STA may send frames not only in EDCA but also in HCCA, which is enabled by QoS CF-Poll to it. A 40 MH capable HT STA which is granted TXOP may only transmit frames to the AP or other 40 MHz capable HT STAs.
By the reception of a DCB frame from the AP on the 40 MHz channel, a 40 MHz capable HT STA sets its NAV for the 40 MHz channel. It may switch back to 20 MHz mode if it wishes to communicate in the 20 MHz period when receiving the DCB frame.

A 40 MHz capable HT STA that is attempting an EDCA channel access during a 40MHz period freezes the backoff counter during 20MHz operation and resumes the interrupted backoff during the next 40MHz period. Likewise, if it is attempting a channel access during a 20MHz period, it freezes the backoff counter during 40MHz operation and resumes the interrupted backoff during the next 20MHz period.

#### 8.1.3.4.5 Operation at legacy STAs and 20 MHz HT STAs

The NAVs of Legacy STAs and 20 MHz HT STAs are set either by a Beacon or ICB frame in the control channel or by the CTS-to-self or Beacon frame in the extension channel. Their NAVs are reset when they receive a CF-End frame in their operating channel.

### 8.1.4 Ad-hoc (IBSS) Operation

#### 8.1.4.1 Effect of operating mode as an HT IBSS (Informative)

In IBSS operation, an HT IBSS is always discoverable by the legacy IBSS. A legacy device wishing to join the IBSS will discover it and share in the beaconing. This will alert HT devices to its presence based on omission of HT beacon elements.

#### 8.1.4.2 Rules of operation of an HT IBSS

Each STA maintains a table for STAs it can see according to the mode of operation of the STA. Stale entries in this table are removed by a timeout process. A STA can be classified as legacy if it is seen to transmit a legacy beacon without the HT elements (note, this also includes legacy

APs). Otherwise, its HT IBSS operating parameters are discovered from the HT element in the beacon. This element includes the field: IBSS mode.
The mode of operation of an individual STA is defined in the following table, along with the rules for operation.

**Table 15 – IBSS Mode Definitions**

| HT IBSS Mode | Description | Condition | Beacon Tx |
|---|---|---|---|
| Discoverable IBSS | Only HT IBSS on this channel | No legacy devices in STA table | Legacy format |
| Mixed IBSS | Mixture of HT IBSS and | One or more legacy devices are present in STA table. | Legacy format |

#### 8.1.4.3 Rules for IBSS Use of Protection Mechanism

When operating in Mixed IBSS mode, an HT IBSS STA acting as the initiator of a frame exchange sequence shall use a legacy protection mechanism.
Otherwise, the STA should use HT frame formats.

## 8.2 Channel management

### 8.2.1 Channel Management at the AP

The AP transmits a beacon containing the following elements:

**Table 16 – Beacon Elements for HT Channel Management**

| Element | Description | Values |
|---|---|---|
| Permitted Width Set | This is the set of channel widths that may be used within the BSS. | {20} or {20, 40} |
| Control Channel Number | Channel number for the control channel | |
| Extension Channel Offset | Describes the location of the extension channel relative to the control channel. | 1 = 1 channel above, –1 = 1 channel below, 0 = not present |

An HT AP shall receive the beacons of other HT BSSs on its channel. If one of these indicates a subset of its current permitted width set, the AP shall reduce its permitted width set so that it matches or shall select a new operating channel.

HT BSSs shall only overlap HT BSSs with the same control channel and extension channel location. [7]

### 8.2.2 Channel Management at the STA

All transmissions must use a width in the permitted width set.
In unmanaged mixed mode, all transmissions of unaggregated control and broadcast frames must be receivable by legacy devices operating on the control channel.
A STA shall only transmit an HT PPDU to a peer STA using a width that it knows the peer to support and that is within the permitted width set.

### 8.2.3 Channel Selection Methods

#### 8.2.3.1 Introduction (Informative)

The best coexistence is achieved when all BSSs occupy separate channels and when legacy and HT devices do not overlap.
The HT AP should prefer to operate a pure mode BSS (i.e. no overlapping legacy BSS) because overlapping BSS requires a mixed mode operation that may entail higher overhead.
The mixed-capable AP can detect co-channel legacy BSSs arriving on its control channel without the need for scanning. This may cause it to enter a mixed mode of operation.
The AP may also detect co-channel legacy BSS arriving on a non-control channel. It may do this by scanning during an 802.11h "quiet" period, or by getting one of its STAs to scan for it, again using 802.11h signaling [8]. Alternatively, the AP may be able to receive legacy MPDUs on either overlapped channel.
On detecting the arrival of a co-channel legacy BSS on the non-control channel, the AP has to either adjust its permitted channel widths to avoid the legacy BSS, select a new set of channel parameters or switch to 20 MHz Base Managed Mixed Mode.
The AP may also scan periodically all channels, and evaluate whether there is a better channel (as defined in **Error! Reference source not found.**) to operate on. If it discovers a better channel, it may instruct its STAs to change channel parameters using signaling in its beacon.
Note: If 802.11h-like DFS becomes mandatory in all geographies, this behavior should be consistent with those requirements. If DFS is not mandatory, operation of this automatic channel selection may be disabled to permit fully manually administered installations.

#### 8.2.3.2 Rules

The HT AP shall either be configured manually or configure itself automatically as described in this section.
The HT AP shall scan its environment before selecting channel parameters. If the AP is capable of mixed mode operation, it shall use mixed mode to scan.
If the selected channel parameters overlap an existing HT BSS, then they must use the same control channel and extension channel offset and permitted width set.

[7] This, together with the requirement for the same basic width set ensures that any pure-mode control frames sent in one BSS can be received in any overlapping HT BSS.

[8] Note, the assumption that 802.11h will be used (perhaps in modified form) by TGn.

The AP shall reselect new channel parameters if an HT BSS that does not have the same control channel, extension channel offset and permitted width set starts operating on an overlapped channel.
Given a choice of 40MHz channel selections permitted by the previous rules, the AP should prefer a channel selection that aligns its 40MHz channel with the starting (i.e. lowest frequency) pair of adjacent 20MHz channels within any band or sub-band plus zero or more times 40MHz.

Note: The purpose of this recommendation is to avoid introducing 20MHz "holes" between adjacent operating 40MHz BSS, thus making them unavailable for 40MHz operation.

## 8.3 TRMS Power-Saving Management

MIMO systems can reduce power consumption by only enabling a single receive chain during periods of inactivity. The STA may be raised to full receive capability following the reception of a unicast MPDU contained in a PPDU that can be received on a single receive chain.
This section defines the TRMS protocol. The mechanism is referred to as Timed Receive Mode Switching (TRMS) since it relies on a timer in the STA to trigger the transition to reduced receive mode and corresponding timers in the AP and STA peers to track the state change. The timers are reset when an MPDU is transmitted by the TRMS STA.
As a special case, an operating mode is supported where the STA reduces receive capability after each sequence. This mode could take advantage of any protection mode where a SISO frame exchange already prefixes each sequence by providing power savings at no protocol overhead.
A STA shall support TRMS operation in other STAs with a zero hold-on time. It is an option of a STA to support TRMS operation in other STAs with a non-zero hold-on time.
When a STA that does not support TRMS operation in other STAs with a non-zero hold-on time transmits to a STA that is in TRMS enabled mode, it will assume that the STA uses a zero hold-on time. This will cause it to prefix any exchange to that STA with a SISO packet. This may or may not (depending on the exchange sequence used and the type of protection used) create a performance reduction compared to support of a non-zero hold-on timer.

### 8.3.1 BSS Association, DLP Setup and Mode Changes

#### 8.3.1.1 Association

When associating, a STA that wishes to operate using TRMS includes the TRMS IE in its association or reassociation request.
If the STA wishes to update the TRMS parameters under which it is operating after association, then it sends a directed TRMS Update frame to the AP with the new parameters.

#### 8.3.1.2 DLP Setup

A STA that supports TRMS operation in its DLP peers includes a HT capability element with an asserted TRMS Support bit in the DLP request or response frame. A STA initiating a DLP session that wishes to operate using TRMS includes the TRMS IE in the DLP request frame.
A STA that receives a DLP request with the TRMS Support bit set and that wishes to operate using TRMS includes a TRMS IE in the DLP response.

If a new DLP session results in the STA changing TRMS operating parameters it should send a TRMS Update to the AP and its other DLP peers.

#### 8.3.1.3 Mode Changes

A STA may change its TRMS operating parameters. When doing this it sends a directed TRMS Update to the AP and each of its DLP peers. The STA should send the updates before the new parameters take effect if the parameters decrease the hold-on time or enable TRMS.
A STA may activate or deactivate TRMS operation at any time.

#### 8.3.1.4 IBSS Operation

A STA that wishes to operate using TRMS broadcasts a TRMS Update frame and then enables TRMS operation. Once enabled, the STA should include the TRMS IE in future beacons.
Like IBSS power-saving, a STA only has potentially stale information about a peer's TRMS mode. A STA can refresh this information by performing a capability exchange using directed Probe MPDUs. It may infer that its knowledge is stale if it fails to transmit to a STA on the assumption that is is TRMS-disabled, but successfully transmits when it assumes it to be TRMS-enabled.

### 8.3.2 TRMS Operation

A STA using TRMS maintains a running timer that is reset each time a frame is transmitted. If the timer reaches the hold-on time then the STA switches to reduced receive operation unless a frame is being received, in which case the switch will be delayed until immediately after the frame has been received. The STA returns to full receive operation after transmitting any frame.

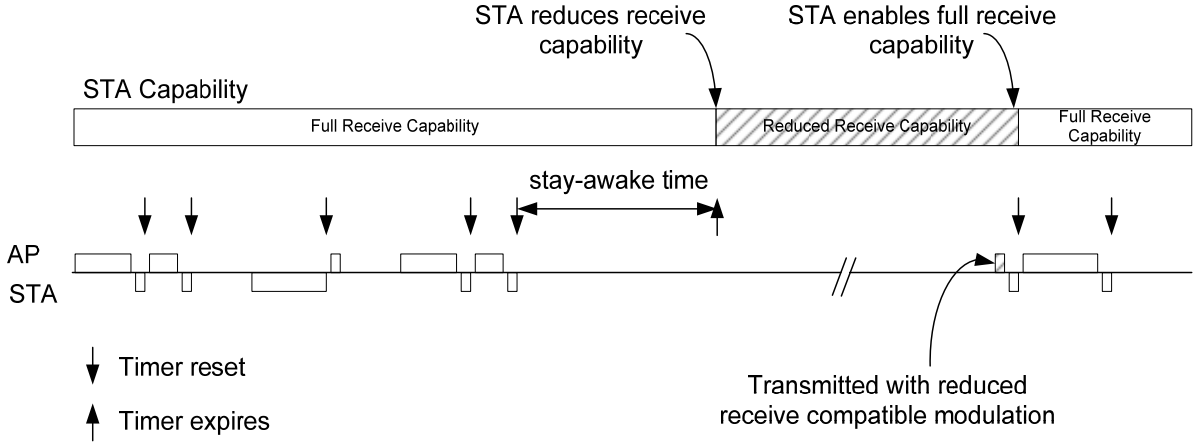



**Figure 36 – Data transfer example with timed receive mode switching**

An AP maintains a running timer for each associated STA that is operating using TRMS. The AP resets the timer for a particular TRMS using STA each time it receives a frame from that STA (whether or not the frame is addressed to the AP). If the timer reaches the hold-on time then the TRMS STA is assumed to have switched to reduced receive operation.
A STA that is a DLP or IBSS peer to other STAs using TRMS maintains a running timer for each such peer. Each time this STA receives a frame that is addressed to it and that was transmitted by such a peer, it resets the corresponding timer. It may also reset the timer if it receives a frame from such a peer that is not addressed to it. If the timer reaches the hold-on time then the peer TRMS STA is assumed to have switched to reduced receive mode.

Frames sent to a TRMS STA that is assumed to be operating with reduced receive capability shall be transmitted using a modulation compatible with the TRMS STA's reduced receive capability.

### 8.3.3 Performance Impact of using TRMS mode (Informative)

In TRMS mode with a non-zero timer value, this value can adjust the compromise between staying MIMO-enabled longer than necessary and the overhead of switching into a MIMO-enabled state. This is only relevant for bursty traffic. For periodic traffic where there is a single exchange sequence per period, there is no benefit in using a non-zero value of the timer. The overhead of entering a MIMO_enabled state depends on the details of the frame exchange sequence and protection used.

| Sequence Type | Overhead |
|---|---|
| LongNAV<br>IAC+RAC+Data/Data/BA+RAC/BA | In the case of a basic sequence, this overhead is zero because the initial packet is already a SISO packet. |
| LongNAV ABF (forward) | The overhead is still zero |
| LongNAV with legacy devices | The overhead is zero because the legacy initial MPDUs are suitable SISO packets |
| LongNAV ABF (both directions) | The ABF sounding for the reverse-link cannot occur in the first packet, so ABF trained reverse-link data can first be sent in the 4th PPDU.<br>However this creates no additional overhead, because the operation of the RDL/RDR/RDG protocol does not permit reverse-direction data until the 4th PPDU, except in the case of periodic RDR.<br>Periodic RDR is there to support applications like VoIP, and I don't expect to see VoIP handsets doing ABF transmissions. |
| Pairwise Spoofing<br>Untrained<br>IAC/Data/Data/BAR+RAC/BA | This sequence will not work with a MIMO MCS for the first MPDU.<br>It makes little sense to transmit a SISO MCS for the first packet. Also there are practical difficulties knowing what MCS to use because any training established when the receiver is MIMO-enabled will not apply when it is MIMO-disabled.<br>The alternative is to add an initial IAC/RAC exchange. This brings the following advantages:<br>• Collisions are detected cheaply<br>• Data is protected from hidden nodes<br>• Data can be trained (fresh MCS and/or/ |

| | |
|---|---|
| | ABF)<br>These benefits are not useful if there are small numbers of contending stations, there are no hidden nodes, and training information is still fresh. In that case the additional IAC/RAC is a real overhead. |
| Pairwise Spoofing<br>Trained forward-direction data | No overhead as the sequence has to be:<br>IAC(TRQ)+RAC(HT-LTFs)+IAC/Data/…<br>The initial IAC can be SISO. |
| Pairwise Spoofing reversed direction trained data | Same analysis as the LongNAV case. There is no additional overhead. |

### 8.3.4 Calibration

#### 8.3.4.1 Introduction

Differences in transmit and receive chains in a STA or AP destroy the inherent reciprocity of the over-the-air TDD channel. Calibration is necessary in order to remove differences in transmit and receive chains and enforce reciprocity in the observed baseband-to-baseband channels. A simple over-the-air calibration procedure effectively corrects for these differences. The calibration procedure ensures that the observed channel matrices in the two directions of the link are transposes of each other and thus renders the resultant channel reciprocal. Thus, if they are able to do so, STAs calibrate upon association. Calibration works for any square or non-square dimensionality, i.e., $N_{Tx}$ and $N_{Rx}$ greater than one and less than five.

#### 8.3.4.2 Procedure

The Calibration Training frame exchange sequence, illustrated in Figure 37 operates as follows:

- STA A transmits a Calibration Training MPDU (Position field = 0).
- In response, STA B transmits a Calibration Training MPDU (Position field = 1) after a SIFS interval, which includes the HT-LTF that allows STA A to estimate the channel matrices.
- In response, STA A transmits a Calibration Training MPDU (Position field = 2) after a SIFS interval, which includes the HT-LTF that allows a receiving STA B to estimate the channel matrices.

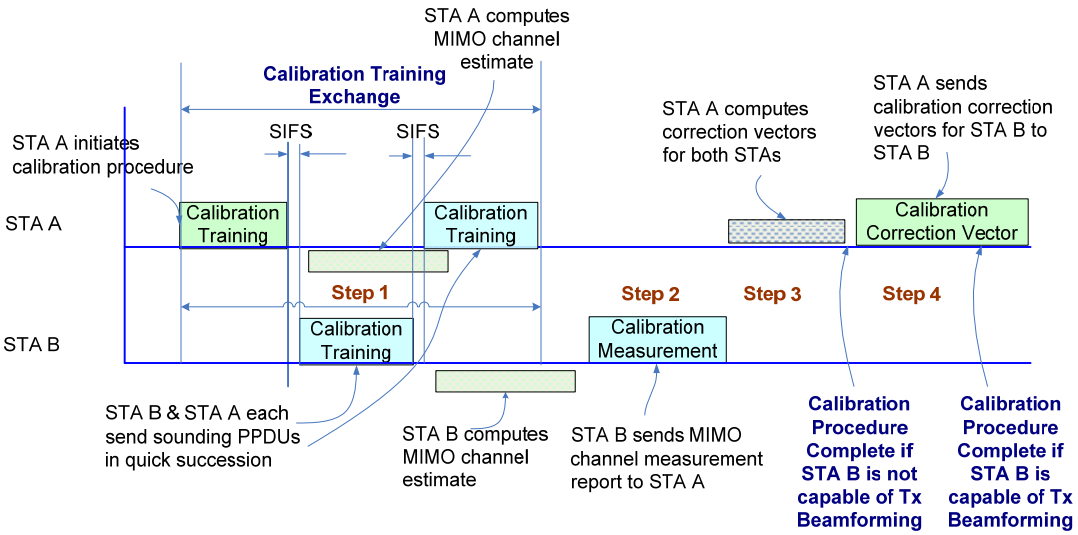



**Figure 37 - Calibration Procedure**

The Calibration Training MPDUs are carried in non-aggregated sounding PPDUs. The last two steps must occur over a sufficiently short time interval so that the channel does not change over the interval. When used in a mixed BSS, this frame exchange sequence must be protected with an appropriate protection mechanism.

The remaining message exchange in the calibration procedure is not time critical.
When the channel measurements become available at STA B, STA B sends one or more Calibration Measurement action frames that contains the MIMO Channel Measurement Report. STA B sets the Calibration Complete bit to '1' in case it is not capable of transmit beamforming. In this case STA A will not send Calibration Correction frame.

In case that both STAs are capable of transmit beamforming, once STA A has the MIMO Channel Measurement Report from STA B, along with its local channel measurement measured from the Calibration Training frame transmitted by STA B, STA A can compute the correction vectors required for both itself and STA B. The Calibration Correction frame is transmitted to complete the calibration procedure by STA A. The message includes the MIMO Correction Vector for STA B.

# 9 MAC Background (Informative)

This section contains informative MAC background material on scheduling, channel selection and the protection mechanisms.

## 9.1 Scheduling

### 9.1.1 Introduction

A data transfer sequence may contain multiple MSDUs carried in one or more aggregate PPDUs. The best throughput performance is gained when the length of the aggregate is maximized and the number of PPDUs is minimized. However, this maximum throughput is potentially gained at the expense of increased transport delay.
Apart from the effects of power-saving and 802.11e prioritization, a legacy 802.11 STA normally transmits MSDUs in the order that they are received at its MAC SAP.
Keeping this constraint on 802.11 HT would make throughput strongly dependent on the application traffic pattern at the MAC SAP. Therefore we allow a STA to reorder and delay transmission in the hope of building longer aggregates and using the medium more effectively.
Note: these schedulers are specific to single-receiver aggregates.

### 9.1.2 Scheduler 1

A STA keeps a queue per access category of Data MPDUs for transmission.
The STA starts its channel access attempt as soon as any queue is non-empty.
When a TXOP is gained, the STA selects one of it's transmit queues according to HCF rules.
The MPDU at the head of this queue defines the receiver address. The STA then scans it's transmit queues for more MPDUs addressed to the same receiver. These are available for transmission during the aggregate exchange.
For a sequence using embedded training, the rate may be modified when rate feedback is received. After an initial IAC/RAC training exchange, the STA can calculate how many of the MPDUs addressed to this receiver can fit in the available TXOP and transmits one or more aggregates containing these MPDUs.

### 9.1.3 Scheduler 2

In scheduler 1, the identity of the receiver is selected by HCF channel access, and is always defined by an MPDU at the top of an access category transmit queue. Furthermore, when an access category is not empty, a channel access attempt is active.
Scheduler 2 changes these two properties.
It delays EDCA channel access until:

- There is an aggregate to send exceeding some threshold length, or
- An MPDU has been delayed more than a certain threshold time in a transmit queue.

Once channel access is gained, the STA selects a receiver address as follows:

- If any MPDUs have exceeded the delay threshold, select the oldest one, or
- Select the receiver with the most buffered data

The effect of this algorithm is that an application flow (i.e. point-point link) that is saturated sees low delay and high throughput. Aggregate throughput is maximized because the scheduler prefers the longest aggregate.
An application flow that is low-rate and isochronous sees additional delay, because it never exceeds the length threshold, so it gets transmitted only when its delay threshold has been exceeded. [9]

### 9.1.4 Retransmissions and Allocation of Time

The strategy that maximizes throughput is to maximize the duration of aggregates, and minimize the number of PPDUs.
According to this strategy, a STA with a fully backlogged transmit queue will generate an aggregate that, together with the expected response, just fills the TXOP.
Any MPDUs that were not correctly received in the TXOP will have to wait for a subsequent channel access for retransmission.
An alternative strategy can be used that trades throughput for average channel access delay. This can be particularly useful with data for which a traffic specification (TSPEC) exists that specifies a delay bound.
In this case, the STA monitors or predicts the PER [10] From this, it can predict the number of failures in an aggregate, and leave enough room for retransmissions.
One way of allocating enough room is to require that the aggregate ($N_{aggregate}$) and its retries ($N_{retries}$) are expected to fit within the TXOP with some defined probability – known here as a confidence limit.
For any defined aggregate length and PER, the space to reserve for retries can be determined by inspecting a cumulative distribution function (Prob errors<N vs N) at the required confidence limit. If the packet errors are independent, a cumulative binomial distribution can be used.

### 9.1.5 Selecting RDL/RDG values (Informative)

#### 9.1.5.1 Scheduling decisions for RDL/RDG

In a bi-directional data sequence, the initiator can control the amount of time spent by the responder in response (aggregate) PPDUs through use of the RDG element. There are two scheduling decisions to be made:

- How much of the time to offer to the responder (RDL and RDG)
- How to use the offered time at the responder

The bi-directional data sequence is designed to allow trained data to flow in both directions, sharing the overhead of channel access and training exchange.
The mechanism was designed specifically to allow a TCP link to "piggyback" TCP ack collection onto TCP data transmission. In the ideal mode of operation, the TCP data downlink for a half congestion window of data collect the TCP ack uplink for the previous half congestion window's worth of data.
In this mode, the transmissions by the responder are short TCP ACK MSDUs.

[9] Note, do not confuse this threshold with an MSDU lifetime limit. The delay threshold is the delay below which no channel access attempt need be made. The MSDU lifetime limit is the delay after which delivery is useless, which is hopefully a bigger number!

[10] How it does this is not relevant here.

Assuming that the Block ACK protocol is being used to allow the use of aggregate PPDUs, there is some limited opportunity for the responder to select Data MPDUs from its transmit buffer, subject to Block ACK windowing constraints so as to use the offered response duration.

#### 9.1.5.2 Simple RDL/RDG heuristic

This section contains an initial recommended heuristic.
The initiator will normally try and fill the TXOP with its own data. Aggregate throughput is maximized by maximizing the length of the data in a TXOP. This is best achieved with known data rather than potential response data.
If there is an excess of data buffered for the chosen receiver address, the initiator does not advertise any reverse direction (RDL=0).
If there is room in a TXOP after delivering all its own data, the initiator can send an aggregate containing a non-zero RDL indicating the remaining TXOP duration. If the responder does not respond with a request (i.e. RDR=0), the sequence terminates.
If, on winning a TXOP, the initiator has less data than will clearly fill the TXOP, it can advertise some fraction of the TXOP in its initial IAC, thereby allowing possible reverse direction data flow early in the sequence, and maximizing throughput.
The responder uses any offered response duration for its data of the same user priority or access category, without any intentional reordering of data packets within the access category. This recommendation is based on the understanding that if there are no large packets in the responder's buffer, any TCP ACKs will get sent. But if there are, the responder's TCP ACKs can be sent as part of a later data exchange sequence it initiates, and that good efficiency will be achieved due to the presence of the large packets.
This proposed mechanism does not seek to achieve low TCP RTT, but only good utilization of the medium.

### 9.1.6 Scheduling heuristics for MRA

When creating an MRA, the HT AP may select receiver addresses so as to optimize throughput.
Typically, if clients are sending small amounts of data, the benefits of MRA aggregation should outweigh any reduction in transmit rate.
Above a certain data duration, this may no longer hold true. The HT AP can, in principle consider sending to an HT STA separately using its known transmit parameter versus including it in an existing MRA in order to determine which is the more effective use of the channel.
When using spoofing protection, the length of spoofed length field in the PLCP header imposes a limit of the total duration of a MRA and its multiple immediate ACKs/BAs plus data.

## 9.2 Method to determine Best channel and channel width

The method described here selects the channel parameters that maximize aggregate throughput.
It also has the side effect of generally avoiding operation with co-channel legacy devices.
The HT AP keeps a database of BSS and load information per 20 MHz channel. In each such channel it records its observations of load [11], and the number of legacy and HT BSSs.
Alternatively it can record load for legacy and HT traffic separately if it is capable of making that distinction.
Each HT BSS that permits 40MHz operation will have an entry for both 20-MHz channels it overlaps. The HT BSS load measurement is applied to both the overlapped channels.

[11] Load is defined as the percentage of time the channel is busy (averaged over some observation interval).

The device monitors or estimates its own load. If its load is not known, the device assumes a load of 100% for itself.
From any configuration of channel parameters, BSSs and loads, the device can calculate the following performance metric. It sums the product of load and rate over all channels to determine an aggregate throughput. For channels with only legacy BSSs, it uses the highest legacy rate. For channels with only HT devices, it uses the highest HT rate. For channels with a mixture, it first de-rates the HT highest rate to allow for use of a protection mechanism and then averages this with the legacy rate weighting the average according to the number of BSSs of each type. Alternatively, if it is collecting the load per BSS type, it sums the product of the appropriate rate (legacy or "mixed mode" HT rate) and load.
In considering a channel parameter configuration to evaluate the performance metric, the device shall not allow a configuration if it:

- Has an HT BSS with a different value of control channel or extension channel offset
- Has an HT BSS with a different permitted width set

### 9.2.1 First time Channel Selection

When starting operation, the device performs the following steps:

- It scans all channels to build the database.
- It considers adding its load into each channel in turn to find the position and width and evaluates the performance metric. As it adds its own load into a channel, it caps the load at 100%.
- It selects the combination of position and width that results in the highest value of the performance metric.

### 9.2.2 Subsequent Channel Selection

In order to update its channel parameters, the device first removes its estimated current load from its current channel(s) and then performs the same algorithm as described in the previous section.

## 9.3 Background to Protection Mechanisms

### 9.3.1 Introduction to Protection Mechanisms

Protection of HT exchanges from legacy devices (if present) and other HT devices is necessary for two reasons:

- Legacy devices do not understand HT PPDU formats
- On a link between two HT STAs that is adapted to the channel between those STAs, the probability that a 3rd party STA will be able to reliably receive the MPDUs is smaller than in the legacy case. This is particularly true when closed-loop adaptation is used.

There are two broad classes of protection defined in this document.
The first is called "Spoofing". It uses the legacy PLCP rate and length fields to indicate a duration that may or may not correspond to the duration implied by the HT signal field.

Spoofing is effective because legacy devices respect the duration contained in the legacy signal field, even if they cannot correctly decode the data. The signal field is transmitted using a robust modulation and omnidirectional antenna pattern.
The second class of protection relies on mechanisms to set the NAV using MAC layer signaling. In the presence of legacy devices, this requires that this signaling is carried in legacy receivable MPDUs.

### 9.3.2 Effect of Spoofing

The Spoofing Mechanism is an effective way to protect media from nodes that can not decode the "Duration" field in the MAC Header, which could be the majority of third party nodes in an 802.11n environment, particularly if Closed-Loop MIMO is being used.
The "Duration" field is purposed to set the NAV for third party nodes that the packet is not intended to, in order to prevent these nodes from interrupting the response from the recipient of that packet. However, when certain PHY features are used in 802.11n, the MAC Header which contains the "Duration" Field will not be decodable to all legacy nodes and most of the third party nodes. This is because the MAC Header will be coded with the optimized rate and mode for the recipient of the packet, which makes it difficult for third party nodes to correctly decode the MAC Header.
The spoofing mechanism solves this problem by virtually setting the NAV Duration in the PHY header where the information is coded at the lowest rate that every recipient can decode. By utilizing this Spoofed NAV, the system can assure higher protection of the media from legacy and third party nodes, without adding unwanted overhead of sending legacy packets for media protection.
An HT STA interprets a spoofed PLCP duration as one source of NAV setting, in addition to any MPDUs that it correctly receives in the PPDU. It can receive after the current PPDU regardless of the spoofed duration.
A legacy STA interprets a spoofed PLCP duration as a PPDU of that duration, and remains in the receiving state for the whole duration. It is therefore not capable of acquiring new PPDUs until this period has finished.

### 9.3.3 Pairwise spoofing

The Pairwise Spoofing mechanism is a way to maintain protection from hidden nodes, by disallowing third party nodes to initiate transmission during the duration of the intended response of a packet.
The mechanism takes after the "Virtual Carrier Sense" with the "Network Allocation Vector (NAV)" specified in the 802.11 standard. Each packet will contain a duration field (or a Spoofed NAV field: See section 7.1.7.1 for details), and nodes that receive packets destined to another node will assume channel occupancy for the time specified in that duration field.

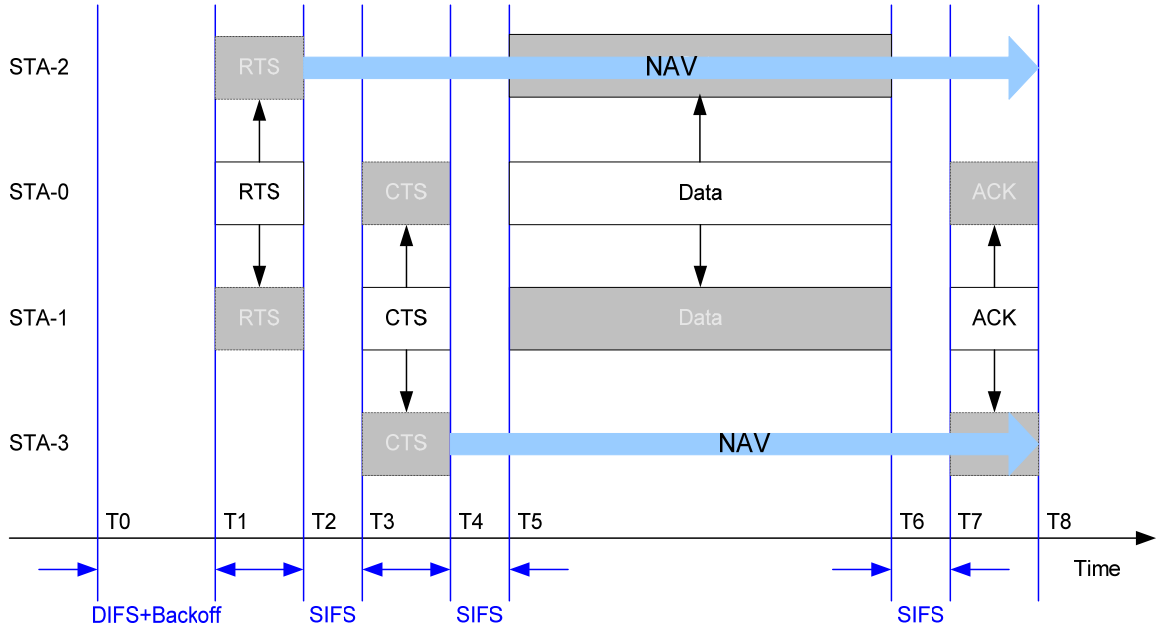



**Figure 38 – Standard Virtual Carrier Sense**

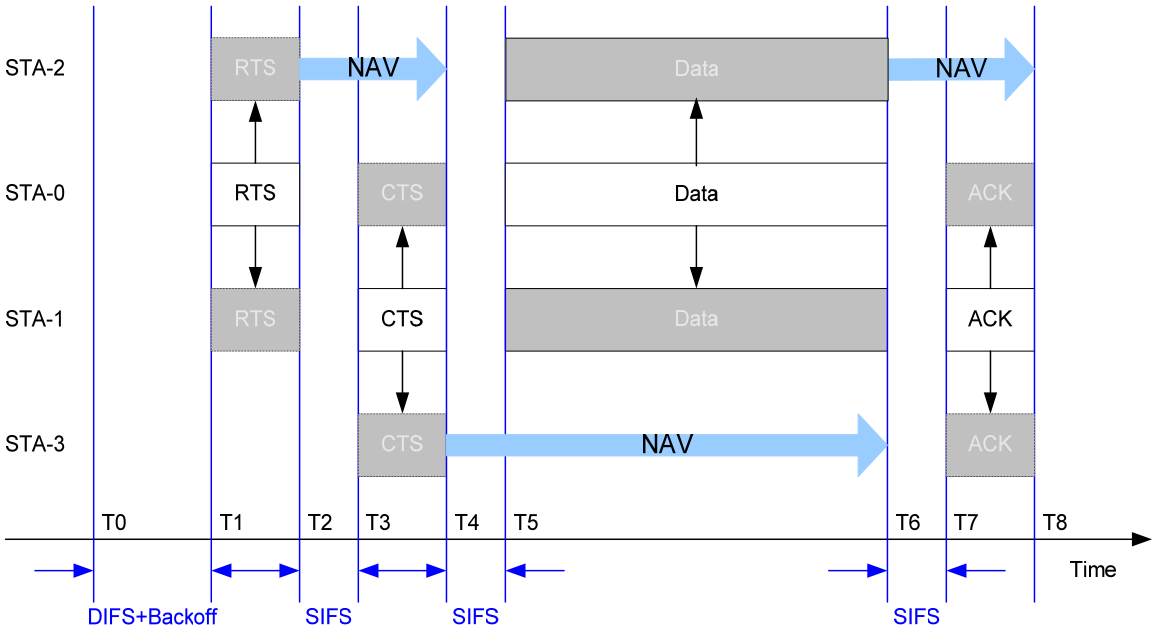



**Figure 39 – Pairwise Spoofing Mechanism**

With the Pairwise Spoofing method, the duration will be set to protect the intended response packet. In the standard 802.11 MAC, when using RTS / CTS, the duration fields in the RTS / CTS / DATA packets point at the end of the ACK. By using this original method, because the Duration must be fixed when sending RTS, the mode and rate in which the data packet would be sent at must be fixed before sending RTS. However, in realistic environments where advanced techniques like MIMO are used, channel conditions vary rapidly and optimization of MIMO modes by the RTS / CTS transaction will become essential. By shortening the NAV duration so that it protects only the following packet, the rate and mode that the DATA packet is sent at can be selected by the recipient of the packet, allowing more flexible adaptation, without sacrificing

the needed protection from hidden nodes. Furthermore, the shortening of the NAV can contribute to less waste of medium time when the RTS / CTS packets fail to be received by their counterparts.

### 9.3.4 Selecting between Pairwise Spoofing and LongNAV

The selection of protection mechanism is made by the initiator.
Use of Pairwise Spoofing is indicated by the FPD element in an IAC. This causes the RAC to generate a PPDU with a spoofed duration.
The initiator should operate under LongNAV rules if the NAV has already been set (e.g. by a QoS CF-poll sent by the HC).
In unmanaged mixed mode, protection from co-channel 802.11b devices shall be provided using LongNAV.
Otherwise the choice between Pairwise Spoofing and LongNAV can be made on the basis of trading flexibility of scheduling with performance.

### 9.3.5 HT PPDU Format with Legacy Protection

An HT PPDU Format looks like the following (See section 11.1.1.3 for a detailed description of the HT PPDU Format.)

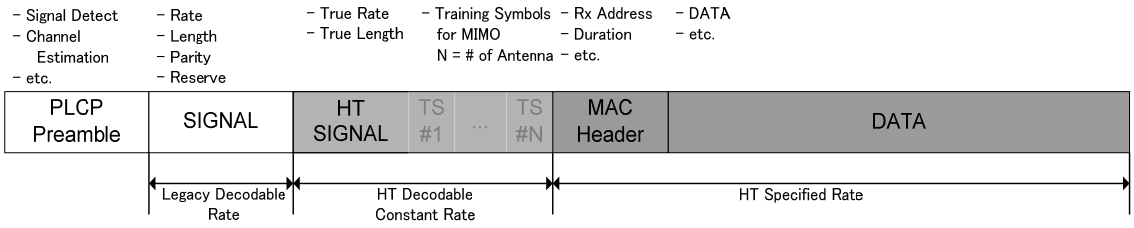



**Figure 40 – PPDU Format with Legacy Protection**

The PLCP Preamble is followed by a legacy SIGNAL Field. This SIGNAL Field is coded at a constant legacy rate that all nodes can decode at (for 802.11a nodes, 6[Mbps]). The legacy SIGNAL Field contains Rate and Length Fields used for spoofing the legacy nodes.
The legacy SIGNAL Field is followed by an HT SIGNAL Field which contains the True Rate and True Length. This field is coded at a rate and mode that all HT nodes can decode.
The HT SIGNAL Field is followed by the MAC Header. In the MAC Header, the Duration Field is set for setting the NAV for third party nodes that receive this packet. However, from the MAC Header on, the mode and rate is optimized for the intend recipient of the packet, so third party nodes will very unlikely be able to decode the MAC Header properly which will destroy protection by the NAV mechanism.

#### 9.3.5.1 Interpretation by a Legacy Node

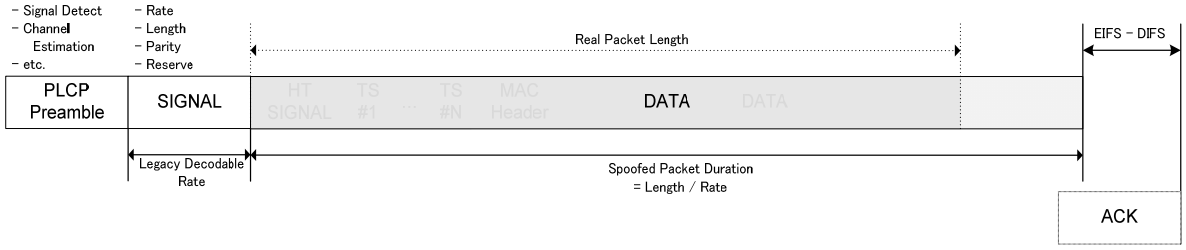



**Figure 41 – When Received by a Legacy Node**

When this HT PPDU is received by a legacy node, it decodes the legacy SIGNAL Field and tries to receive the packet for Length / Rate. When it finishes its reception, it finds that the CRC has failed for the data frame and defers for the EIFS period (instead of DIFS). After the media has been idle for that EIFS period, it restarts its contending mechanism. Therefore, an HT node who requires protection from legacy nodes, will set its Length and Rate Field so that the;
Length / Rate = NAV Duration – (EIFS – DIFS)
There could be a number of combinations of Lengths and Rates to achieve the same "Length / Rate", so the initiator will have the liberty to choose among the combinations. The maximum duration that an initiator can set by spoofing is determined by the maximum length of the packet and the minimum rate that the original protocol can withstand.
The signal energy level will go down during the reception of the packet, because the actual packet length is less than the spoofed length. But, according to the IEEE 802.11a MAC Specification (See IEEE Std 802.11a – 1999, page37, Figure 125), legacy nodes are required to honour the Length and Rate field, and must keep quiet for the Length / Rate. This requirement is also a part of the compliant test plan specified by the WiFi Alliance.

#### 9.3.5.2 Interpretation by an HT Node

As seen in Figure 40, in an HT PPDU, a legacy SIGNAL Field is followed by an HT SIGNAL Field coded at unified rate. This HT SIGNAL Field will contain the True Rate and the True Length that HT nodes will use. However, after decoding the legacy SIGNAL Field, an HT node will not know whether the SIGNAL Field is spoofed and is followed by an HT SIGNAL Field (sent at unified rate), or the packet is a legacy "un-spoofed" packet and is followed by a MAC Header coded at a rate specified in the SIGNAL Field.

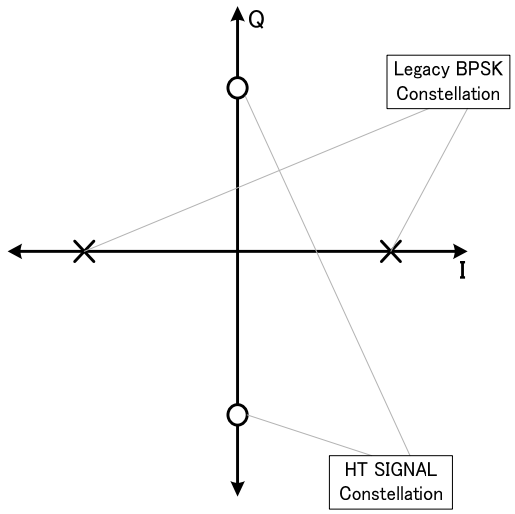



**Figure 42 – HT Signal Field BPSK Constellation**

Therefore, an HT SIGNAL Field will be transmitted with a 90[degrees] rotation, for BPSK mapping, from the I-Q plane indicated in the legacy PLCP Preamble. An HT device will decode the BPSK constellation specified in the PLCP Preamble at the rate indicated in the SIGNAL Field, and at the same time will decode, at the unified rate for HT SIGNAL Field, the BPSK constellation 90[degrees] from its original.
After decoding the two constellations in parallel for a given length of the HT SIGNAL Field, an HT node will check its CRC for the HT SIGNAL Field. If the CRC passes, it will recognize that

this is an HT PPDU and continue to decode the MAC Header using the True Rate and True Length specified in the HT SIGNAL Field. If the CRC fails, it will recognize that it is a legacy PPDU and interpret the legacy MAC Header that it has been receiving.

#### 9.3.5.2.1 MPDU Not Decodable

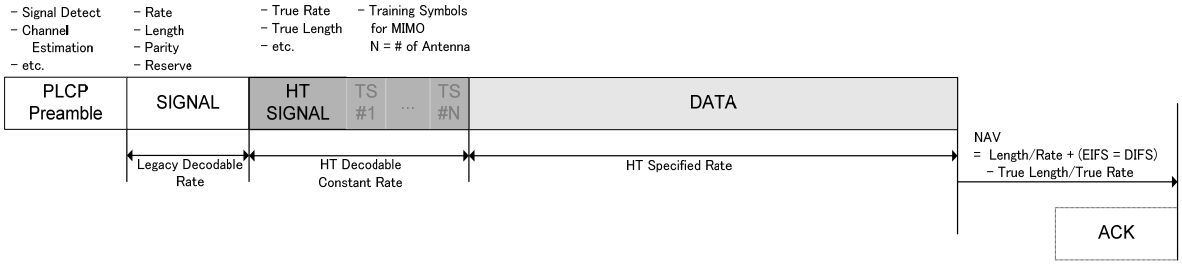



**Figure 43 – When Received by an HT Node but MPDU is not Decodable**

After decoding the HT SIGNAL Field, an HT node will attempt to decode the following MPDU with the specified rate. When the MPDU's FCS is not correct, it will discard the MPDU and will calculate the NAV duration that it should defer. Because the spoofed NAV Duration is (EIFS – DIFS) less than the intended Duration, to prevent unfairness to legacy nodes, the NAV will be set according to the rules defined in section **Error! Reference source not found.**.

#### 9.3.5.2.2 MPDU Decodable

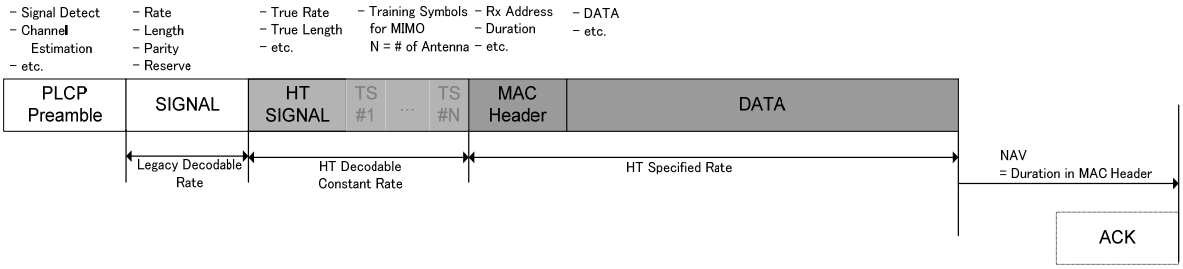



**Figure 44 – When Received by an HT Node and the MPDU is Decodable**

When the MPDU is decodable, an HT node will continue on with its MAC operation. If the Receive Address in the MAC Header does not match itself, it will set its NAV to the Duration indicated following existing 802.11 rules.

### 9.3.6 Protection mechanisms for MRA

#### 9.3.6.1 How to choose between LongNAV and spoofing in MRA

The choice of protection mechanism is the choice of the initiator. If using a polled TXOP, or during the CFP, NAV protection has already been provided, and spoofing is not necessary. However if the NAV has not been set, it is more effective to use spoofing protection.
There is only one possible performance advantage for LongNAV, if the final (or only) response PPDU is shorter than the grant, the initiator does not need to wait until the end of the scheduled response period, but can initiate additional transmissions a SIFS after the end of the actual response.
The recommended choice of protection mechanism is listed below:
Use LongNAV:

- During Polled TXOPs (zero overhead)
- For long aggregates
- Where maximum flexibility in scheduling decisions must be kept
- For .11b coexistence

Use spoofing:

- For short aggregates
- In IBSS or ad-hoc mesh networks

#### 9.3.6.2 Protection from Third Party HT Nodes

The protection of multi-responses from third party HT nodes is achieved using either single-ended spoofing or LongNAV.
In both cases, all STAs that can hear the initiator will have a non-zero NAV during the response periods, preventing them from transmission.
A response period for a receiver might not be used up, for some reason. This leaves the WM idle, possibly for more than a SIFS time. Although this unused TXOP is wasted, it does not create any problem, since all nodes that can hear the initiator will have their NAV set during the responses.

#### 9.3.6.3 Protection from Hidden Nodes

In the case of MRA transmission from an HT AP, all nodes within the BSS should be able to hear and honor the spoofed NAV in the aggregate header, which is always transmitted at the most robust rate, there are no nodes hidden to the AP.

#### 9.3.6.4 Protection from Legacy Nodes

Protection of the MRA from legacy nodes may be achieved via the spoofed NAV in the PLCP header of a MRA aggregate. Although not recognizing an HT MPDU, a legacy client should still be able to recognize such a spoofed NAV from the legacy PLCP header of the MRA aggregate and therefore enters a receiving state for the indicated duration, thereby stopping it from initiating transmissions during the indicated duration.
Alternatively the initiator transmits a legacy compatible PPDU that sets the NAV.
In both cases, the level of protection afforded by this method is the same as CTS-to-self.

1

# 10 PHY-SAP service specification

The PHY service is provided to the MAC entry at an STA through the PHY service access point (PHY-SAP), as shown in Figure 11 of [1] and described in Clause 12 of that reference.

The amendments to the PHY-SAP parameters TXVECTOR and RXVECTOR are described in Sections 10.1.1 and 10.1.2 respectively.

## 10.1 PHY Specific Service Parameter List

The architecture of the IEEE 802.11 MAC is intended to be PHY independent. Some PHY implementations require PHY-dependent MAC state machines running in the MAC sublayer in order to meet certain PMD requirements. The PHY-dependent MAC state machine resides in a sublayer defined as the MAC sublayer management entity (MLME). In certain PMD implementations, the MLME may need to interact with the PLME as part of the normal PHY SAP primitives. These interactions are defined by the PLME parameter list currently defined in the PHY service primitives as TXVECTOR and RXVECTOR. The list of these parameters, and the values they may represent, are defined in the specific PHY specifications for each PMD. This subclause addresses the TXVECTOR and RXVECTOR for the MIMO-OFDM High Throughput (HT) PHY. The service parameters for TXVECTOR and RXVECTOR shall follow subclause 10.1.1 and 10.1.2.

### 10.1.1 TXVECTOR

The TXVECTOR is an array of fields sent from the MAC to the PHY instructing the PHY how to transmit the PPDU.

| **Parameter** | **Associated Primitive** | ***Value*** |
|---|---|---|
| PPDU FORMAT | PHY-TXSTART.request (TXVECTOR) | *Legacy 20 in 20*<br>*HT 20 in 20*<br>*Legacy upper 20 in 40*<br>*Legacy lower 20 in 40*<br>*HT upper 20 in 40*<br>*HT lower 20 in 40*<br>*HT 40 in 40* |
| L-LENGTH | PHY-TXSTART.request (TXVECTOR) | *1 – 4095* |
| L-DATARATE | PHY-TXSTART.request (TXVECTOR) | *6, 9, 12, 18, 24, 36, 48, and 54 (Support of 6, 12, and 24 data rates are mandatory.)* |
| L-SERVICE | PHY-TXSTART.request (TXVECTOR) | *Scrambler initialization;*<br>*7 null bits + 9*<br>*reserved null bits* |
| TX_PWR_LEVEL | PHY-TXSTART.request (TXVECTOR) | *1 – 8* |
| HT-LENGTH | PHY-TXSTART.request (TXVECTOR) | *1 – 262143* |

| | | |
|---|---|---|
| MCS | PHY-TXSTART.request (TXVECTOR) | *0 – 63* |
| ADV CODING | PHY-TXSTART.request (TXVECTOR) | *0, 1* |
| SOUNDING | PHY-TXSTART.request (TXVECTOR) | *0, 1* |
| NLTF | PHY-TXSTART.request (TXVECTOR) | *1 – 4* |
| AGGREGATE | PHY-TXSTART.request (TXVECTOR) | *0, 1* |
| SCRAMBLER-INIT | PHY-TXSTART.request (TXVECTOR) | *0, 1, 2, 3* |
| SHORT-GI | PHY-TXSTART.request (TXVECTOR) | *0, 1* |
| BEAMFORMED | PHY-TXSTART.request (TXVECTOR) | *0, 1* |
| BEAMFORM MATRIX | PHY-TXSTART.request (TXVECTOR) | $N_{TX} \times N_{SS} \times N_{SD}$ *complex matrices* |

**Table 17: Table of parameters for the TX Vector**

#### 10.1.1.1 TXVECTOR PPDU FORMAT

The PPDU FORMAT field specifies whether the PPDU is to be sent using a legacy PPDU format or using a high-throughput format. Legacy is interpreted to be 802.11g if operating in the 2.4 GHz band and 802.11a if operating in the 5 GHz band. Furthermore, it specifies the channel (i.e, the full 20MHz channel, the upper 20MHz sub-channel in the 40MHz channel, the lower 20MHz sub-channel in the 40MHz channel, or the full 40MHz channel) at which the PPDU is to be sent.

The value of this field affects the interpretation of several other TXVECTOR fields.

#### 10.1.1.2 TXVECTOR L-LENGTH

The allowed values for the L-LENGTH parameter are in the range of 1–4095.

In legacy format this parameter is used to indicate the number of octets in the MPDU which the MAC is currently requesting the PHY to transmit. This value is used by the PHY to determine the number of octet transfers that will occur between the MAC and the PHY after receiving a request to start the transmission. In high-throughput format this parameter (along with L-DATARATE) is used to spoof the length of the current PPDU and possibly additional PPDUs.

#### 10.1.1.3 TXVECTOR L-DATARATE

In legacy format the L-DATARATE parameter describes the bit rate at which the PLCP shall transmit the PSDU. Its value can be any of the rates: 6, 9, 12, 18, 24, 36, 48, and 54. Data rates of 6, 12, and 24 shall be supported; other rates may also be supported. In high-throughput format

this parameter (along with L-LENGTH) is use to spoof the length of the current PPDU and possibly additional PPDUs. For spoofing purposes, L-DATARATE in the L-SIG is set to 6Mbps.

#### 10.1.1.4 TXVECTOR L-SERVICE

In legacy format the L-SERVICE parameter consists of 7 null bits used for the scrambler initialization and 9 null bits reserved for future use. In HT format this parameter is Null.

#### 10.1.1.5 TXVECTOR TXPWR_LEVEL

The allowed values for the TXPWR_LEVEL parameter are in the range from 1–8. This parameter is used to indicate which of the available TxPowerLevel attributes defined in the MIB shall be used for the current transmission. In high-throughput format the transmit power is the aggregate of the power from all transmit antennas.

#### 10.1.1.6 TXVECTOR HT-LENGTH

The allowed values for this parameter are 1 – 264143. In HT format this parameter indicates the number of octets in the PSDU to be sent in the PPDU. In legacy format this parameter is Null.

#### 10.1.1.7 TXVECTOR MCS

The allowed values for this parameter are 0 – 63. In HT format this parameter indicates the modulation and coding scheme. The number is an index into the MCS table given in Table 26 and Table 29. In legacy format this parameter is Null.

#### 10.1.1.8 TXVECTOR ADV CODING

In HT format this parameter indicates whether advanced coding is used. A value of 0 indicates that advanced coding is not used. In legacy format this parameter is Null. A value of 1 indicates LDPC coding is used.

#### 10.1.1.9 TXVECTOR SOUNDING

In HT format this parameter indicates whether this PPDU is a sounding PPDU. A value of 0 indicates that it is not a sounding PPDU. A value of 1 indicates that it is a sounding PPDU. In legacy format this parameter is Null.

#### 10.1.1.10 TXVECTOR NLTF

In high-throughout format this parameter specifies the number of long training fields. In legacy format this parameter is Null.

#### 10.1.1.11 TXVECTOR AGGREGATE

In high-throughout format this parameter indicates whether the PPDU contains an aggregate PSDU. A value of 0 indicates that the PSDU is not an aggregate and a value of 1 indicates that the PSDU is an aggregate. In legacy format this parameter is Null.

#### 10.1.1.12 TXVECTOR SCRAMBLER-INIT

In high-throughout format this is the scrambler initialization field. It is a two-bit field, which serves as a pointer to one of four 7-bit long scrambler initialization sequences. In legacy format this parameter is Null.

The 2 bits are mapped to the following four scrambler initialization sequences:

| |
|---|
| b'00 → step 15 b'0111100 |
| b'01 → step 84 b'0111101 |
| b'10 → step 103 b'0111110 |
| b'11 → step 127 b'0111111 |

**Table 18: Scrambler Initialization Sequence**

#### 10.1.1.13 TXVECTOR SHORT-GI

In high-throughout format this parameter indicates whether the data is sent with a short guard interval (400 ns). A value of zero indicates a full GI (i.e. 800ns) and a value of 1 indicates a short GI (i.e. 400 ns). In legacy format this parameter is Null.

#### 10.1.1.14 TXVECTOR BEAMFORMED

In high-throughout format this parameter indicates whether a beamforming matrix is applied to the data. A value of zero indicates that no beamforming is applied and a value of 1 indicates that beamforming is applied. In legacy format this parameter is Null.

#### 10.1.1.15 TXVECTOR BEAMFORM MATRIX

In high-throughout format this field specifies the complex matrix $N_{TX} \times N_{SS} \times N_{SD}$ which is used to beamform the PPDU. This field is only valid when the BEAMFORMED parameter is 1. In legacy format this parameter is Null.

### 10.1.2 RXVECTOR

The RXVECTOR is an array of fields sent from the PHY to the MAC providing information regarding the received PPDU.

| Parameter | Associated Primitive | *Value* |
|---|---|---|
| PPDU FORMAT | PHY-RXSTART.indicate (RXVECTOR) | *Legacy 20 in 20*<br>*HT 20 in 20*<br>*Legacy upper 20 in 40*<br>*Legacy lower 20 in 40*<br>*HT upper 20 in 40*<br>*HT lower 20 in 40*<br>*HT 40 in 40* |
| L-LENGTH | PHY-RXSTART.indicate (RXVECTOR) | *1 – 4095* |
| RSSI | PHY-RXSTART.indicate (RXVECTOR) | *0 – RSSI maximum* |
| L-DATARATE | PHY-RXSTART.indicate (RXVECTOR) | *6, 9, 12, 18, 24, 36, 48, and 54* |
| BW | PHY-RXSTART.indicate (RXVECTOR) | *20, 40* |
| HT-LENGTH | PHY-RXSTART.indicate (RXVECTOR) | *1 – 262143* |
| MCS | PHY-RXSTART.indicate (RXVECTOR) | *0 – 63* |
| ADV CODING | PHY-RXSTART.indicate (RXVECTOR) | *0, 1* |
| SOUNDING | PHY-RXSTART.indicate (RXVECTOR) | *0, 1* |
| NLTF | PHY-RXSTART.indicate (RXVECTOR) | *1 – 4* |
| AGGREGATE | PHY-RXSTART.indicate (RXVECTOR) | *0, 1* |
| SHORT-GI | PHY-RXSTART.indicate (RXVECTOR) | *0, 1* |

**Table 19: Table of parameters for the RX Vector**

#### 10.1.2.1 RXVECTOR PPDU FORMAT

The PPDU FORMAT field specifies whether the received PPDU has a legacy PPDU format or a high-throughput format. Legacy is interpreted to be 802.11g if operating in the 2.4 GHz band and 802.11a if operating in the 5 GHz band. Furthermore, it specifies the channel (i.e, the full 20MHz channel, the upper 20MHz sub-channel in the 40MHz channel, the lower 20MHz sub-channel in the 40MHz channel, or the full 40MHz channel) at which the received PPDU was sent.

#### 10.1.2.2 RXVECTOR L-LENGTH

The allowed values for the L-LENGTH parameter are in the range of 1–4095. This parameter is used to indicate the value of the L-LENGTH field in received PPDU. If this was a legacy PPDU then this parameter is the actual length of the PPDU. If this is a HT PPDU then this parameter, along with the L-DATARATE parameter, is used to calculate the spoofed duration.

#### 10.1.2.3 RXVECTOR RSSI

The allowed values for the receive signal strength indicator (RSSI) parameter are in the range from 0 through RSSI maximum. This parameter is a measure by the PHY sub-layer of the energy observed at the antenna used to receive the current PPDU. RSSI shall be measured during the reception of the PLCP preamble. RSSI is intended to be used in a relative manner, and it shall be a monotonically increasing function of the received power. The value of RSSI is the maximum of the RSSI values from each receive antenna.

#### 10.1.2.4 RXVECTOR L-DATARATE

The allowed values for L-DATARATE are: 6, 9, 12, 18, 24, 36, 48, and 54. This parameter is used to indicate the value of the L-DATARATE field in the received PPDU. If this is a legacy PPDU this is the data rate at which the data was transmitted. If this is an HT PPDU then this parameter, along with L-LENGTH, is used to calculate the spoof duration.

#### 10.1.2.5 RXVECTOR BW

In high-throughput format this parameter specifies whether the received PPDU is a 20 MHz bandwidth or 40 MHz bandwidth HT PPDU. In legacy format this parameter is Null.

#### 10.1.2.6 RXVECTOR HT-LENGTH

The allowed values for this parameter are 1 – 264143. In HT format this parameter indicates the value contained in the HT-LENGTH field. This parameter specifies the number of octets to be transferred from the PHY to the MAC sub-layer. In legacy format this parameter is Null.

#### 10.1.2.7 RXVECTOR MCS

The allowed values for this parameter are 0 – 63. The number is an index into the MCS table given in Table 26 and Table 29. In high-throughput format this parameter indicates the value of the MCS field in the PPDU HT-SIG. In legacy format this parameter is Null.

#### 10.1.2.8 RXVECTOR ADV CODING

In HT format this parameter indicates whether advanced coding was used in the PPDU. A value of 0 indicates that advanced coding is not used. In legacy format this parameter is Null. A value of 1 indicates that LDPC coding is used.

#### 10.1.2.9 RXVECTOR SOUNDING

In HT format this parameter indicates whether this PPDU is a sounding PPDU. A value of 0 indicates that it is not a sounding PPDU. A value of 1 indicates that it is a sounding PPDU. In legacy format this parameter is Null.

#### 10.1.2.10 RXVECTOR NLTF

In high-throughout format this parameter specifies the number of long training fields. In legacy format this parameter is Null.

#### 10.1.2.11 RXVECTOR AGGREGATE

In high-throughout format this parameter indicates whether the PPDU contains an aggregate PSDU. A value of 0 indicates that the PSDU is not an aggregate and a value of 1 indicates that the PSDU is an aggregate. This value is used by the MAC sub-layer to indicate whether de-aggregation is required. In legacy format this parameter is Null.

#### 10.1.2.12 RXVECTOR SHORT-GI

In high-throughout format this parameter indicates whether the data was sent with a short guard interval (400 ns). A value of zero indicates a full GI (800 ns) and a value of 1 indicates a short GI (400 ns). In legacy format this parameter is Null.

# 11 MIMO-OFDM HT PHY specification

## 11.1 Overview

### 11.1.1 Introduction (Informative)

With the aim to increase the maximum PHY layer data rate, we have introduced two primary techniques that are mandatory in our proposal:

- Transmission of Multiple Spatial Streams via Multiple Transmit Antennas. Our recommendation is to make 2 spatial streams mandatory, with the option to scale to 4 spatial streams.

- Extended Bandwidth signaling. 20MHz channelization shall be mandatory worldwide. Our recommendation is to support 40MHz channelization as mandatory in regulatory domains that will permit wider bandwidth operation

We have also introduced several secondary techniques for increasing throughput. These include:

- A reduced guard interval of 400ns (i.e. half-GI), channel dispersion permitting (e.g. TGn channel model B). Support for half-GI is mandatory in 20MHz.

- Higher channel coding rate of 7/8. Support for 7/8 is mandatory in 20MHz.

- Support for 256-QAM is optional in our proposal.

Due to the susceptibility of a wireless link to multipath fading, especially in a MIMO channel, our proposal introduces two optional techniques for improving the robustness of the link between the transmitter and the receiver, with the aim to keep the client (station) configuration low-cost and low-power:

- Transmitter beamforming, with the understanding that Access Points will be able to support more than 2 antennas, while the client stations would be restricted to 2 antennas.

- Advanced channel coding. Our proposal includes LDPC as an option. LDPC codes exhibit a larger minimum free distance compared to the existing 802.11a convolutional code, and hence are able to better exploit the frequency and spatial diversity in the channel.

#### 11.1.1.1 Frequency Bands of Operation

Our proposal supports operation of devices in 2.4GHz, 5GHz, and 4.9GHz. Operation in 4.9GHz shall conform to 802.11j rules.

#### 11.1.1.2 Options for throughput enhancement

The throughput calculation for 802.11a, at its highest data rate, can be factorized as:

$$\text{Data Rate} = \underbrace{\frac{20M \text{ time samples}}{\text{second}}}_{\text{channel spacing}} \cdot \underbrace{\frac{48 \text{ freq tones}}{64 \text{ freq tones}}}_{\text{guard band overhead}} \cdot \underbrace{\frac{6 \text{ coded bits}}{\text{freq tone}}}_{\text{constellation size}} \cdot \underbrace{\frac{3 \text{ info bits}}{4 \text{ coded bits}}}_{\text{coding rate}} \cdot \underbrace{\frac{64 \text{ freq tones}}{80 \text{ times samples}}}_{\text{guard interval overhead}}$$

$$= 54M \text{ info bits/second}$$

Besides spatial multiplexing, there are four other options for increasing data rate: (a) increasing the channel bandwidth, (b) increasing the constellation size, (c) increasing the coding rate, and (d) reducing the guard interval (GI) overhead. These options are summarized in Table 20.

| **802.11a/g** | **Our Proposal** | **Requirement** | ***Throughput Scaling Factor*** |
|---|---|---|---|
| Channel BW = 20MHz<br><br>Number of data subcarriers = 48 | Channel BW = 20MHz<br>Number of data subcarriers = 48 | Mandatory in device | *1x* |
| | Channel BW = 40MHz<br>Number of data subcarriers = 108 | Mandatory in device | *2.25x* |
| | Channel BW larger than 40MHz | Not supported in device | |
| Number of Transmit Antennas = 1 | Number of Transmit Antennas = 2 | Mandatory in device | *2x* |
| | Number of Transmit Antennas > 2 | Optional in device (e.g. 3 and 4) | *3x or 4x* |
| Maximum Constellation Size = 64QAM | 64-QAM | Mandatory in device | *1x* |
| | greater than 64QAM (i.e. 128 or 256 QAM) | 256 QAM is optional in device | *1.16x (128-QAM)*<br><br>*1.33x (256-QAM)* |
| GI = 800ns<br><br>Tsymbol = 3200ns | GI / Tsymbol = 800ns/3200ns | Mandatory in device | *1x* |
| | GI / Tsymbol = 400ns/3200ns | Mandatory in device | *1.11x* |
| | GI / Tsymbol = 800ns / 6400ns | Not supported in device | *1.11x* |
| | GI / Tsymbol = 400ns / 6400ns | Not supported in device | *1.176x* |
| Coding Rate | 1/2, 2/3, 3/4 | Mandatory in device | *1x* |
| | 7/8 (advanced coding option) | Mandatory in device | *1.167x* |

**Table 20: Options for Throughput Enhancement**

Of the options presented in Table 20 for throughput enhancement, our proposal focuses upon using spatial multiplexing (via multiple transmit antennas) and bandwidth expansion (from 20 MHz to 40 MHz) as the primary means for increasing the physical layer data rates. This is because both spatial multiplexing and channel bandwidth increase data rate by integer increments, whereas the rest of the techniques increase the data rate by fractional increments. The use of a shorter Guard Interval (GI=400ns) and 7/8-th rate coding is also mandatory for the data portion of the PPDU. With 4 spatial streams in 40MHz, the maximum PHY data rate in our proposal corresponds to 630Mbps, which is more than 10x the current data rate of 54Mbps. Note that the High Throughput (HT) preamble shall always use the full GI, i.e. 800us.

The basic mandatory configuration in our PHY proposal for throughput enhancement is 2 spatial streams (i.e. 2 transmit antennas) across a 20MHz channel bandwidth. The transmitter datapath is shown in Figure 45.

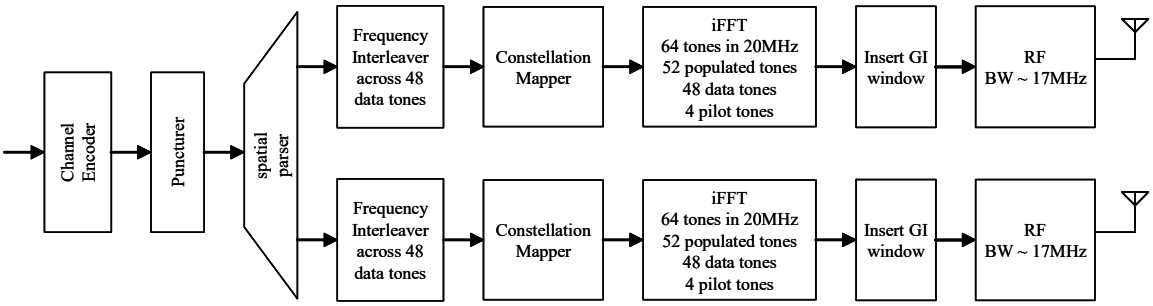



**Figure 45: Transmitter Datapath for 2-antenna MIMO in 20MHz**

Our proposal also includes provisions for 40MHz signaling in regulatory domains that permit it. The transmitter datapath for such a configuration is shown in Figure 46:

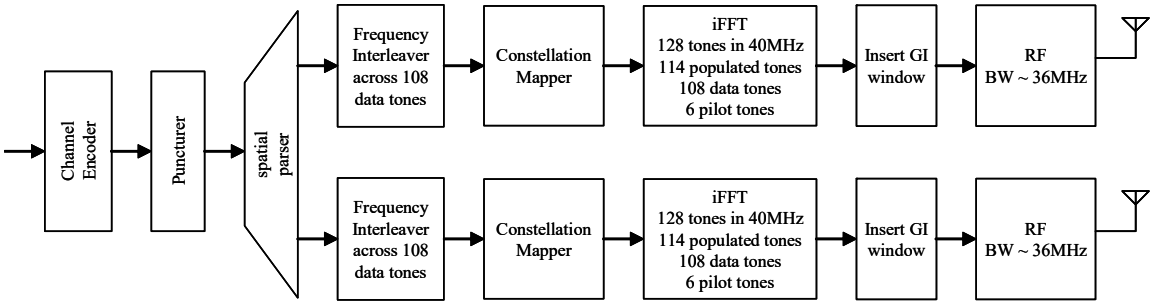



**Figure 46: Transmitter datapath for 2-antenna MIMO in 40MHz[12]**

### 11.1.1.3 PPDU Format for the Basic (Mandatory) MIMO Transmission

The PPDU format for transmission using 2 antennas in a 20MHz channelization is shown in Figure 47:

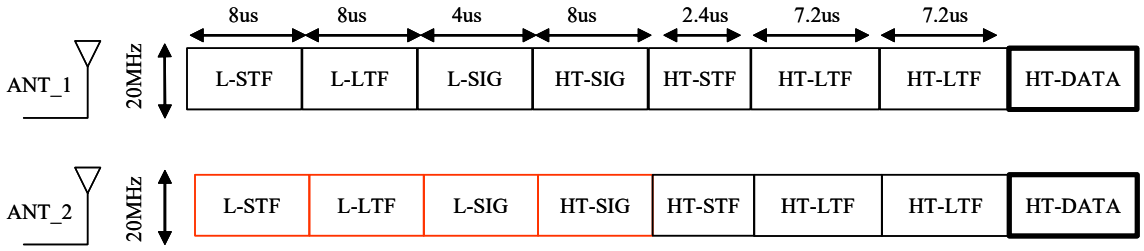



**Figure 47: PPDU Format for 2x20 Mandatory Basic MIMO Transmission**

In the 40MHz bandwidth, there are two 20MHz wide sub-channels. The upper sub-channel spans from 0 to +63, and the lower sub-channel spans from -64 to -1, as shown in Figure 48. A 40MHz-HT device receiving a 20MHz-only transmission shall indicate to the MAC which sub-channel is currently active.

[12] 40MHz operation by an HT device shall only be permitted in those regulatory domain that allow it.

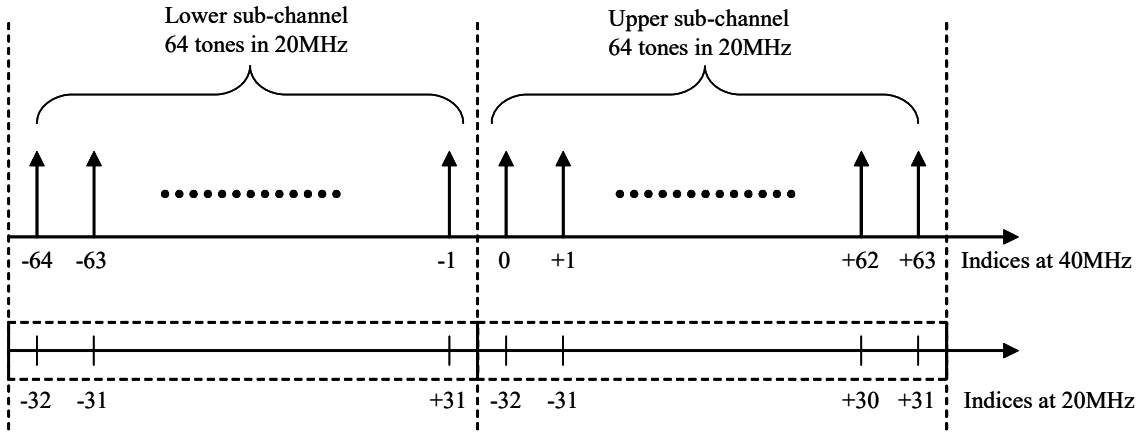



**Figure 48: Upper and Lower sub-channel specification in 40MHz**

The PPDU format from two transmit antennas, each 40MHz wide, is shown in Figure 49.

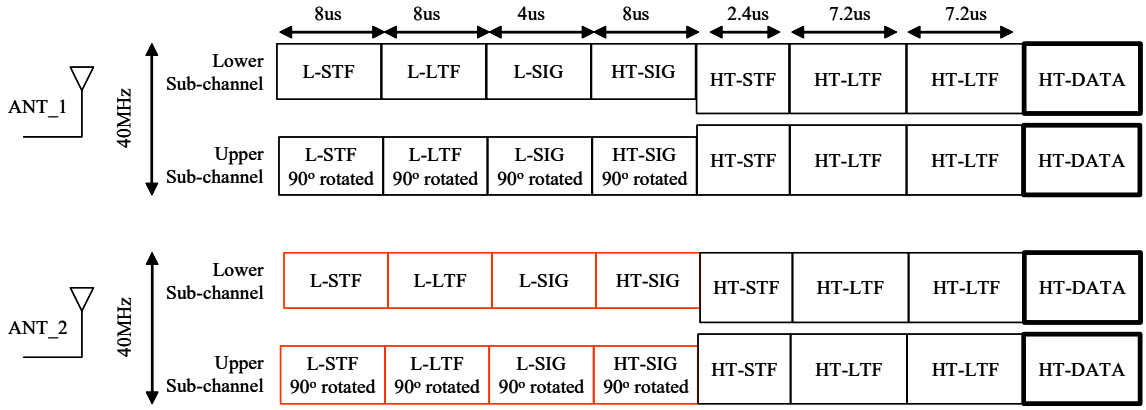



**Figure 49: PPDU Format for 2x40 Mandatory Basic MIMO Transmission[13]**

The legacy part of the HT preamble (i.e. L-STF to L-SIG) and HT-SIG may either be transmitted from one antenna or both antennas. If transmitted from both antennas, the mapping of this single spatial stream to two antennas has to be such that beamforming in the far-field is mitigated. One method for achieving this is to use a cyclical delay diversity (CDD) mapping. The optional part of the PPDU, corresponding to the CDD format, is shown in red color in Figure 47 and Figure 49.

### 11.1.1.4 HT PCLP Preamble for Synchronization purposes and Legacy Interoperability

The functions performed by the preamble include:

1. Start-of-Packet (SoP) detection
2. AGC
3. Coarse Frequency Offset Estimation
4. Coarse Timing Offset Estimation

[13] 40MHz operation by an HT device shall only be permitted in those regulatory domain that allow it.

5. Fine Timing Offset Estimation
6. Fine Frequency Offset Estimation
7. Channel Estimation

The High Throughput (HT) preamble in our proposal is a concatenation of the legacy preamble (identical to 802.11a/g) and a HT-specific preamble, as shown in Figure 50:

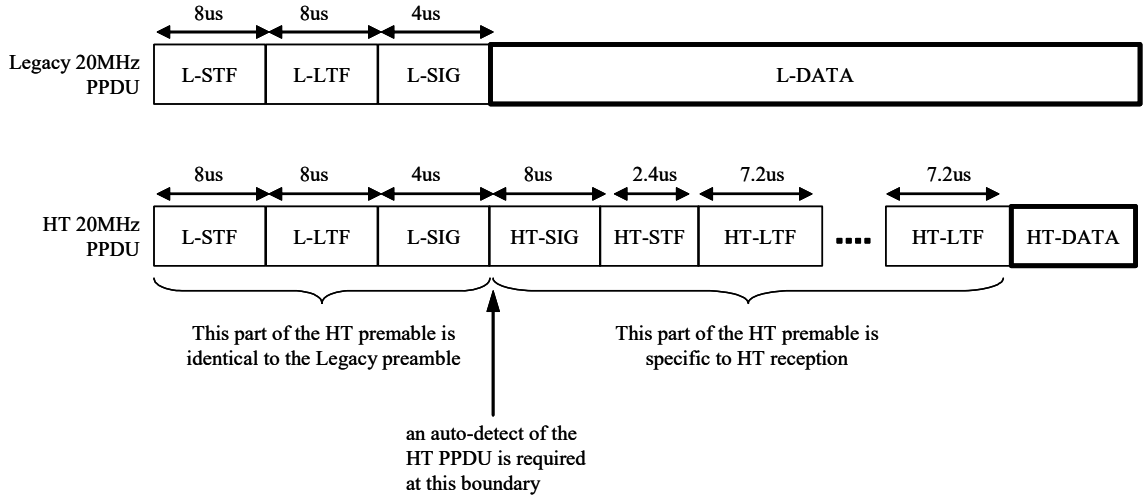



**Figure 50: HT Preamble format**

Concatenation of the legacy preamble allows PHY layer interoperability with 802.11a and ERP-802.11g modems.

A HT receiver does not know apriori whether it is receiving a legacy PPDU or a HT PPDU. Hence, a HT receiver has to perform an auto-detect after the legacy signal field (L-SIG) as to whether a HT-SIG is being received or legacy data (L-DATA). Our preamble format includes two provisions for auto-detecting the HT-SIG: (a) transmitting the HT-SIG as a BPSK signal on the quadrature axis instead of the in-phase axis, and (b) inverting the pilot polarity in going from the L-SIG to the HT-SIG.

The legacy part of the HT preamble allows a legacy receiver to properly decode the L-SIG. A HT receiver shall also perform functions 1 through 7 (SoP to Channel Estimation) to successfully decode the HT-SIG. It is anticipated that functions 1 through 4 (and perhaps function 5) are performed by the legacy short training field (L-STF), and functions 5 through 7 are performed by the legacy long training field (L-LTF).

Since a HT device (in our proposal) shall support multiple transmit antennas, the legacy part of the preamble can either be transmitted from one antenna or from multiple antennas. If more than one antenna is used for transmission, it is recommended that the signal be shifted in a cyclical fashion across the transmit antenna array. This technique introduces cyclical delay diversity (CDD), and it tends to reduce the “effective” length of the guard interval, as seen by a legacy device. Hence, the total shift across the transmit antenna array should be limited to 50ns.

In the 40MHz mode, the L-STF in the lower sub-channel is identical to legacy, whereas the L-STF in the upper sub-channel is a 90 degree phase rotation of the legacy STF. This rotation is performed to keep the PAPR of the STF low (see Figure 48 and Figure 49)

Since a legacy OFDM RX is not expected to "understand" any transmission after the L-SIG, the RATE and LENGTH fields in the L-SIG are "spoofed" such that a legacy OFDM RX can defer for the correct period of time.

The HT-SIG contains information needed to correctly de-map and decode the HT data field (i.e. the MIMO-OFDM symbols). It also contains fields for supporting advanced techniques that are described next.

Since the L-STF does not provide a sufficiently accurate power measurement for MIMO AGC purposes, a HT-STF has been introduced after the HT-SIG. The HT-STF is tone-interleaved symbol across the transmit antenna array. The HT short training symbol uses 24 tones (L-STF uses 12 tones in a 20 MHz channel). The choice of 24 tones permits accurate AGC measurements across 4 transmit antennas. In the 40 MHz channel, 48 tones are used in the HT-STF. The 24 (48) tones are interleaved across the antennas, i.e., 6 (12) tones are used per antenna if there are 4 transmitter antennas, and likewise 12 (24) are used per antenna if there are 2 transmitter antennas. The length of the HT-STS is 1.6µs. Since, the purpose of HT-STF is purely for AGC purposes, only one STS is needed. Together with the 0.8µs guard interval, the total length of the HT-STF is 2.4µs. The GI of the HT-STF, i.e. the first 0.8us, would contain echoes from the previous symbol. Hence, a clean measurement of power is made in the 1.6us portion of the HT-STF. It is anticipated that the RF transient settling after the AGC switch would occur in the GI of the HT-LTF that follows the HT-STF.

After the AGC has been "fine-tuned" for HT reception, channel estimation and fine frequency offset estimation are performed using the HT Long Training Symbols. The number of HT-LTFs is equal to the number of antennas in the basic MIMO mode. For example, with two transmit antennas, two HT-LTFs are sent. The HT-LTF is also tone interleaved to minimize the power fluctuation with respect to the AGC setting (obtained via the HT-STF). Therefore, one HT-LTF would cover half of the tones in the two antenna case. Remaining tones are covered in the second HT-LTF. The HT-LTF consists of two Long Training Symbols (LTS) as in 802.11a/g and a regular guard interval of 0.8 µs. The total length of one HT-LTF is 7.2µs.

#### 11.1.1.5 Duplicate 6Mbps mode

The lowest data rate in the 40MHz mode would be 13.5Mbps (= 6Mbps x 2.25), if independent information bits are mapped to the upper and lower sub-channels. A 6Mbps mode in 40MHz is obtained by duplicating the data from the lower sub-channel to the upper sub-channel. For the 6Mbps mode in 40MHz, the MPDU is encoded, punctured, interleaved, and constellation-mapped as a 6Mbps transmission in 20MHz. The duplication is performed just prior to the iFFT sub-carrier mapping, as shown in Figure 51.

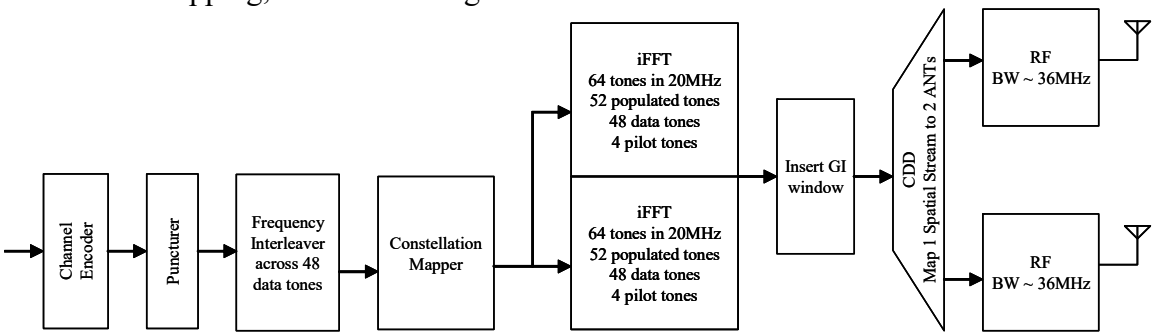


**Figure 51: Transmitter configuration for 6Mbps in 40MHz[14]**

Since the 6Mbps duplicate mode comprises of 1 spatial stream, only 1 HT-LTF is needed. Also note that there is no tone-fill past the HT-SIG, unlike the regular 40MHz PPDU format show in Figure 49. The PPDU format for the 6Mbps duplicate mode is shown in Figure 52:

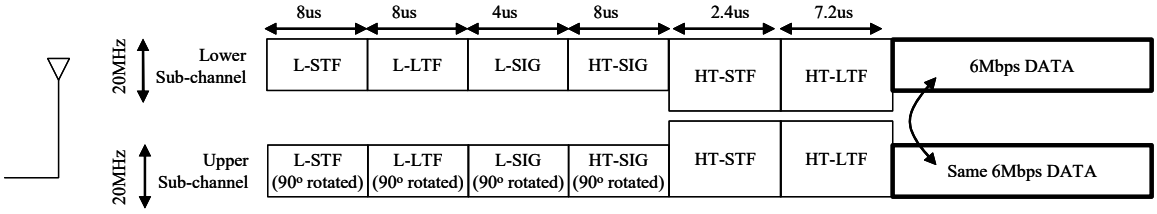



**Figure 52: PPDU format for 6Mbps duplicate mode**

Pilot locations in the duplicate mode follow the pilot locations in the 20MHz mode. The duplicate 6Mbps mode (in 40MHz) is signaled as mode 32 in the MCS set (see Table 26).

### 11.1.1.6 Support for Advanced Techniques

All advanced techniques are optional in our proposal.

In our basic mandatory 20/40MHz MIMO mode, the number of data streams created by the spatial parser in Figure 45 is the same as the number of transmit antennas. And, in this basic configuration, each spatial stream is mapped to exactly one transmit antenna.

If Channel State Information (CSI) is available at the transmitter, we can perform spatial "shaping" using a steering matrix for each sub-carrier, as shown in Figure 53. In SVD style MIMO, the steering matrix is obtained via singular value decomposition (SVD) of the physical channel transfer function matrix, *H*. In SVD-MIMO, each spatial stream is "transmitted" on a "singular vector" obtained from the SVD of *H*. We can further perform spatial water-filling by selecting an optimum power level, modulation level, and coding rate for each spatial stream.

Our proposal introduces two classes of transmit beamforming: basic beamforming with MIMO (BF-MIMO), and advanced beamforming with MIMO (ABF-MIMO). In basic transmit beamforming, only spatial steering is performed. Support for basic beamforming is mandatory in a receiver since there is minimal implemenation overhead. In advanced beamforming, each spatial stream may have a unique MCS and a unique power level. We also support bi-directional beamforming in the ABF-MIMO mode.

[14] 40MHz operation by an HT device shall only be permitted in those regulatory domain that allow it.

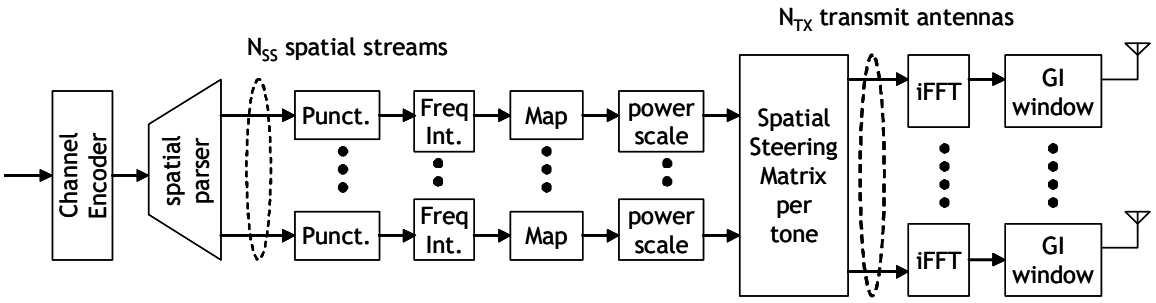



**Figure 53: Transmitter Datapath with option to perform spatial shaping**

We have also introduced an advanced coding option, i.e. LDPC coding. The use of LDPC coding is signaled in the HT-SIG.

### 11.1.1.7 Feedback Mechanisms

Our proposal consists of several feedback mechanisms, supported at the MAC layer, as shown in Table 21.

| Nature of Feedback | Device Requirement | Type of Feedback | Description |
|---|---|---|---|
| Implicit Feedback | Mandatory in device | Binary Response packet | • This only provides information to the TX whether its choice of the modulation-coding mode was supported by the channel.<br>• Does not provide any information to help perform spatial shaping<br>• Used when transmitting to legacy devices |
| Implicit Feedback | Optional | Binary Response packet sent as a sounding packet | • Allows the Initiator to estimate the physical channel in the reverse link. If reciprocity can be assumed, and if the number of TX and RX antennas are identical at the recipient, the TX can use the derived CSI to perform spatial shaping (e.g. in the style of ABF-MIMO) |
| Explicit Feedback | Mandatory | RR (Rate Recommendation) Response packet | • The response packet contains a rate recommendation to the TX<br>• Since spatial shaping at the initiator is not desired, HT-LTFs are not appended |
| Explicit Feedback | Mandatory | RR Response packet sent as a sounding packet | • The response packet contains a rate recommendation to the TX<br>• Response packet does not contain forward link Channel State Information (CSIT)<br>• However, the sounding packet allows reverse link channel estimation. And, assuming reciprocity and equal number of TX RX antennas at the recipient, the initiator can perform spatial shaping. |

**Table 21: Feedback Mechanisms**

### 11.1.1.8 Comparison among MIMO transmission modes

Our proposal supports three classes of MIMO Transmissions Modes, as outlined in Table 22:

| MIMO Modes | Characteristic | Extent of TX adaptation |
|---|---|---|
| Basic-MIMO (Mandatory) | • Typically, $N_{SS} = N_{TX}$<br>• Each spatial stream is mapped to one antenna | • No adaptation is performed in the spatial domain<br>• MCS selection (adaptation) is based upon either: (1) binary feedback (i.e. ACK/noACK), or (2) recommendation from the RX, or (3) availability of CSI at the TX<br>• All spatial streams shall use the same MCS and transmit at same power |
| Basic-MIMO with TX Beamforming (Optional) | • Typically, $N_{SS} \leq N_{TX}$<br>• All spatial streams are spatially shaped via a steering matrix<br>• The steering matrix is defined for each tone in the OFDM modulation<br>• All spatial streams have identical MCS and power levels | • CSI is required at the TX<br>• Sounding packet from the recipient to the initiator is required to estimate the CSI at the transmitter<br>• RF calibration is required since reciprocity is used to perform TX beamforming |
| Advanced MIMO with TX Beamforming (Optional) | • Typically, $N_{SS} \leq N_{TX}$<br>• All spatial streams are spatially shaped via a steering matrix<br>• The steering matrix is defined for each tone in the OFDM modulation<br>• Power levels for each spatial stream do not have to be identical<br>• MCS for each spatial stream does not have to be identical<br>• Bi-Directional Advanced Beamforming MIMO is supported via UD decomposition | • CSI is required at the TX<br>• Sounding packet from the recipient to the initiator is required to estimate the CSI at the transmitter<br>• RF calibration is required since reciprocity is used to perform TX beamforming |

**Table 22: MIMO Transmission options**

### 11.1.1.9 "Modulation-Coding Scheme" (MCS) set for basic MIMO mode

Our proposal augments the 802.11a MCS set through the use of multiple spatial streams and bandwidth extension. The complete set is shown in Table 26. Our proposal recommends a mandatory data of 243Mbps using two spatial streams in regulatory domains that permit 40MHz operation. And, with an eye towards the future, our proposal supports scalability to 4 spatial streams, offering data rates in excess of 600Mbps.

### 11.1.2 Timing related parameters

| Parameter | Value for 20 MHz Channel | Value for 40 MHz Channel |
|---|---|---|
| $N_{SD}$ : Number of data subcarriers | 48 | 108 |
| $N_{SP}$ : Number of pilot subcarriers | 4 | 6 |
| $N_{SN}$ : Number of center null subcarriers | 1 (tone = 0) | 3 (tones = -1,0,+1) |
| $N_{SR}$ : Subcarrier range (index range) | 26 (-26 … +26) | 58 (-58 … +58) |
| $\Delta_F$ : Subcarrier frequency spacing | 0.3125 MHz (= 20 MHz / 64) | 0.3125 MHz (= 40 MHz / 128) |
| $T_{FFT}$ : IFFT/FFT period | 3.2 μsec | 3.2 μsec |
| $T_{GI}$ : GI duration | 0.8μsec | 0.8μsec |
| $T_{ShortGI}$ : Short GI duration | 0.4μsec | 0.4μsec |
| $T_{GI2}$ : Legacy LongTraining symbol GI duration | 1.6μsec | 1.6μsec |
| $T_{SYM}$ : Symbol interval | 4μsec | 4μsec |
| $T_{LONG}$ : Long training field duration | 8μsec | 8μsec |
| $T_{HT-LONG}$ :HT Long training field duration | 7.2μsec | 7.2μsec |
| $T_{SHORT}$ : Short training field duration | 8μsec | 8μsec |
| $T_{HT-SHORT}$ : HT Short training field duration | 2.4μsec | 2.4μsec |
| $T_S$ : Nyquist sampling interval | 50nsec | 25nsec |

**Table 23: Timing Related Parameters**

### 11.1.3 Mathematical conventions in signal descriptions

The transmitted signals will be described using the complex baseband signal notation. The transmitted signal at RF, $r_{RF}(t)$, is related to the complex baseband signal by the following relationship:

$$r_{RF}(t) = \mathrm{Re}\left\{ r(t)\exp\left(j2\pi f_c t\right)\right\} \quad (1)$$

where

$\mathrm{Re}\{\cdot\}$ represents the real part of a complex variable;

$f_c$ denotes the center frequency of the carrier.

The transmitted baseband signal consists of several subframes. The timing boundaries for the various subframes are shown in Figure 54:

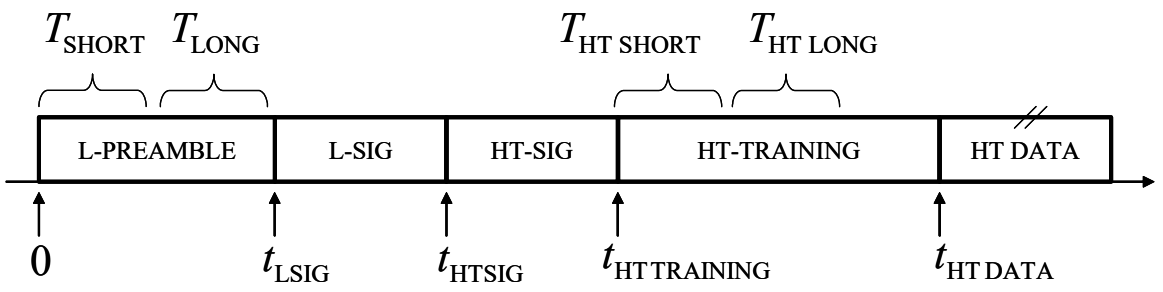



**Figure 54: Timing boundaries for subframes in a HT transmission**

The signal transmitted on antenna $i_{Tx}$ is given by:

$$\begin{aligned} r_{PACKET}^{(i_{Tx})}(t) \;=\; & r_{PREAMBLE}^{(i_{Tx})}(t) + r_{LSIG}^{(i_{Tx})}(t - t_{LSIG}) \\ & + r_{HTSIG}^{(i_{Tx})}(t - t_{HTSIG}) \\ & + r_{HT\ TRAINING}^{(i_{Tx})}(t - t_{HT\ TRAINING}) \\ & + r_{HT\ DATA}^{(i_{Tx})}(t - t_{HT\ DATA}) \end{aligned} \qquad (2)$$

The subframes of (2) are described in 11.2.1.3.1, 11.2.1.3.2, 11.2.1.4.1, 11.2.1.4.2 and 11.2.1.5. The time offsets $t_{SUBFRAME}$ determines the starting time of the corresponding subframe. Per convention, it is assumed that the signal in equation (2) is causal, i.e. signal value is zero when its argument is zero.

All subframes of the signal are constructed using an inverse Fourier transform:

$$r_{SUBFRAME}^{(i_{Tx})}(t) \;=\; w_{SUBFRAME}(t) \sum_{k=-N_{SR}}^{N_{SR}} C_k \exp\left(j2\pi k \Delta_F t\right) \qquad (3)$$

The PHY related parameters are listed in Table 23.

# 11.2 PLCP sublayer

## 11.2.1 Basic MIMO Mode

As described in Table 22, the basic MIMO mode does not involve any spatial steering. The basic MIMO mode can operate in both 20MHz and 40MHz channel bandwidths.

### 11.2.1.1 Basic MIMO PPDU format

The HT Physical layer defines a PPDU format that provides interoperability and coexistence with 802.11a stations and with ERP-OFDM stations of 802.11g at the link level without protection mechanisms. Figure 55 shows the PPDU format for the basic MIMO mode:

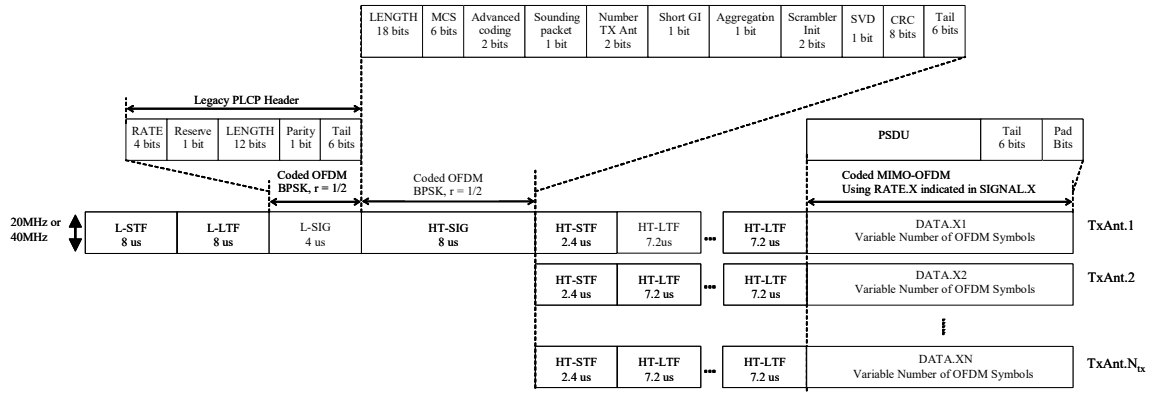



**Figure 55: PPDU Format for $N_{TX}$ antennas**

L-STF is the Legacy Short Training Field. Details of the L-STF symbols can be found in clause 11.2.1.3.1. The HT-STF is specific for HT. Details can be found in 11.2.1.3.3

L-LTF stands for Legacy Long Training Field. Details of the L-LTF symbols can be found in clause 11.2.1.3.2**.** The HT-LTFs are specific for HT and the details can be found in clause 11.2.1.3.4

L-SIG is based on the Legacy SIGNAL field as defined in clause 17.3.4 in [1]. The modulation and coding procedure also follows the steps of 17.3.4 in [1]. The RATE and LENGTH fields in L-SIG are defined in accordance with "spoofing" procedures described in 11.2.1.4.1.

The HT-SIG field is the signal field dedicated to the HT mode. The structure of this field is the same as the L-SIG. Since our proposal supports interoperability between HT devices and legacy OFDM devices at the PHY layer, a HT receiver will not a-priori know whether a legacy packet is being received or a HT packet. That determination can only be made after the L-SIG. Our proposal supports two mechanisms for signaling a HT transmission: (a) send the HT-SIG as a BPSK signal on the quadrature axis, instead of on the in-phase axis, and (b) invert the polarity of the pilots in the HT-SIG with respect to the pilots in the L-SIG. These two mechanism allow an auto-detect of a HT transmission. Note that the pilots in the HT-SIG are not transmitted on the Quadrature axis. The definition of the contents of HT-SIG is specified in 11.2.1.4.2.

The L-STF, L-LTF, L-SIG, and HT-SIG should be transmitted from the antenna array such that an omni-directional beam pattern is created in the far field. This reduces the probability of creating hidden nodes in the BSS. One way to create an omni-beam is to transmit these fields from strictly one antenna. However, if the transmitter is power-amplifier limited, array gain can be derived by transmitting on multiple antennas. Since transmitting the same signal from multiple antennas invariably creates beamforming, one way to mitigate beamforming is to phase shift (i.e. time delay) the signal across the transmit antenna array. For an OFDM symbol, the delay can be introduced cyclically. Since delaying the same signal introduces frequency selectivity at the receiver, such a transmission is commonly referred to as "cyclical delay diversity" or CDD. This transmission format is shown in Figure 56:

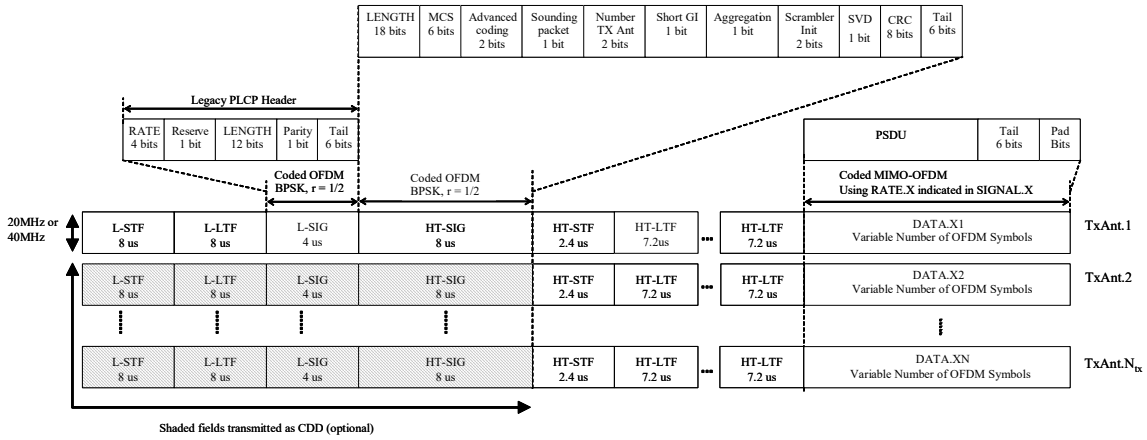



**Figure 56: PPDU format leveraging CDD transmission**

### 11.2.1.2 Legacy Protection

All MIMO transmissions (whether basic or advanced) are protected against legacy OFDM devices at the physical layer, and protected against legacy CCK/DSSS devices at the MAC layer. The legacy short training field, the legacy long training field and the legacy signal field are transmitted such that a legacy OFDM receiver (802.11g or 802.11a) is able to "understand" these fields. In the basic MIMO mode, the transmitter selects the Modulation Coding Scheme either based on conventional rate selection heuristics or via implicit or explicit feedback. Thus, the RATE and LENGTH fields in the legacy signal field can be "spoofed" to allow the legacy OFDM receivers to correctly set their NAV.

RTS/CTS or CTS-to-self mechanism may be used to protect against legacy CCK/DSSS devices in an 802.11n BSS.

### 11.2.1.3 Training symbols specification

The training fields are used for synchronization purposes. As shown in Figure 55 and Figure 56, at the start of a packet, a legacy short training field is transmitted .The legacy short training field (L-STF) contains ten identical short training symbols. The legacy short training field may be transmitted from a single antenna, or from multiple antennas using CDD (refer to the next section).The legacy long training field follows the legacy short training field. Mapping of the legacy long training field (L-LTF), the L-SIG and the HT-SIG to the antenna array shall be identical to that of the legacy short training field (L-STF). After the HT-SIG, a HT-STF is transmitted across all the antennas to "fine tune" the AGC for MIMO reception. The HT-LTFs subsequently follow the HT-STF. The number of HT LTFs is equal to the number of spatial streams (which equals the number of transmit antennas in the basic MIMO mode). Data transmission follows the HT-LTFs.

#### 11.2.1.3.1 Legacy Short Training Field

The legacy short training symbol in our proposal is identical to the 802.11a short training symbol. The legacy short training OFDM symbol in the 20MHz mode is:

$$S_{-26,26} = \sqrt{13/6}\{0,0,1+j,0,0,0,-1-j,0,0,0,1+j,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,$$
$$0,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0\}. \quad (4)$$

The normalization factor accounts for the fact that 12 tones out of 52 are used in the STF, and also because QPSK is used as the constellation on the 12 tones.
The legacy short training OFDM symbol in 40MHz mode is:

$$\begin{aligned} S_{-58,58} = \sqrt{13/6}\{&0,0,1+j,0,0,0,-1-j,0,0,0,1+j,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,\\ &0,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,0,0,\\ &0,0,0,0,0,0,0,0,0,0,0,j-1,0,0,0,-j+1,0,0,0,j-1,0,0,0,-j+1,0,0,0,-j+1,0,0,0,j-1,\\ &0,0,0,0,0,0,0,-j+1,0,0,0,-j+1,0,0,0,j-1,0,0,0,j-1,0,0,0,j-1,0,0,0,j-1,0,0\} \end{aligned} \quad (5)$$

The tones in the upper subchannel (see Figure 48) are obtained by phase rotating the 802.11a short OFDM training symbol tones by 90 degrees, whereas the tones in the lower subchannel are identical to the 802.11a short training OFDM symbol tones. The 90º rotation helps keep the PAPR of the STF in 40MHz comparable to that in 20MHz. A scaling factor of $\sqrt{13/6}$ ensures that the legacy short training symbols have the same power as the L-LTF, L-SIG, and HT-SIG fields, all of which have 104 tones in 40MHz. There are 24 tones in the L-STF (with QPSK constellation) in 40MHz.

Let $N_{TX}$ be the total number of transmit antennas. We normalize the transmit power across $N_{TX}$ transmit antennas to be $N_{TX}$.

The short training symbols can be mapped to the transmit antenna array in several ways. L-STF should be transmitted omni-directionally to avoid beamforming, else hidden nodes can be potentially created in the BSS. One simple way is to transmit the L-STF on just one antenna. The L-STF is then described as follows:

$$r_{SHORT}^{(i_{TX})}(t) = \left\{ \begin{array}{ll} \sqrt{N_{TX}}\, w_{T\,SHORT}(t) \sum_{k=-N_{SR}}^{N_{SR}} S_k \exp\{j2\pi k\Delta_F t\} & i_{Tx}=1 \\ 0 & otherwise \end{array} \right\} \quad (6)$$

Since the legacy short training field (L-STF) constitutes a single spatial stream, it is also possible to map L-STF to multiple transmit antennas. This may be particularly useful if the transmit power is limited by the power amplifier characteristics. However, mapping 1 spatial stream to multiple transmit antennas would invariably result in beamforming, which can be mitigated by introducing a linear phase shift across the transmit antenna array. In the case of OFDM, the delay is introduced cyclically, and is commonly knows as Cyclical Delay Diversity (CDD). When the STF is transmitted in a CDD fashion, the short training signal at the $i_{TX}$ th transmit antenna is generated according to the following rule:

$$r_{SHORT}^{(i_{TX})}(t) = w_{TSHORT}(t) \sum_{k=-N_{SR}}^{N_{SR}} S_k \exp\left\{j2\pi k\Delta_F \left(t-(i_{TX}-1)T_{shift}\right)\right\} \quad (7)$$

The short training signal is repeated every 0.8μs. The entire short training field includes ten such periods, with a total duration of 8μs. The short training field at the $i_{TX}$ th transmit antenna is cyclically shifted by $(i_{TX}-1)T_{shift}$, where $T_{shift}$ is defined such that $(N_{TX}-1)\cdot T_{shift} = 50ns$ for both 20MHz and 40MHz. For example, with 4 transmit antennas, $T_{shift} = 16.67ns$

#### 11.2.1.3.2 Legacy Long Training Field

The legacy long training OFDM symbol is identical to the 802.11a long training OFDM symbol. In the 20MHz mode, the long training OFDM symbol is given by

$$L_{-26,26} = \{1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,0,$$
$$1,-1,-1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,1,-1,-1,1,-1,1,-1,1,1,1,1\} \quad (8)$$

Similar to the L-STF, the legacy long training field (L-LTF) can be mapped to either a single antenna, or to multiple antennas via CDD. However, to guarantee AGC accuracy, the antenna mapping for the L-LTF should be identical to that of the L-STF. If only one antenna is used to transmit the legacy long training field, then the long training signal is given by:

$$r_{LONG}^{(iTX)}(t) = \begin{cases} \sqrt{N_{TX}}\, w_{T\,LONG}(t) \sum_{k=-N_{SR}}^{N_{SR}} L_k \exp\left(j2\pi k \Delta_F \left(t - T_{G12}\right)\right) & i_{Tx} = 1 \\ 0 & otherwise \end{cases} \quad (9)$$

where $T_{G12} = 1.6\mu s$.

If the long training signal is generated in a CDD fashion, we get:

$$r_{LONG}(t) = w_{T\,LONG}(t) \sum_{k=-N_{SR}}^{N_{SR}} L_k \exp\left\{j2\pi k \Delta_F \left(t - \left(i_{TX} - 1\right) T_{Shift} - T_{G12}\right)\right\} \quad (10)$$

There are two legacy long training symbols in the legacy long training field. This is to ensure channel estimation accuracy, and also to permit fine frequency offset estimation. The total duration of the long training field (L-LTF) is $T_{LONG} = 1.6 + 2 \times 3.2 = 8\mu s$.
The legacy long training OFDM signal in the 40MHz mode is given by:

$$L_{-58,58} = \{1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,0,$$
$$1,-1,-1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,1,-1,-1,1,-1,1,-1,1,1,1,1,1,0,0,0,0,0,0$$
$$0,0,0,0,0,0,0,j,j,-j,-j,j,j,-j,j,-j,j,j,j,j,j,j,-j,-j,j,j,-j,j,-j,j,j,j,j,0,$$
$$j,-j,-j,j,j,-j,j,-j,j,-j,-j,-j,-j,-j,j,j,-j,-j,j,-j,j,-j,j,-j,j,j,j\} \quad (11)$$

Tones in the upper subchannel (subcarriers +6 to +58) are obtained by phase rotating the 802.11a long OFDM training symbol tones by 90 degrees, whereas the tones within the lower subchannel (subcarriers -58 to -6) are identical to the 802.11a long OFDM training symbol tones.
It should be noted that neither the legacy fields (L-STF, L-LTF, LSIG) nor the HT-SIG undergo any phase rotation in the lower subchannel.

The subcarriers at ±32 in 40MHz, which are the DC subcarriers for the legacy 20MHz transmission, are both nulled in the L-LTF. Such an arrangement allows proper synchronization of the 20MHz legacy device.

The legacy long training field together with the short training field constitutes the legacy PLCP preamble. The legacy device can perform the necessary synchronization to decode the legacy signal field. Hence, we can write $r_{PREAMBLE}(t)$ in (2) as

$$r_{PREAMBLE}^{(iTX)}(t) = r_{SHORT}^{(iTX)}(t) + r_{LONG}^{(iTX)}(t - T_{SHORT}) \quad (12)$$

### 11.2.1.3.3 HT-Short Training Field

The HT-STF follows the HT signal field (see Figure 55), whose only purpose it to "fine tune" the AGC for HT MIMO reception. Note that the first AGC operation is performed on the L-STF. The HT short training symbol in the 20MHz mode is

$$HTS_{-26,26} = \sqrt{13/12}\begin{cases} \{0, 0, 1+j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, \\ 0, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 0\} & N_{Tx}=1 \\ \{0, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, \\ 0, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, \} & N_{Tx}=2 \\ \{0, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, \\ 0, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, 0\} & N_{Tx}=3 \\ \{0, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, \\ 0, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 0\} & N_{Tx}=4 \end{cases} \quad (13)$$

Unlike the legacy short training symbol which uses 12 tones, the HT-Short training Symbol uses 24 tones in 20MHz which are tone-interleaved across the transmit antennas. For example, with $N_{TX}=4$, each antenna would transmit 6 tones, which provide sufficient accuracy for estimating the received power from one transmit-antenna to one receive-antenna.

The HT short training symbol in the 40 MHz mode consists of 48 tones, and is given by:

$$HTS_{-58,58} = \sqrt{19/16}\begin{cases} \{0, 0, 1+j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, \\ 0, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, 0, 0, 0, 0, 0, 0, 0, \\ 0, 0, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, 1+j, 0, \\ 0, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 0\} & N_{Tx}=1 \\ \{0, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, \\ 0, 0, 1+j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, 0, 0, 0, 0, 0, 0, 0, \\ 0, 0, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, 1+j, 0, \\ 0, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 0\} & N_{Tx}=2 \\ \{0, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, \\ 0, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, 0, 0, 0, 0, 0, 0, 0, \\ 0, 0, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, \\ 0, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 0\} & N_{Tx}=3 \\ \{0, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, \\ 0, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, 0, 0, 0, 0, 0, 0, 0, \\ 0, 0, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, \\ 0, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 0\} & N_{Tx}=4 \end{cases} \quad (14)$$

In the duplicate 6Mbps mode in 40MHz, the HT-STF shown in (14) is used, except for a scaling factor change. The scaling factor for the 6Mbps duplicate mode is $\sqrt{13/12}$.

The HT short training signal is then generated by the following rule.

$$r^{(i_{Tx})}_{MIMOSHORT}(t) = w_{TMIMOSHORT}(t)\sqrt{N_{TX}}\sum_{m}\sum_{k=0}^{\left\lfloor \frac{11}{N_{TX}} \right\rfloor} MS_{2N_{TX}k+2(i_{Tx}-1)+m}\exp\{j2\pi(2N_{TX}k+2(i_{Tx}-1)+m)\Delta_F(t-T_{GI})\} \quad (15)$$

where $T_{GI} = 0.8\mu s$. The elements of $m$ are $m \in \{-24, 2\}$ for 20MHz and $m \in \{-54, -30, 8, 34\}$ for 40MHz, respectively. The HT short training signal has a period of 1.6μs – corresponding to 24 tones in 20MHz, and 48 tones in 40MHz – which is deemed sufficient for power measurement purposes. Since the HT-STF is tone-interleaved at the transmitter, the power periodicity of the HT-STF is also $1.6\mu s$.

#### 11.2.1.3.4 HT-Long Training Field

The HT long training fields are transmitted after the HT-STF. The number of HT long training fields is equal to the number of spatial streams. In the basic MIMO mode, the number of spatial streams is equal to the number of transmit antennas.

To minimize the power fluctuation between the HT-LTF and the AGC setting (which is derived from the HT-STF), the HT long training symbols are also tone-interleaved across the transmit antenna array. Since each antenna only transmits a sub-set of the tones, the HT long training sequences have been optimized to achieve the lowest peak-to-average power ratio (PAPR). There are a total of 9 sequences:

**Table 24: List of HT Long Training Fields**

| Sequence Number | $N_{TX}$ | BW | *Comment* |
|---|---|---|---|
| 1 | 1 | 20MHz | *Same as 802.11a* |
| 2 | 2 | 20MHz | *52 tones* |
| 3 | 3 | 20MHz | *52 tones* |
| 4 | 4 | 20MHz | *52 tones* |
| 5 | 1 | 40MHz | *Duplicate format, 6Mbps in 40MHz (104 Tones)* |
| 6 | 1 | 40MHz | *114 tones* |
| 7 | 2 | 40MHz | *114 tones* |
| 8 | 3 | 40MHz | *114 tones* |
| 9 | 4 | 40MHz | *114 tones* |

In 20MHz, for $N_{TX} = 1$, sequence 1 is identical to the 802.11a LT sequence, as shown in (8). In 20MHz, for $N_{TX} = 2$, sequence 2 is:

$$HTL_{-26,+26} = \{-1, 1, -1, 1, 1, 1, -1, -1, -1, -1, 1, 1, 1, 1, -1, 1, -1, 1, -1, -1, 1, 1, 1, -1, 1, 1, 0, -1, 1, 1, -1, -1, 1, -1, -1, 1, -1, -1, 1, -1, -1, 1, 1, 1, 1, -1, 1, 1, 1, 1, 1, 1\} \quad (16)$$

The tone-interleaving rule across the two antennas in 20MHz is grouped into 2 sets:

$$set\_1 = [-26:2:-2], [+2:2:+26]$$
$$set\_2 = [-25:2:-1], [+1:2:+25] \quad (17)$$

where the notation in the brackets should be read as [starting index : step value : ending index].

In 20MHz, for $N_{TX} = 3$, sequence 3 is:

$$HTL_{-26,+26} = \{\text{-1 -1 1 1 1 1 1 -1 -1 -1 1 -1 -1 -1 -1 -1 1 1 1 1 1 1 1 1 -1 -1 1}$$
$$\text{0 1 -1 -1 -1 1 -1 1 -1 1 -1 1 1 -1 1 -1 -1 1 1 -1 1 1 -1 1 -1 -1 1}\} \quad (18)$$

The tone-interleaving rule across three antennas in 20MHz is grouped into 3 sets:

$$set\_1 = [-26:3:-2], [2:3:26]$$
$$set\_2 = [-25:3:-1], [3:3:24] \quad (19)$$
$$set\_3 = [-24:3:-3], [1:3:25]$$

In 20MHz, for $N_{TX} = 4$, sequence 4 is:

$$HTL_{-26,+26} = \{\text{-1 1 1 1 1 -1 -1 -1 1 -1 1 1 1 -1 1 1 -1 1 -1 -1 -1 1 1 1 -1 1}$$
$$\text{0 1 1 -1 1 -1 -1 1 -1 -1 -1 -1 1 -1 -1 -1 1 1 1 1 -1 1 1 -1 1 1 1}\} \quad (20)$$

The tone-interleaving rule across four antennas in 20MHz is grouped into 4 sets:

$$set\_1 = [-26:4:-2], [3:4:23]$$
$$set\_2 = [-25:4:-1], [4:4:24]$$
$$set\_3 = [-24:4:-4], [1:4:25] \quad (21)$$
$$set\_4 = [-23:4:-3], [2:4:26]$$

In the 40MHz mode, the subcarriers at ±32 are populated in the HT long training OFDM symbol. In 40MHz, for $N_{TX} = 1$, sequence 5 is identical to sequence 6. Sequence 5 is used in the duplicate 6Mbps mode, whereby only 104 tones are needed, whereas sequence 6 corresponds to the 114 tones. Note that all 114 tones are transmitted in the 6Mbps duplicate mode.

$$HTL_{-58,+58} = \{\text{-1 1 1 1 1 -1 1 1 -1 -1 -1 -1 1 1 1 1 1 -1 1 1 -1 1 -1 1 1 -1 -1}$$
$$\text{1 1 -1 -1 1 1 -1 -1 -1 -1 -1 1 -1 1 1 -1 -1 -1 1 -1 -1 1 -1 -1 1 1 -1 1 1 1}$$
$$\text{0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 1 1 1 -1 1 -1 1 1 -1 -1 1-1 -1 1 -1 1}$$
$$\text{-1 1 -1 -1 -1 -1 1 1 -1 1 -1 -1 -1 1 -1 1 -1 1 -1 1 1 -1 1 -1 -1 1 -1 1 1 1}\} \quad (22)$$

In 40MHz, for $N_{TX} = 2$, sequence 7 is:

$$HTL_{-58,+58} = \{\text{-1 1 1 1 1 -1 1 1 -1 -1 -1 -1 1 1 -1 1 1 -1 1 1 -1 1 -1 1 1 -1}$$
$$\text{-1 1 1 -1 -1 -1 1 1 -1 -1 -1 1 -1 1 -1 1 1 1 -1 -1 1 -1 -1 -1 -1 -1 -1 1 -1 1 -1 1}$$
$$\text{0 0 0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 1 1 1 -1 1 -1 1 1 -1 -1 1 -1 1 1 1 -1 1 -1}$$
$$\text{1 -1 -1 -1 -1 1 1 -1 1 -1 -1 -1 -1 -1 1 -1 1 1 1 1 -1 1 1 -1 1 -1 1 1 1}\} \quad (23)$$

The tone-interleaving rule across two antennas in 40MHz is grouped into 2 sets:

$$set\_1 = [-58:2:2], [2:2:58]$$
$$set\_2 = [-57:2:-3], [3:2:57] \quad (24)$$

The tone-interleaving pattern in space and time for the HT long training fields is shown in Figure 57 for 2 antennas (2 spatial streams):

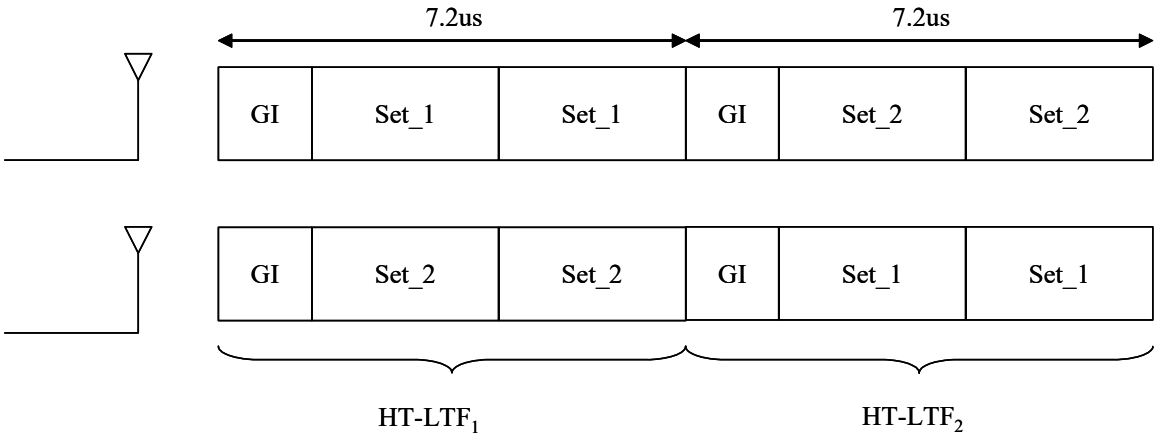



**Figure 57: HT-LTF pattern for 2 antennas (2 spatial streams)**

In 40MHz, for $N_{TX} = 3$, sequence 8 is:

$$HTL_{-58,+58} = \{-1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1$$
$$1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 0 \quad (25)$$
$$0\ 0\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1$$
$$-1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\}$$

The tone-interleaving rule across 3 antennas in 40MHz is grouped into 3 sets:

$$set\_1 = [-58:3:-4], [2:3:56]$$
$$set\_2 = [-57:3:-3], [3:3:57] \quad (26)$$
$$set\_3 = [-56:3:-2], [4:3:58]$$

The tone-interleaving pattern in space and time for the HT long training fields is shown in Figure 58 for 3 antennas (3 spatial streams):

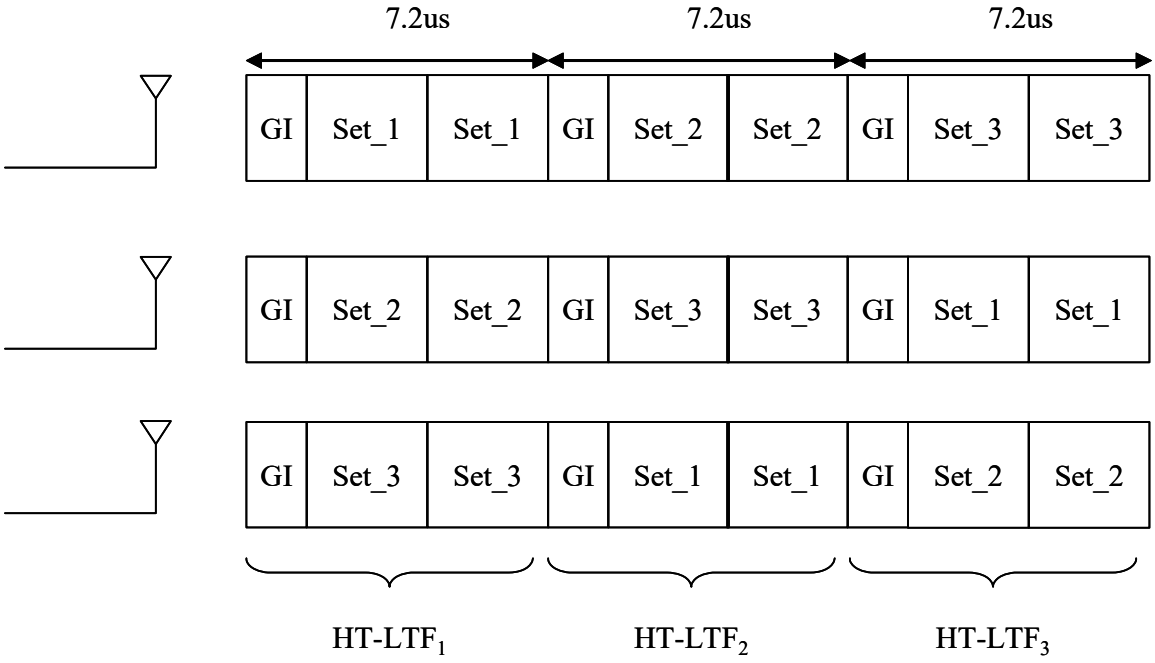



**Figure 58: HT-LTF pattern for 3 antennas (3 spatial streams)**

In 40MHz, for $N_{TX} = 4$, sequence 9 is:

$$\begin{aligned} HTL_{-58,+58} = \{&\text{-1 1 -1 -1 -1 1 1 -1 1 1 1 -1 1 1 1 1 -1 -1 -1 -1 1 -1 -1 -1 1 -1 1 -1} \\ &\text{1 -1 -1 -1 -1 1 1 1 -1 -1 -1 1 1 1 1 -1 1 -1 -1 1 -1 1 1 1 1 1 -1 -1 -1 1 0} \\ &\text{0 0 -1 1 1 -1 -1 -1 -1 -1 1 1 1 -1 1 1 -1 -1 -1 1 -1 1 -1 -1 -1 1 -1 1 -1} \\ &\text{-1 1 1 1 1 1 1 1 -1 -1 -1 -1 1 1 -1 1 1 1 -1 1 1 -1 -1 1 -1 1 -1 -1 1 1}\} \end{aligned} \quad (27)$$

The tone-interleaving rule across 4 antennas in 40MHz is grouped into 4 sets:

$$\begin{aligned} set\_1 &= [-58:4:2], [5:4:57] \\ set\_2 &= [-57:4:-5], [2:4:58] \\ set\_3 &= [-56:4:-4], [3:4:55] \\ set\_4 &= [-55:4:-3], [4:4:56] \end{aligned} \quad (28)$$

The tone-interleaving pattern in space and time for the HT long training fields is shown in Figure 59 for 4 antennas (4 spatial streams):

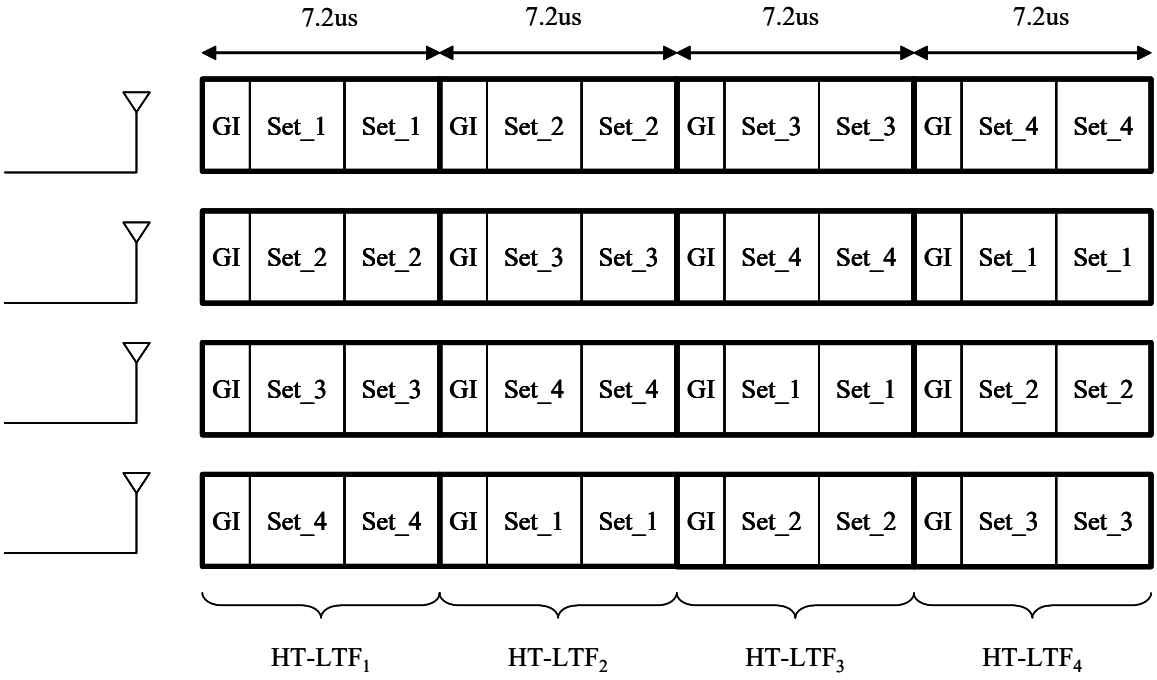



**Figure 59: HT-LTF pattern for 4 antennas (4 spatial streams)**

The HT long training signal is generated similarly to the HT short training signal.

$$r_{HT\,LONG}^{(i_{Tx})}(t) = w_{T\,HT\,LONG}(t)\sqrt{N_{TX}} \sum_{k\in set\_(1+[(i_{TX}-1)+(n-1)]\bmod N_{TX})} HTL_k \exp\left\{j2\pi k\Delta_F\left(t - T_{GI} - (n-1)T_{HT\,LONG}\right)\right\}$$
$$for \quad (n-1)T_{HT\,LONG} \le t < nT_{HT\,LONG} \quad and \quad n = 1,\cdots,N_{TX} \qquad (29)$$
$$for \quad i_{TX} \in \{1,\ldots,N_{TX}\}$$

One HT long training field consists of two such long training symbol plus a regular 0.8μs guard interval. The total length of one long training field is 7.2μs, i.e., $T_{HT\,LONG} = 7.2\mu s$. Since only part of tones are transmitted on each antenna at any given long training symbol, it takes $N_{TX} \cdot T_{HT\,LONG}$ for all the antennas to cover all the tones. The duration of the HT-LTF is $N_{TX} \cdot T_{HT\,LONG}$.

The HT training fields in (2) for purposes of MIMO training can now be expressed as:

$$r_{HT\,TRAINING}^{(i_{Tx})}(t) = r_{HT\,SHORT}^{(i_{Tx})}(t) + r_{HT\,LONG}^{(i_{Tx})}\left(t - T_{HT\,SHORT}\right) \qquad (30)$$

If TX beamforming is performed on 1 spatial stream, i.e. $N_{ss} = 1$, *and* $N_{TX} > 1$, only one HT-LTF is needed after the HT-STF, and this HT-LTF is identical to the 802.11a sequence, as shown in (8). We should point out that the legacy part of the HT preamble is never beamformed, i.e. L-STF, L-HTF, L-SIG, and HT-SIG. And, the HT-STF and the HT-LTF are shaped by the same steering matrix as the HT-DATA, such that channel estimation is independent of the choice of the steering matrix used at the transmitter.

We should point out that the above discussion can be generalized for $N_{SS} \ge 2$ and $N_{TX} > N_{SS}$. This case corresponds to TX beamforming with multiple spatial streams, whereby the number of HT-LTFs is equal to NSS. And, as mentioned above, in addition to tone-interleaving, the HT-LTF also undergoes the same spatial steering as the HT-DATA fields.

#### 11.2.1.4 Signal fields specification

The legacy long training field L-LTF shall be followed by the signal fields LSIG and HTSIG. The coding and modulation follow the steps of clause 17.3.4 in ref[2]: BPSK modulation is used for the L-SIG and HT-SIG, with code rate ½ resulting in 6 Mbit/s. Between the LSIG and the HTSIG symbol, the BPSK modulation shall be rotated counterclockwise by 90 degrees. This phase rotation can be used to "auto-detect" whether the frame being received is legacy or HT. The constellation bit encoding is depicted in Figure 60.

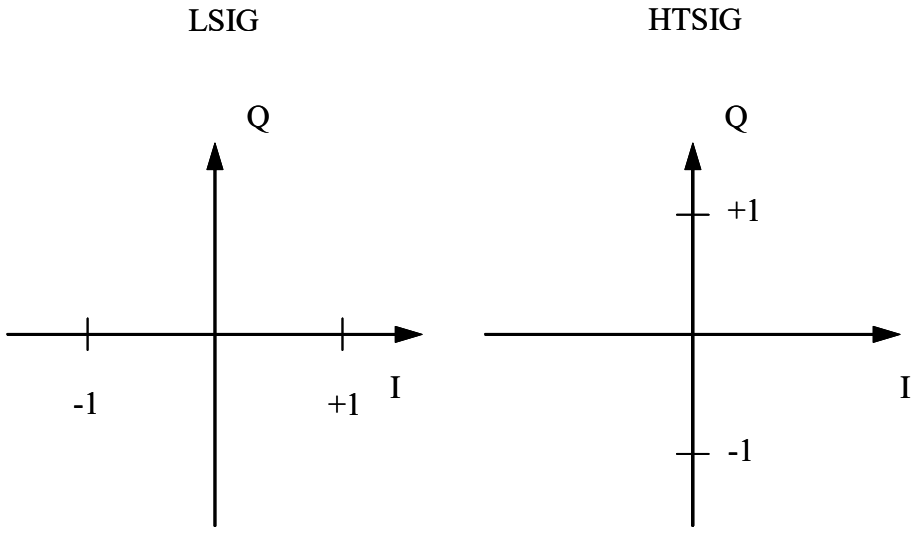



**Figure 60: Constellation specification for LSIG and HTSIG**

##### 11.2.1.4.1 LSIG

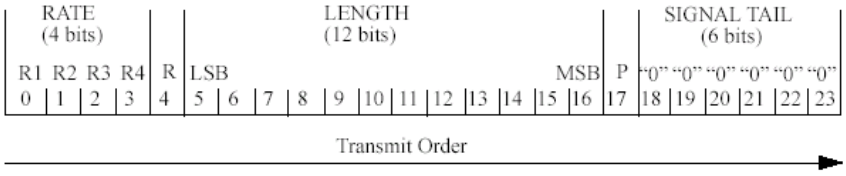



**Figure 61: SIGNAL field bit assignment**

In the 20MHz mode, the format of the LSIG field shall be the same as the SIGNAL field as defined in figure 111 in 17.3.4 in [1]. The combination of RATE and LENGTH is used to signal a station (OFDM mode only) the duration of a HT transmission. This duration does not have to be the actual duration of the HT frame. It can be used to reserve the medium beyond the actual transmission. The reservation of the medium through this kind of signaling is called "spoofing".

To prevent a legacy station from accessing the medium during a HT frame transmission, the "duration" calculated from the RATE and LENGTH fields shall be at least as large as the actual duration of the HT frame, which is measured from the end of the L-SIG field to the end of the DATA field. During an HT transmission, the RATE field is set to 6Mbps, whereas the LENGTH field is set based on the "duration" value.

In the 40MHz mode, the legacy signal field is duplicated such that tones are filled from -58 to -6 (lower-subchannel), and from +6 to +58 (upper-subchannel). The upper subchannel shall be phase rotated by 90 degrees, in the same way as the LTS as described in 11.2.1.3.2

The LSIG shall be transmitted in the same fashion as the legacy short and the legacy long training fields. If L-STF and L-LTF are transmitted from a single antenna, we index that antenna as $i_{Tx} = 1$ to be consistent with 11.2.1.3.2. Denote $LSIG_{-26,26}$ and $LSIG_{-58,58}$ as the LSIG OFDM symbol generated for 20 MHz and 40 MHz respectively. Then, for transmission over a single antenna, we have,

$$r_{LSIG}^{i_{Tx}}(t) = \begin{cases} \sqrt{N_{Tx}}\, w_{SYM}(t) \sum_{k=-N_{SR}}^{N_{SR}} LSIG_k \exp\left\{ j2\pi k \Delta_F \left( t - T_{GI} \right) \right\} & i_{Tx} = 1 \\ 0 & otherwise \end{cases} \quad (31)$$

Similarly, if the legacy training fields are transmitted across multiple transmit antennas using CDD, we have

$$r_{LSIG}^{(i_{Tx})} = w_{SYM}(t) \sum_{k=-N_{SR}}^{N_{SR}} LSIG_k \exp\left\{ j2\pi k \Delta_F \left( t - T_{GI} - \left( i_{Tx} - 1 \right) T_{shift} \right) \right\} \quad (32)$$

#### 11.2.1.4.1.1 Data rate (RATE)

For a legacy station (11a or 11g), RATE has the original meaning as is defined in Table 80 of section 17.3.4.1 in [1]. For reference the table is repeated here:

| Rate (Mbits/s) | R1–R4 |
|---|---|
| 6 | 1101 |
| 9 | 1111 |
| 12 | 0101 |
| 18 | 0111 |
| 24 | 1001 |
| 36 | 1011 |
| 48 | 0001 |
| 54 | 0011 |

**Table 25: Content of the legacy SIGNAL field**

#### 11.2.1.4.1.2 PLCP length field (LENGTH)

The PLCP length field in HT is used to indicate to both legacy and HT stations a protection duration. It contains a value, which when combined with the rate field defines a duration. The number of bytes in the LENGTH field is calculated based on the perceived RATE of a legacy station defined in R1-R4 and the actual number of bytes that the MAC is currently requesting the

PHY to transmit, taking into account the number of transmit antennas (spatial streams), the bandwidth and the extra fields (symbols) in the preamble.

As indicated in 11.2.1.4.1, the calculated duration is allowed to be longer than the actual duration of the HT transmission. However the LENGTH value should be equal to or smaller than 2346 bytes to avoid mis-interpretation by existing legacy devices.

#### 11.2.1.4.2 HTSIG

The LSIG field shall be followed by the HTSIG, which serves as the signal field for the HT PHY. HTSIG consists of two OFDM symbols: HTSIG1 and HTSIG2. HTSIG1 shall be transmitted first in time.

The encoding of HTSIG1 and HTSIG2 shall be the same as LSIG, with the exception that the BPSK modulation is rotated 90 degrees as described in clause 11.2.1.4.

In the 40MHz mode, the HTSIG1 and HTSIG2 are duplicated. The upper sub-channel shall be phase rotated by 90 degrees in the same way as the L-LTF, as described in 11.2.1.3.2 Figure 62 shows the bit assignment for the two symbols. They will be described in the next clauses.

HTSIG1 and HTSIG2 shall be transmitted in a similar fashion as the LSIG. Denote $HTSIG^{1,2}_{-26,26}$ and $HTSIG^{1,2}_{-58,58}$ as the first and second OFDM symbol of the following defined HTSIG as a data field. Then:

$$r^{(i_{Tx})}_{HTSIG}(t) = \begin{cases} \sqrt{N_{Tx}} \sum_{n=1}^{2} \left[ w_{SYM}(t) \sum_{k=-N_{SR}}^{N_{SR}} HTSIG^{n}_{k} \exp\left\{ j2\pi k\Delta_F \left( t - T_{GI} - (n-1)T_{SYM} \right) \right\} \right] & i_{Tx} = 1 \\ 0 & otherwise \end{cases} \quad (33)$$

if the legacy training fields are sent only on the first antenna. And, if CDD is used to transmit the legacy signal fields, then

$$r^{(i_{Tx})}_{HTSIG}(t) = \sum_{n=1}^{2} \left[ w_{SYM}(t) \sum_{k=-N_{SR}}^{N_{SR}} HTSIG^{n}_{k} \exp\left\{ j2\pi k\Delta_F \left( t - T_{GI} - (n-1)T_{SYM} - (i_{Tx}-1)T_{shift} \right) \right\} \right] \quad (34)$$

where $T_{SYM} = 4\mu s$ is the OFDM symbol duration.

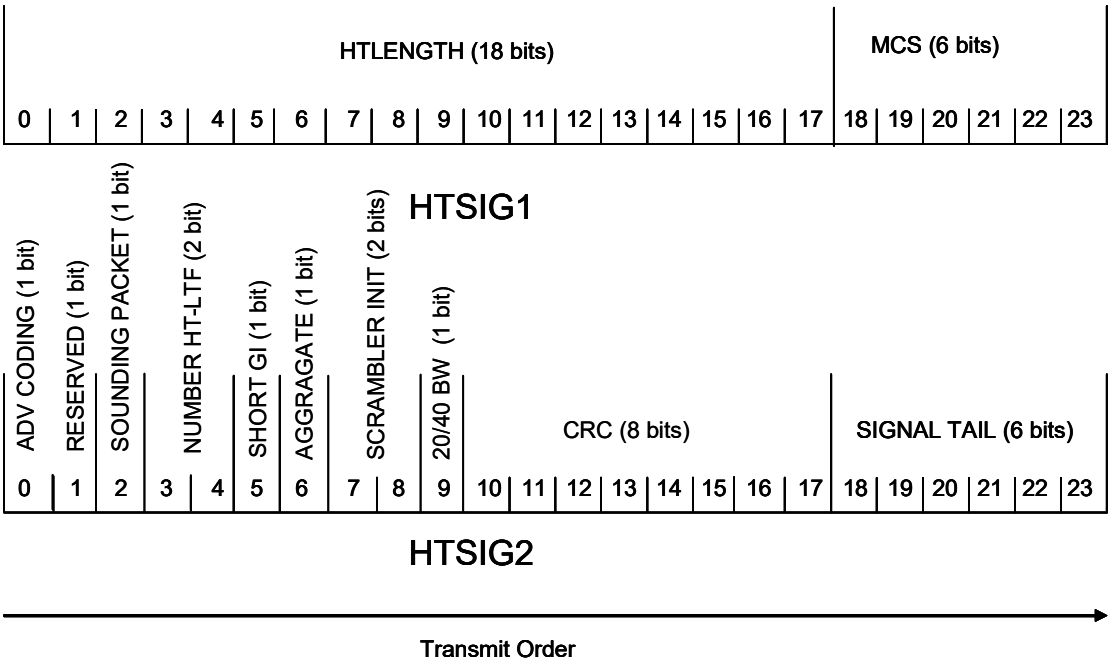



**Figure 62: HT SIGNAL FIELD (HTSIG1 and HTSIG2) bit assignment**

#### 11.2.1.4.2.1 HTLENGTH field

The HTLENGTH field shall be an unsigned 18-bit integer that indicates the number of octets in the PSDU that the MAC is currently requesting the PHY to transmit. This value is used by the PHY to determine the number of octets that will occur between the MAC and the PHY after receiving a request to start transmission.

Bit 0 is the LSB (least significant bit) and shall be transmitted first in time to the channel encoder.

#### 11.2.1.4.2.2 MCS field

The MCS field is a 6-bit field (bit 18-23 of HTSIG1) and defines the modulation and coding scheme, as indicated in Table 26.

| Bits 18-23 in HT-SIG1 (MCS index) | Number of spatial streams | Modulation | Coding rate | GI = 800ns | | GI = 400ns | |
|---|---|---|---|---|---|---|---|
| | | | | Rate in 20MHz | Rate in 40MHz | Rate in 20MHz | Rate in 40MHz |
| 0 | 1 | BPSK | 1/2 | 6 | 13.5 | 6.67 | 15 |
| 1 | 1 | QPSK | 1/2 | 12 | 27 | 13.33 | 30 |
| 2 | 1 | QPSK | 3/4 | 18 | 40.5 | 20 | 45 |
| 3 | 1 | 16-QAM | 1/2 | 24 | 54 | 26.67 | 60 |
| 4 | 1 | 16-QAM | 3/4 | 36 | 81 | 40 | 90 |
| 5 | 1 | 64-QAM | 2/3 | 48 | 108 | 53.33 | 120 |
| 6 | 1 | 64-QAM | 3/4 | 54 | 121.5 | 60 | 135 |
| 7 | 1 | 64-QAM | 7/8 | 63 | 141.75 | 70 | 157.5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8 | 2 | BPSK | 1/2 | 12 | 27 | 13.33 | 30 |
| 9 | 2 | QPSK | 1/2 | 24 | 54 | 26.67 | 60 |
| 10 | 2 | QPSK | 3/4 | 36 | 81 | 40 | 90 |
| 11 | 2 | 16-QAM | 1/2 | 48 | 108 | 53.33 | 120 |
| 12 | 2 | 16-QAM | 3/4 | 72 | 162 | 80 | 180 |
| 13 | 2 | 64-QAM | 2/3 | 96 | 216 | 106.67 | 240 |
| 14 | 2 | 64-QAM | 3/4 | 108 | 243 | 120 | 270 |
| 15 | 2 | 64-QAM | 7/8 | 126 | 283.5 | 140 | 315 |
| 16 | 3 | BPSK | 1/2 | 18 | 40.5 | 20 | 45 |
| 17 | 3 | QPSK | 1/2 | 36 | 81 | 40 | 90 |
| 18 | 3 | QPSK | 3/4 | 54 | 121.5 | 60 | 135 |
| 19 | 3 | 16-QAM | 1/2 | 72 | 162 | 80 | 180 |
| 20 | 3 | 16-QAM | 3/4 | 108 | 243 | 120 | 270 |
| 21 | 3 | 64-QAM | 2/3 | 144 | 324 | 160 | 360 |
| 22 | 3 | 64-QAM | 3/4 | 162 | 364.5 | 180 | 405 |
| 23 | 3 | 64-QAM | 7/8 | 189 | 425.25 | 210 | 472.5 |
| 24 | 4 | BPSK | 1/2 | 24 | 54 | 26.67 | 60 |
| 25 | 4 | QPSK | 1/2 | 48 | 108 | 53.33 | 120 |
| 26 | 4 | QPSK | 3/4 | 72 | 162 | 80 | 180 |
| 27 | 4 | 16-QAM | 1/2 | 96 | 216 | 106.67 | 240 |
| 28 | 4 | 16-QAM | 3/4 | 144 | 324 | 160 | 360 |
| 29 | 4 | 64-QAM | 2/3 | 192 | 432 | 213.33 | 480 |
| 30 | 4 | 64-QAM | 3/4 | 216 | 486 | 240 | 540 |
| 31 | 4 | 64-QAM | 7/8 | 252 | 567 | 280 | 630 |
| 32 | 1 | BPSK | 1/2 | | 6 | | 6.67 |

**Table 26: MCS field content for the basic mode**

MCS indices from 33 to 63 (31 in number) are reserved for the Advanced MIMO Mode.

#### 11.2.1.4.2.3 ADVCODING

ADVCODING is a 1-bit field that indicates if advanced coding has been applied to the PPDU.

#### 11.2.1.4.2.4 SOUNDING PACKET

This bit indicates that MIMO training is per antenna, implying that all transmit antennas are excited. If this bit is set, the packet can be used for antenna-to-antenna channel estimation necessary for closed loop beam forming. If NOT set, the packet cannot be used as a sounding packet either because the MIMO training excites fewer spatial streams than antennas, or because beam forming has been applied.

#### 11.2.1.4.2.5 NUMBER (of) HT-LTF

These bits indicate the number of HT-LTFs in the current PPDU. This enumeration relates to the sounding packet, which is used to train the full spatial channel between the transmit and the receive antenna array. Note that the number of HT-LTFs is less than or equal to the number of transmit antennas.

#### 11.2.1.4.2.6 SHORT GI

SHORT GI is a 1-bit field. If SHORT GI is 1, the Short Guard Interval is used in the data portion of the frame.

#### 11.2.1.4.2.7 AGGREGATE

AGGREGATE is a 1-bit field. If AGGREGATE is 1, aggregation in the PPDU is used.
This field robustly transports the AGGREGATE parameter of the PHY DATA service, which is present in both TXVECTOR and RXVECTOR. The MAC uses this transported parameter to interpret the PSDU as either unaggregated or aggregated.

#### 11.2.1.4.2.8 SCRAMBLERINIT

SCRAMBLERINIT is a 2-bit field that contains the initialization value of the scrambler. This value is used to initialize the scrambler at the receiver. The mapping of the 2-bit field to initialization sequences is described in Table 18.

#### 11.2.1.4.2.9 20/40 BW

This bit indicates whether the current PPDU is signaled in 20MHz or 40MHz bandwidth. A value of 0 indicates 20MHz, whereas a value of 1 indicates 40MHz.

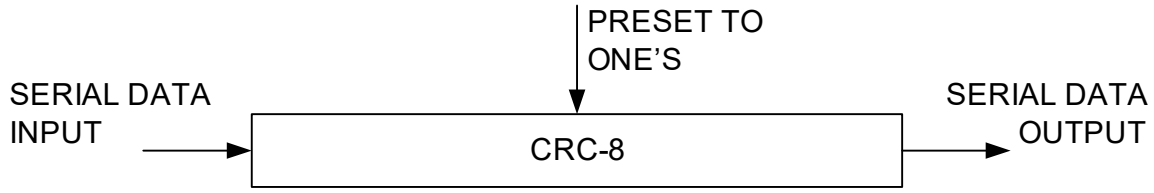
#### 11.2.1.4.2.10 CRC

CRC is an 8-bit CRC value. The CRC is taken over LSIG, HTSIG1 and bit0-bit9 of HTSIG2. The CRC field shall be the one's complement of the remainder generated by the modulo 2 division of the protected bits by the polynomial

$$x^8 + x^2 + x^1 + x^0 \quad (35)$$

where the shift-register state shall be preset to all-ones. The protected bits shall be bit0-bit16 of LSIG, bit0-bit23 of HTSIG1, and bit0-bit9 of HTSIG2. The protected bits shall be processed by the CRC encoder in transmit order. A schematic of the processing is shown in Figure 63.
As an example, consider the following values for the LSIG, HTSIG1 and HTSIG2 fields:
1101 0001 1101 1101 0000 0000 [LSIG]
0111 1011 0100 1011 1010 0000 [HTSIG1]
0010 1101 10CC CCCC CC00 0000 [HTSIG2]

where $b_0$.....$b_{23}$ [leftmost bit ($b_0$) is transmitted first in time]
Then, the protected bits that are input to the CRC encoder are
1101 0001 1101 1101 0, 0111 1011 0100 1011 1010 0000, 0010 1101 10
and the calculated CRC8 equals
00001101
so that HTSIG2 equals
0010 1101 1000 0011 0100 0000




1. Present shift register to all one's
2. Shift bit0-bit16 of LSIG, HTSIG1, and bit0-bit9 of HTSIG2 through the shift register
3. Take one's complement of the remainder
4. Transmit out serial $x^7$ first

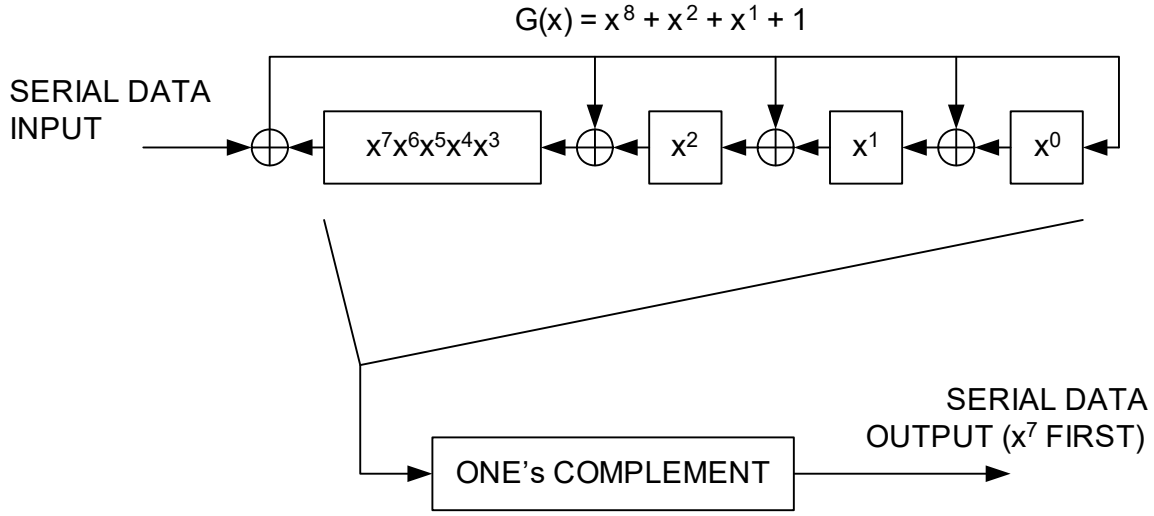



**Figure 63: Generation of CRC bits**

### 11.2.1.4.2.11 SIGNALTAIL

The bits 18-23 constitute the SIGNALTAIL field, and all 6 bits shall be set to zero.

### 11.2.1.5 Datafield

Contrary to 801.11a, the data field in our proposal does not contain a SERVICE field.

The data field contains the PSDU, the Tail bits and the PAD bits. All bits in the DATA field are scrambled, as described in 11.2.1.5.3. The PPDU is de-multiplexed across several spatial

streams, which are created after the parser. Figure 45. shows the de-multiplexing across 2 spatial streams. Our proposal supports up to 4 spatial streams.

#### 11.2.1.5.1 PSDU tail bit field (TAIL)

The PSDU tail bit field shall be six bits of "0," which are required to return the convolutional encoder to the "zero state." This procedure improves the error probability of the convolutional decoder, which relies on future bits when decoding and which may be not be available past the end of the message. The PLCP tail bit field shall be produced by replacing six scrambled "zero" bits following the message end with six nonscrambled "zero" bits.

#### 11.2.1.5.2 Pad bits (PAD)

The length of the message is extended so that it becomes a multiple of the number of data bits per OFDM symbol for each data (spatial) stream. The number of Pad bits is dependent how the bits are divided over the spatial streams.

#### 11.2.1.5.3 PLCP Data Scrambler and Descrambler

The 11a Scrambler and Descrambler will be used as described in 17.3.5.4 in ref [1].
The DATA field, composed of PSDU, tail, and pad parts, shall be scrambled with the length-127 frame-synchronous scrambler.
The scrambler shall be initialized according to the SCRAMBLERINIT fields in HTSIG2.
As described in 11.2.1.5.1 the PLCP tail bit field shall be produced by replacing six scrambled "zero" bits following the message end with six nonscrambled "zero" bits.

#### 11.2.1.5.4 Antenna streams / Transmitter architecture

The transmitter architecture with 2 spatial streams in the basic MIMO mode is shown in Figure 45. In the basic MIMO mode, the number of spatial streams equals the number of active transmit antennas. By active, we imply those antennas that transmit datafields.

The information bits first go through a convolutional encoder. The convolutional encoder is of rate ½ , from which other rates are derived by puncturing (see 11.2.1.5.6). The output of the puncturer feeds into the spatial parser, which creates several spatial streams, using round robin cycling. The frequency interleaver places the bits in the frequency domain and the constellation position according to the rules of the 802.11a interleaver. The interleaved bits are then mapped to constellation points. The resulting QAM symbols are fed as a block of data to the iFFT to create the time-domain signal. The pilot tones are also inserted in the frequency domain. The cyclical prefix is inserted in the time domain, and windowing of the OFDM symbols is also performed in the time domain. The resulting signal is then converted into analog format via a Digital-to-Analog (D/A) converter.

#### 11.2.1.5.5 Encoder

The DATA field shall be coded with the convolutional encoder of coding rate R=1/2. The encoder is defined in clause 17.3.5.5 in [1] (i.e. the 11a encoder).
.

#### 11.2.1.5.6 Puncturing of Coded Data

Coded bits at the output of the convolutional encoder are at rate 1/2. For lower rates, the puncturer can selectively puncture the coded bits to achieve the desired "effective" coding rate of 2/3, 3/4 or 7/8. For code rates of 2/3 and 3/4 the puncturing patterns are as defined in clause 17.3.5.5 in [1]. For a code rate of 7/8, the puncturing pattern is illustrated in Figure 64.

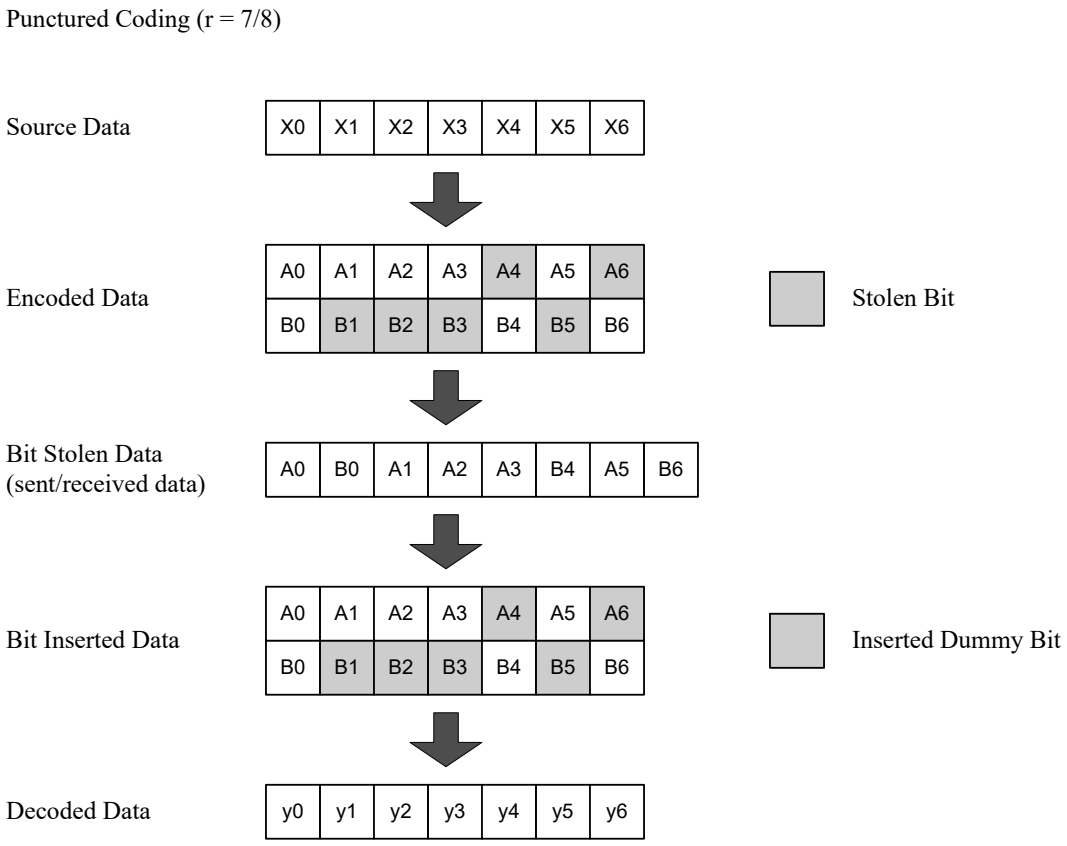



**Figure 64: Puncturing pattern for code rate = 7/8**

In the basic MIMO mode, all spatial streams are identically punctured.

#### 11.2.1.5.7 Data interleaving

Coded and punctured bits are interleaved across spatial streams and frequency tones. There are two steps to the space-frequency interleaving: spatial stream parsing and frequency interleaving.

##### 11.2.1.5.7.1 Spatial Parsing

Encoded and punctured bits are parsed to multiple spatial streams by a round-robin parser. Define:

$$s = \max\{N_{BPSC}/2, 1\} \quad (36)$$

which is the number of QAM bit order values, as in [1] equation (17). Then the parser sends consecutive blocks of $s$ bits to different spatial streams in a round-robin fashion starting with the first spatial stream. The reason for parsing in blocks of $s$ bits is to prevent clustering of QAM orders.

#### 11.2.1.5.7.2 Frequency interleaver

All encoded bits shall be interleaved by a separate block interleaver for each spatial stream, with a block size corresponding to the number of coded bits in a single OFDM symbol, $N_{CBPS}$. The block interleavers are based on the 802.11a interleaver, with certain modifications to allow for multiple spatial streams and 40MHz transmissions as shown in Figure 65.

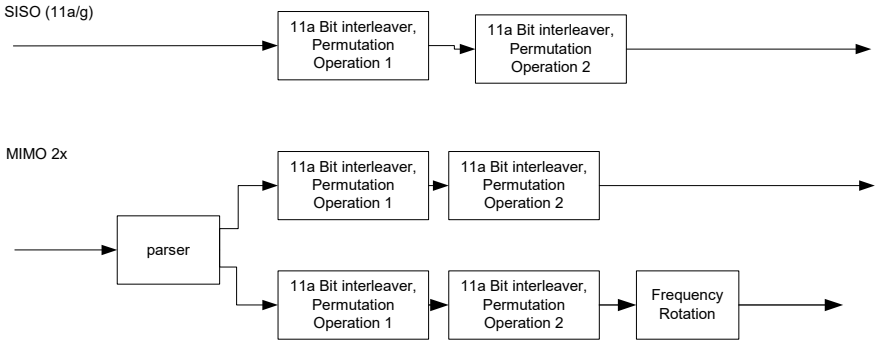



**Figure 65: Structure of interleaver**

The interleaver is defined by a three-step permutation. The first permutation ensures that adjacent coded bits are mapped onto nonadjacent subcarriers. The second permutation ensures that coded bits are mapped alternately onto less and more significant bits of the constellation and thereby long runs of low reliability (LSB) bits are avoided. The third permutation ensures that coded bits are mapped to achieve better frequency-spatial diversity among all spatial streams via frequency rotation. The operations of the first two permutations are the same as in 802.11a.

The basic interleaver array has $N_{row}$ rows and $N_{column}$ columns and the base of frequency rotation is defined by $N_{rot}$. These parameters are specified in

Table 27 where $N_{BPSC}$ is the number of coded bits per subcarrier (e.g., $N_{BPSC}$ = 1 for BPSK, 2 for QPSK, 4 for 16 QAM, etc).

**Table 27: Interleaver Parameters**

| | $N_{column}$ | $N_{row}$ | $N_{rot}$ |
|---|---|---|---|
| 20 MHz channels | 16 | 3 $N_{BPSC}$ | 11 |
| 40 MHz channels | 18 | 6 $N_{BPSC}$ | 29 |

The exact amount of frequency rotation for different spatial streams is illustrated in Table 28.

**Table 28: Amount of Frequency Rotation**

| Frequency Rotation | Total Number of Streams | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 1st stream | 0 | 0 | 0 | 0 |
| 2nd stream | | $2N_{rot}$ | $2N_{rot}$ | $2N_{rot}$ |
| 3rd stream | | | $N_{rot}$ | $N_{rot}$ |
| 4th stream | | | | $3N_{rot}$ |

The index of the coded bit before the first permutation shall be denoted by *k*; *i* shall be the index after the first and before the second permutation; *j* shall be the index after the second permutation and before the third permutation; *r* shall be the index after the third permutation and just prior to modulation mapping. Mathematically,

The first permutation is defined by the rule

$$i = N_{row} \times \left(k \bmod N_{column}\right) + \text{floor}\left(k / N_{column}\right) \quad k = 0,1,\ldots,N_{CBPS} - 1 \tag{37}$$

The second permutation is defined by the rule

$$j = s \times \text{floor}\left(i / s\right) + \left(i + N_{CBPS} - \text{floor}\left(N_{column} \times i / N_{CBPS}\right)\right) \bmod s \quad i = 0,1,\ldots,N_{CBPS} - 1 \tag{38}$$

where *s* is determined according to

$$s = \max\left(N_{BPSC} / 2,1\right) \tag{39}$$

The third permutation is defined by the rule

$$r = \left(j - \left(\left(2 \times i_{ss}\right) \bmod 3 + 3 \times \text{floor}(i_{ss} / 3)\right) \times N_{rot} \times N_{BPSC}\right) \bmod N_{CBPS} \quad j = 0,1,\ldots,N_{CBPS} - 1 \tag{40}$$

where $i_{SS} = 0,1,\ldots,N_{SS} - 1$ is the index of the spatial stream on which this interleaver is operating.

The deinterleaver, which performs the inverse relation, is also defined by three permutations. Here the index of the original received bit before the first permutation shall be denoted by *r*; *j* shall be the index after the first and before the second permutation; *i* shall be the index after the second and before the third permutation; and *k* shall be the index after the third permutation.

The first permutation is defined by the rule

$$j = \left(r + \left(\left(2 \times i_{ss}\right) \bmod 3 + 3 \times \text{floor}(i_{ss} / 3)\right) \times N_{rot} \times N_{BPSC}\right) \bmod N_{CBPS}, \quad r = 0,1,\ldots,N_{CBPS} - 1 \tag{41}$$

This permutation is the inverse of the permutation described in Equation (40).

The second permutation is defined by the rule

$$i = s \times \text{floor}\left( j / s \right) + \left( j + \text{floor}\left( N_{column} \times j / N_{CBPS} \right) \right) \bmod s, \quad j = 0,1,\ldots, N_{CBPS} - 1 \qquad (42)$$

where *s* is as defined in Equation (39). This permutation is the inverse of the permutation described in Equation (38).

The third permutation is defined by the rule

$$k = N_{column} \times i - \left( N_{CBPS} - 1 \right) \text{floor}\left( i / N_{row} \right), \quad i = 0,1,\ldots, N_{CBPS} - 1 \qquad (43)$$

This permutation is the inverse of the permutation described in Equation (37).

#### 11.2.1.5.8 Subcarrier Modulation Mapping

The subcarrier modulation mapping will be identical to clause 17.3.5.7 in [1].

There is one exception as described in clause 11.2.1.4. The mapping of the HTSIG field shall be rotated by 90 degrees.

#### 11.2.1.5.9 MIMO-OFDM symbol iFFT mapping

For the MIMO-OFDM operation in 20 MHz bandwidth, the modulation coding scheme (MCS) for each spatial stream will be identical to that in IEEE 802.11a (clause 17.3.5.9 in [1]).

Construction of the OFDM data symbol in 40MHz begins with bonding two adjacent 20MHz OFDM symbols, as shown in Figure 66. There are a total of 11 guard tones between the two 20MHz channels, ranging from -5 to +5. Note that the legacy channels occupy tones from -58 to -6 in the lower sub-channel, and from +6 to +58 in the upper sub-channel. Of the 11 guard tones, 3 are nulled out: -1, 0, +1. This provides 8 additional data tones. Two DC tones are also inherited from the legacy sub-channels. These occur at -32 and +32 in the lower and upper sub-channels respectively. There are 4 pilot tones in each legacy sub-channel, and when mapped to the 40MHz iFFT indices, they occur at ±53, ±39, ±25, ±11. Of these 8 tones, the two tones at -39 and +39 are swapped with data, leading to a total of 6 pilot tones in the 40MHz channel. Tone assigned during 40MHz for DATA symbols can be summarized as:

$$\begin{aligned} &Nulled\ Tones = \{-64\ldots-59, -1, 0, +1, +59\ldots+63\} \\ &Populated\ Tones = \{-58\ldots-2, +2\ldots+58\} \\ &Pilot\ Tones = \{-53, -25, -11, +11, +25, +53\} \\ &Data\ Tones = \{Populated\ Tones\} - \{Pilot\ Tones\} \end{aligned} \qquad (40)$$

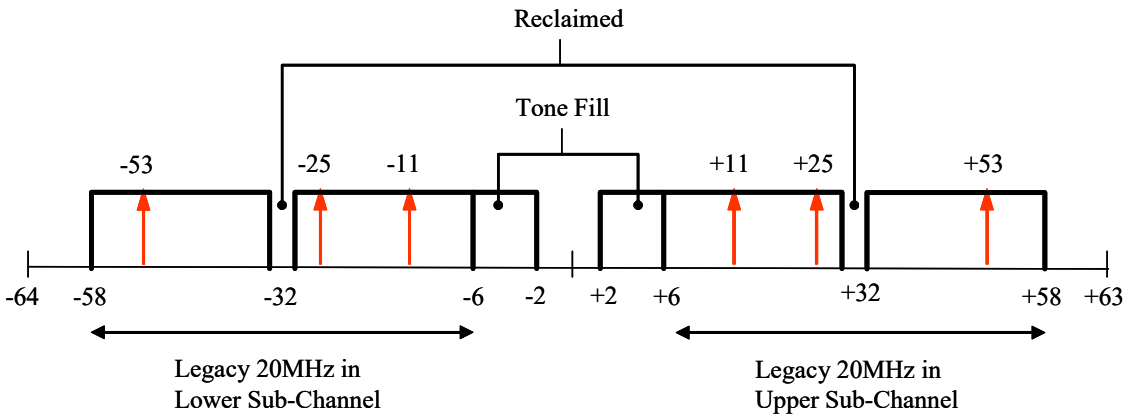



**Figure 66: Tone Format for 40MHz channelization**

The mapping of the input of the 40MHz channel to a 128-point IFFT is illustrated in Figure 67.

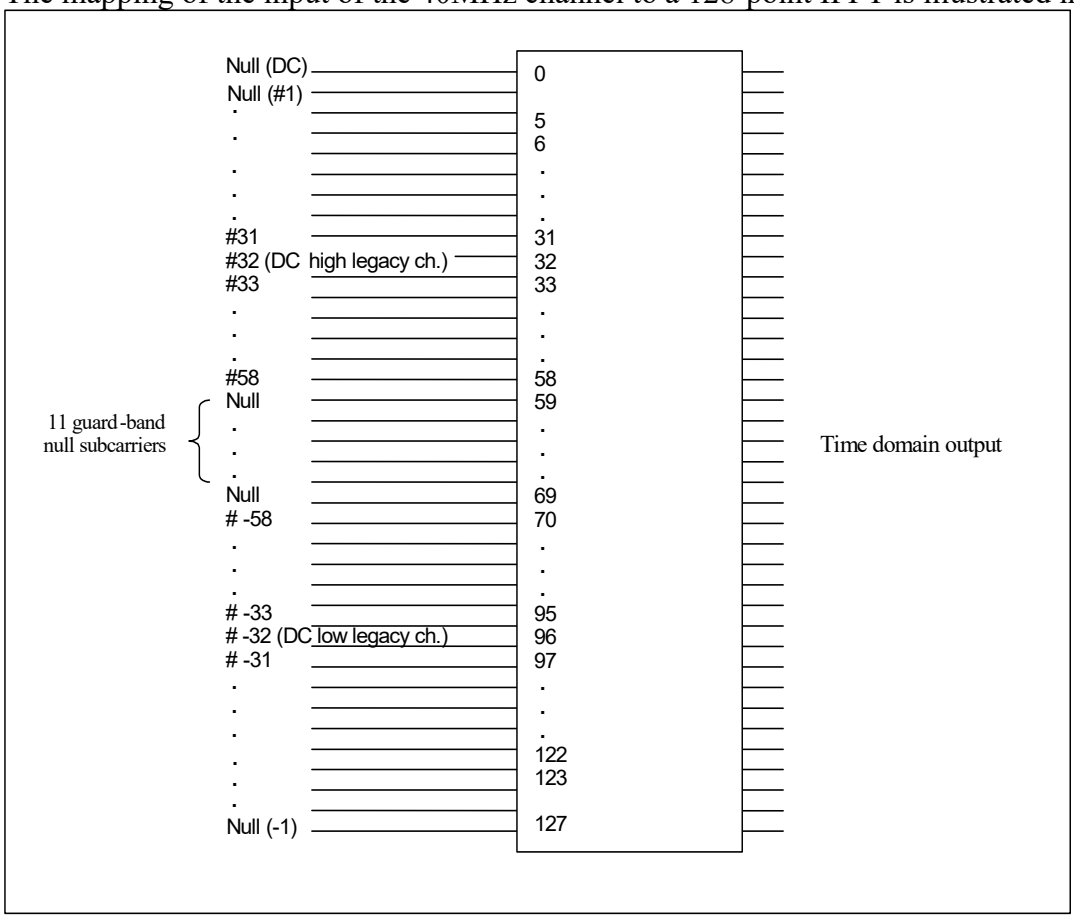



**Figure 67 Inputs and Outputs of IFFT for a 40 MHz channel**

The complex numbers after the mapping are divided into groups of $N_{SD}$, where $N_{SD} = 48$ in the 20MHz mode and $N_{SD} = 108$ in the 40MHz mode. Following the convention in clause 17.3.5.9 in [1], the complex number is denoted as $d_{k,n}^{(i_{Tx})}$, which corresponds to the $k$ th subcarrier in the $n$ th OFDM symbol that is transmitted from the $i_{Tx}$ th antenna.

An OFDM data symbol, $r_{DATA,n}^{(i_{Tx})}(t)$, is defined as

$$r_{DATA,n}^{iTX}(t) = w_{SYM}(t)\left(\sum_{k=0}^{N_{SD}-1} d_{k,n}^{(i_{TX})} \exp\left(j2\pi M(k)\Delta_F\left(t-T_{GI}\right)\right) + p_{n+3}\sum_{k=-N_{SR}}^{N_{SR}} P_k^{(i_{TX})} \exp\left(j2\pi k\Delta_F\left(t-T_{GI}\right)\right)\right) \quad (41)$$

where function $M(k)$, defines the mapping from the logical subcarrier number $k$ to a value between $-N_{SR}$ and $+N_{SR}$, while skipping the pilot subcarriers and DC and its adjacent subcarriers. $M(k)$ in the 20MHz mode is same as the one defined in clause 17.3.5.9 in [1]. $M(k)$ in the 40MHz mode is defined as

$$M(k) = \begin{cases} k-58 & 0 \le k \le 4 \\ k-57 & 5 \le k \le 31 \\ k-56 & 32 \le k \le 44 \\ k-55 & 45 \le k \le 53 \\ k-52 & 54 \le k \le 62 \\ k-51 & 63 \le k \le 75 \\ k-50 & 76 \le k \le 102 \\ k-49 & 103 \le k \le 107 \end{cases} \quad (42)$$

The contribution of pilot subcarriers in the 20MHz mode is given by (24) in clause 17.3.5.9 in ref [1]. The subcarrier frequency locations in the 20MHz mode is shown in Figure 117 in clause 17.3.5.9 in ref [1]. The subcarrier frequency locations in the 40MHz mode is shown in Figure 66.

The iFFT mapping for the 6Mbps duplicate mode in 40MHz differs slightly from the mapping shown in (41):

$$r_{DATA,n}^{(1)}(t) = w_{SYM}(t)\left(\sum_{k=0}^{N_{SD}-1} d_{k,n}\exp\left(j2\pi\left(M(k)-32\right)\Delta_F\left(t-T_{GI}\right)\right) + j\sum_{k=0}^{N_{SD}-1} d_{k,n}\exp\left(j2\pi\left(M(k)+32\right)\Delta_F\left(t-T_{GI}\right)\right) + p_{n+3}\sum_{k=-N_{SR}}^{N_{SR}} P_k\exp\left(j2\pi\left(k-32\right)\Delta_F\left(t-T_{GI}\right)\right) + jp_{n+3}\sum_{k=-N_{SR}}^{N_{SR}} P_k\exp\left(j2\pi\left(k+32\right)\Delta_F\left(t-T_{GI}\right)\right)\right) \quad (43)$$

where, $N_{SD}=48$ and $N_{SR}=26$ are values that correspond to a 20MHz transmission. $M(k)$, $P_k$ and $p_n$ follow the definitions in (23) to (25) in clause 17.3.5.9 in [ref 2]. $P_k$ for the HT 40MHz mode is defined in 11.2.1.5.10.2.

The concatenation of $N_{SYM}$ OFDM symbols can now be written as

$$r_{DATA}^{(iTx)}(t) = \sum_{n=0}^{N_{SYM}-1} r_{DATA,n}^{(iTx)}\left(t-nT_{SYM}\right) \quad (44)$$

### 11.2.1.5.10 Pilot subcarrier

In each OFDM symbol, four of the subcarriers in 20 MHz mode and six of the subcarriers in 40 MHz mode are dedicated to pilot signals in order to make the coherent detection robust against frequency offsets and phase noise. These pilot signals shall be put in subcarriers –21, -7, 7, and 21 in 20MHz mode, and in subcarriers -53, -25, -11, 11, 25 and 53 in 40MHz mode.

#### 11.2.1.5.10.1 Legacy pilot subcarriers

Legacy pilots are defined as in 802.11a; refer to clause 17.3.5.8 in [1].

#### 11.2.1.5.10.2 Pilot subcarriers in HT mode

The contribution of pilot subcarriers at the $i_{Tx}$ th transmission stream in 20MHz mode is produced by inverse Fourier transform of sequence $P_{k,n}^{(i_{Tx})}$ given by

$$\begin{aligned} P_{-26..26,n}^{(i_{Tx})} = \{&0,0,0,0,0,P_{-21,n}^{(i_{Tx})},0,0,0,0,0,0,0,0,0,0,0,0,0,P_{-7,n}^{(i_{Tx})},0,0,0,0,0,0,0, \\ &0,0,0,0,0,0,P_{7,n}^{(i_{Tx})},0,0,0,0,0,0,0,0,0,0,0,0,0,-P_{21,n}^{(i_{Tx})},0,0,0,0,0\} \end{aligned} \quad (45)$$

where non-zero element of $P_{k,n}^{(i_{Tx})}$ is generated by the following rule

$$P_{k,n}^{(i_{Tx})} = \exp\left\{\frac{j\pi}{2}(i_{Tx}-1)m\right\}, \quad m = \left(\frac{1}{2}\left(\frac{k}{7}+3\right)+n\right) \bmod 4 \quad (46)$$

In the 40MHz mode, $P_{k,n}^{(i_{Tx})}$ is given by

$$\begin{aligned} P_{-58..58,n}^{(i_{Tx})} = \{&0,0,0,0,0,P_{-53,n}^{(i_{Tx})},0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,P_{-25,n}^{(i_{Tx})},0,0, \\ &0,0,0,0,0,0,0,0,0,0,0,-P_{-11,n}^{(i_{Tx})},0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,P_{11,n}^{(i_{Tx})},0,0,0,0, \\ &0,0,0,0,0,0,0,0,0,0,-P_{25,n}^{(i_{Tx})},0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0, \\ &0,0,P_{53,n}^{(i_{Tx})},0,0,0,0,0\} \end{aligned} \quad (47)$$

where non-zero element of $P_{k,n}^{(i_{Tx})}$ is generated by the following rule

$$P_{k,n}^{(i_{Tx})} = \exp\left\{\frac{j\pi}{2}(i_{Tx}-1)m\right\}, \quad m = \begin{cases} \left(\frac{(k+11)}{14}+3+n\right) \bmod 4, & k = -53,-25,-11 \\ \left(\frac{(k+3)}{14}+3+n\right) \bmod 4, & k = 11,\ 25,\ 53 \end{cases} \quad (48)$$

The polarity of the pilot subcarriers is controlled by sequence $p_n$, which is a cyclic extension of the 127 elements sequence as defined in clause 17.3.5.9 in ref[2].

#### 11.2.1.5.11 GI / windowing

The windowing function in both 20MHz and 40MHz modes is the same as the one described in clause 17.3.2.4 and 17.3.2.5 in [1]. The example in clause 17.3.2.5 in [1] still holds for the 20MHz modes. In the 40MHz modes, the changes in this example is the sampling rate becomes 40MHz and $T_{TR} = 50ns$, then the discrete implementation of the windowing function is

$$w_T[n] = w_T(nT_s) = \begin{cases} 1 & 1 \le n \le 159 \\ 0.5 & 0,160 \\ 0 & otherwise \end{cases} \quad (49)$$

#### 11.2.1.6 Clear channel assessment

When operating in the 5 GHz band the HT PHY shall follow the CCA requirements of 11a, clause 17.3.10.5 in [1]. When operating in the 2.4 GHz band the HT PHY shall follow the 11g spec according to 19.3.5 and 19.4.6 in ref [3].

#### 11.2.1.7 PMD operating spec

In the 20 MHz bandwidth mode the HT PHY shall follow the 11a spec (clause 17.3.8 in ref [1]) and subsequent specifications when operating in the 5 GHz band.
In the 20 MHz bandwidth mode the HT PHY shall follow the 11g spec (clause 19.4) when operating in the 2.4 MHz band.

##### 11.2.1.7.1 Transmit spectral mask

###### 11.2.1.7.1.1 20MHz channel spacing

In the 20 MHz bandwidth mode the HT PHY shall follow 17.3.9.2 in ref [1]. The transmitted spectrum shall have a 0dBr (dB relative to the maximum spectral density of the signal) bandwidth not exceeding 18MHz, -20dBr at 11 MHz frequency offset, -28dBr at 20MHz frequency offset and -45dBr at 30MHz frequency offset and above. The transmitted spectral density of the transmitted signal shall fall within the spectral mask, as shown in Figure 1. The measurements shall be made using a 100kHz resolution bandwidth and a 30kHz video bandwidth.

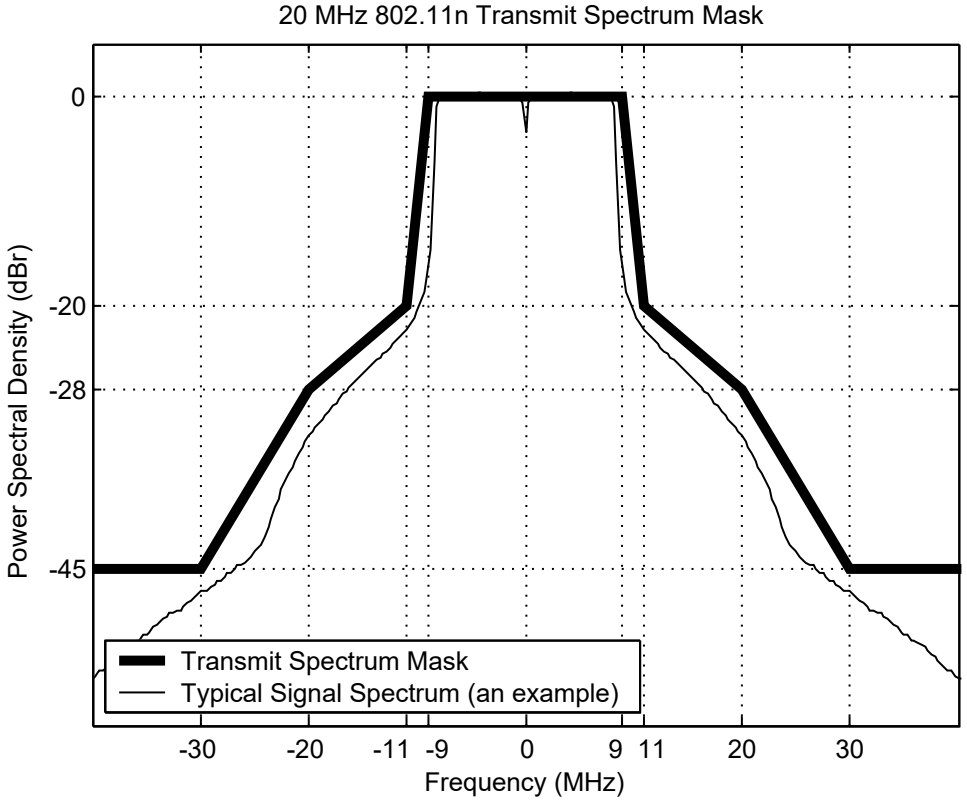



**Figure 68: Transmit Spectrum Mask for 20MHz channelization**

#### 11.2.1.7.1.2 40MHz channel spacing

The transmitted spectrum shall have a 0dBr (dB relative to the maximum spectral density of the signal) bandwidth not exceeding 38MHz, -20dBr at 21 MHz frequency offset, and -45dBr at 60MHz frequency offset and above. The transmitted spectral density of the transmitted signal shall fall within the spectral mask, as shown in Figure 2. The measurements shall be made using a 100kHz resolution bandwidth and a 30kHz video bandwidth.

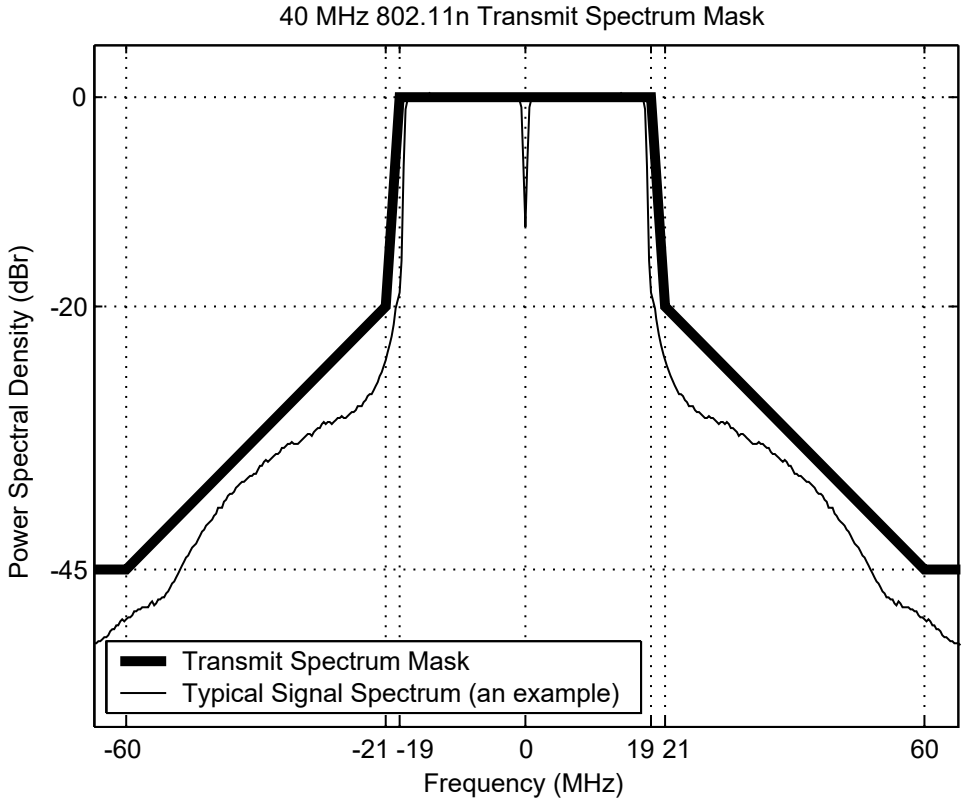



**Figure 69: Transmit spectrum mask for 40MHz channelization**

A HT device transmitting a 20MHz signal in a 40MHz BSS shall conform to the spectral mask shown in Figure 69.

### 11.2.2 Basic Transmit Beamforming (Optional Mode)

#### 11.2.2.1 Introduction

One method of improving the SNR at the receiver, for a given distance between stations, is to apply transmit beamforming. A basic requirement for transmit beamforming is the availability of channel state information (CSI). In our proposal, CSI is obtained by assuming channel reciprocity. The initiator sends a request for a sounding packet to the intended recipient, which in turn sends a sounding packet back to the initiator. The initiator extracts the CSI from this packet, and assumes that the forward channel is identical to the reverse channel. Assumption of channel reciprocity also requires radio calibration, since the TX-RX radio pair on the reverse link is different from the TX-RX pair on the forward link. Our proposal also includes a packet exchange sequence to help perform radio calibration.

#### 11.2.2.2 Motivation of MIMO-Beamforming (Informative)

Beamforming-MIMO can achieve higher throughput than basic MIMO at same SNR, or conversely, higher range at the same data rate. The benefit of TX beamforming is most pronounced when the number of TX antennas is larger than the RX antennas, when multiple spatial streams are being transmitted. For e.g., a typical configuration involving TX beamforming could be either 3 or 4 antennas at the AP, and 2 antennas at the client. Hence, the client is kept low-cost, while the AP shoulders a higher cost burden.

#### 11.2.2.3 Description of BF-MIMO

##### 11.2.2.3.1 Beamformed PPDU

The transmitter may choose to use antenna beamforming in order to increase the antenna gain in the direction of an intended receiver. The beamforming process is represented mathematically as a linear transformation, mapping the streams of data to the transmit antennas.

Let *x* be the $N_{SS}$ dimensional vector of data, where each element of *x* is from one of the spatial streams of data. The beamforming transformation is represented by a $N_{TX}$ x $N_{SS}$ matrix, V. The beamforming operation, on a per subcarrier basis, is represented by,

$$y_{N_{TX}\times 1} = V_{N_{TX}\times N_{SS}} \cdot x_{N_{ss}\times 1} \quad (50)$$

The *y* vector is an $N_{TX}$ dimensional vector whose elements get mapped to the $N_{TX}$ antennas. The beamforming matrix V is applied to the HT-STF and HT-LTF training fields as well as the data. There are several methods for calculating V. One of them involves singular value decomposition (SVD) of the channel transfer matrix H.

It is optional for a device to be able to perform TX beamforming. However, it is mandatory that a device to receive a beamformed packet, which implies that the device should be able to send a sounding packet to the initiator.

##### 11.2.2.3.2 Channel sounding

###### 11.2.2.3.2.1 Channel sounding principle

In order for a STA to send a beamformed PPDU (BF-PPDU) to another STA it is necessary for the STA to have channel state information from the transmitter to the receiver. To simplify the explanation we will introduce several new terms. The STA that is to send a BF-PPDU is referred to as the beamforming STA and the STA that is to receive the BF-PPDU is referred to as the non-beamforming STA.

Using implicit feedback, the non-beamforming STA sends a sounding PPDU to the beamforming STA, which enables the beamforming STA to estimate the channel from the non-beamforming STA to the beamforming STA. This channel estimate is used to calculate the required beamforming matrix for the beamforming-STA to non-beamforming STA transmission.

#### 11.2.2.3.2.2 Sounding PPDU format

In a non-sounding PPDU the number of HT-LTFs is equal to the number of spatial streams, which may be less than the number of transmit antennas. However, in order to calculate the beamforming matrix from one STA to another STA it is necessary to estimate the full channel matrix, which requires that the PPDU include a full set of $N_{TX}$ LTFs. In order to facilitate estimation of the complete channel matrix, a sounding PPDU is introduced. A sounding PPDU fully excites the channel, enabling estimation of the full channel matrix. No beamforming shall be applied to either the LTFs or the data in a sounding-PPDU. In other words the beamforming matrix, V, is the identity matrix. Thus techniques such as Walsh + CDD should not be applied to sounding PPDU.

In the sounding PPDU, the "sounding bit" in the HT-SIG is set to "one". The number of HT-LTFs is equal to the number of transmit antennas, and not necessarily the number of spatial streams. Thus in a sounding PPDU the number of HT-LTFs is set by the NLTF portion of the HT-SIGNAL field, which overrides the setting of the number of HT-LTFs specified by the MCS portion of the HT-SIGNAL field. The NUMBER HT-LTF is identical to the number of TX antennas.

It is mandatory that a STA support the transmission of a sounding PPDU in response to a TRQ message in the IAC MPDU.

### 11.2.2.3.3 Calculation of beamforming matrix using SVD (Informative)

Once a STA has a proper estimate of the channel, then it can use that channel estimate to select a recommended beamforming matrix. There are a variety of techniques that can be used to select the beamforming matrix. One method of selecting the beamforming matrix is by calculating the singular value decomposition of the channel from this STA to the intended receiving STA. Let H be the channel matrix from the transmitter to the receiver. The SVD of the channel matrix is given by,

$$H = UDV^H \quad (51)$$

Both U and V are unitary matrices and D is a diagonal matrix of singular values. The transmitter selects the dominant $N_{SS}$ singular values and then sends only $N_{SS}$ spatial streams. The first $N_{SS}$ rows of the V matrix are used as the beamforming matrix, mapping the spatial streams of data to the TX antennas. This same beamforming matrix is applied to the HT-LTFs, except for one difference. The number of HT-LTFs is equal to Nss, and each transmission of HT-LTF is shaped by one singular vector.

#### 11.2.2.3.3.1 Channel Reciprocity

To determine the beamforming matrix, the transmitter needs to know the channel from the transmitter to the intended receiver. That channel is estimated using implicit feedback and channel reciprocity. The transmitter uses the previous sounding PPDU sent from the intended receiver to estimate the channel from the intended receiver to the transmitter. In order to estimate the channel from the receiver to the transmitter, it uses the principle of reciprocity. The principle of reciprocity is that the downlink channel (the channel from the AP to the STA) is the transpose of the uplink channel (the channel from the STA to the AP). Letting $H_D$ be the downlink channel and $H_U$ be the uplink channel, reciprocity is,

$$H_U = H_D^H \quad (52)$$

#### 11.2.2.3.4 Calibration Methodology (Informative)

##### 11.2.2.3.4.1 Calibration Overview

In order for a transmitting 802.11n STA to transmit to another 802.11n STA using beamforming, it must have a good characterization of the channel that it is transmitting over so that it can choose the correct transmit steering vectors. The STA obtains this characterization by observing the HT-LTF transmitted by the STA to which it is transmitting. This approach is based on the reciprocal property of the over-the-air (antenna-to-antenna) TDD channel, and reciprocity must be in effect for the approach to provide the best rate and range performance available.

Although the Basic MIMO and Walsh-CDD modes do not require it, calibration neither improves nor degrades performance with those modes. Thus, STAs may calibrate upon entering a BSS in which the AP is transmit beamforming capable, or at any other time, and if they are capable of transmitting in beamforming mode, the resulting calibration correction vectors may be employed for all transmission modes and on all frames. STAs that are not capable of transmitting in beamforming mode may also perform the calibration procedure with any transmit beamforming capable AP with which they associate, in order to enable that AP to transmit to them in beamforming mode.

Throughout the discussion of beamforming transmission in this document, it is assumed that communication in beamforming mode takes place between devices that have been calibrated.

The following section describes the calibration procedure for a communication link, where the two communicating STAs are referred to as STA A and STA B. Note: calibration as described here is only applicable to STAs with two or more antennas, where both transmission and reception are possible on each antenna.

##### 11.2.2.3.4.2 Calibration procedure for Tx Corrections

In order to consider the operation of a TDD MIMO OFDM system in conjunction with beamforming techniques through transmit and receive steering, it is necessary to first consider the need to ensure that the over-the-air reciprocity of the TDD channel is preserved in the observed, baseband-to-baseband TDD channel. Reciprocity is critical in the functioning of these systems because it provides efficient means for a STA to learn the transfer function of the channel over which it will transmit.

In order to ensure that the baseband-to-baseband channel seen by the spatial processing engines is reciprocal, it is necessary to calibrate the STA radio to correct the differences in phase and amplitude response in the transmit and receive chains.

The reciprocity of the over-the-air TDD MIMO channel can be expressed as a transpose relationship between the channel response matrices associated with forward and reverse channels between two STAs. Consider, for example, STA A and STA B, where we will refer to the channel over which STA A transmits as the forward link, and the channel over which STA B transmits as the reverse link. Thus we will define the

following two gain matrices for the over-the-air channels (the over-the-air channel is the complex baseband channel that would be realized if the transmitter and receiver responses have ideal constant gain and zero phase across the channel bandwidth):

- $\mathbf{H}_{A\to B}(\ell)$: forward link gain matrix for subcarrier $\ell$
- $\mathbf{H}_{B\to A}(\ell)$: reverse link gain matrix for subcarrier $\ell$,

The reciprocal relationship between these two channels is expressed as:

$$\mathbf{H}_{B\to A}(\ell) = \mathbf{H}^{t}_{A\to B}(\ell).$$

The observed channels, however, are effected by the amplitude and phase responses of the transmit and receive chains. Assuming good isolation, these can be expressed as diagonal matrices with complex valued diagonal entries, of the form $\mathbf{C}_{A,Tx}(\ell)$. The relationship between the observed channels, $\tilde{\mathbf{H}}_{A\to B}(\ell)$ and $\tilde{\mathbf{H}}_{B\to A}(\ell)$, and the over-the-air channel is

$$\tilde{\mathbf{H}}_{A\to B}(\ell) = \mathbf{C}_{B,Rx}(\ell)\mathbf{H}_{A\to B}(\ell)\mathbf{C}_{A,Tx}(\ell), \text{ and}$$

$$\tilde{\mathbf{H}}_{B\to A}(\ell) = \mathbf{C}_{A,Rx}(\ell)\mathbf{H}_{B\to A}(\ell)\mathbf{C}_{B,Tx}(\ell).$$

The resulting observed channels are not, in general, reciprocal. However, through a simple channel sounding procedure that involves an exchange of training sequences, correction vectors can be calculated that are applied on transmit to restore reciprocity. The resulting calibration is quite stable and needs to be updated infrequently, typically on association.

The object of the procedure is to compute correction vectors $\mathbf{K}_A(\ell)$ and $\mathbf{K}_B(\ell)$ that restore reciprocity such that

$$\tilde{\mathbf{H}}_{A\to B}(\ell)\mathbf{K}_A(\ell) = \left[\tilde{\mathbf{H}}_{B\to A}(\ell)\mathbf{K}_B(\ell)\right]^{t}.$$

The correction vectors are applied on transmit in such a way that each element in the correction vector scales the transmit vector element associated with a specific antenna. Given a modulation symbol vector, $\mathbf{s}_A(\ell)$, in subcarrier $\ell$ at STA A, and beamforming matrix $\mathbf{V}(\ell)$, then the transmitted vector in subcarrier $\ell$ is given by $\mathbf{x}(\ell) = \mathbf{K}_A(\ell)\mathbf{V}_A(\ell)\mathbf{s}_A(\ell)$.

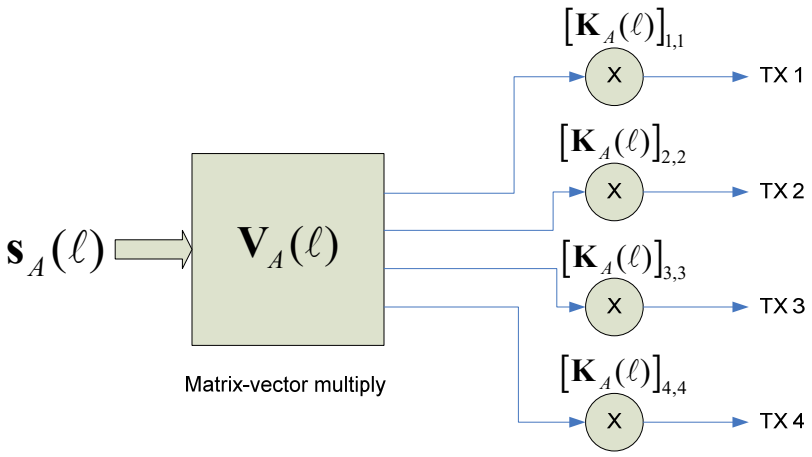



**Figure 70: Application of calibration correction vector on Tx**

Correction vectors that will satisfy this relationship are given by:

$$\mathbf{K}_A(\ell) = \left(\mathbf{C}_{A,Tx}(\ell)\right)^{-1} \mathbf{C}^t_{A,Rx}(\ell), \text{ and}$$

$$\mathbf{K}_B(\ell) = \left(\mathbf{C}_{B,Tx}(\ell)\right)^{-1} \mathbf{C}^t_{B,Rx}(\ell).$$

Calibration can also be applied on receive in a similar manner. Tx calibration only is addressed here.

For STAs that support only 20 MHz operation, calibration must be performed for subcarriers with indices between -26 and 26, except for the subcarrier with index 0. For STAs supporting both 20 MHz and 40 MHz operation, calibration must be performed for subcarriers with indices between -58 and 58, except for the subcarriers with indices -1, 0, and 1.

The calibration procedure is as follows:

1. STA A transmits a Calibration Training message, initiating the calibration procedure.
2. STA B transmits a Calibration Training message, which includes the HT-LTF that allows a receiving STA A to estimate the channel matrices $\mathbf{H}_{B\to A}(\ell)$.
3. STA A transmits a Calibration Training message, which includes the HT-LTF that allows STA B to estimate the channel matrices $\mathbf{H}_{A\to B}(\ell)$.
    a. The previous two steps must occur over a sufficiently short time interval that the channel does not change over the interval.
4. STA A computes an estimate of $\mathbf{H}_{B\to A}(\ell)$ based on the received HT-LTF.
5. STA B computes an estimate of $\mathbf{H}_{A\to B}(\ell)$ based on the received HT-LTF.

6. STA B sends the quantized estimates of $\mathbf{H}_{A\to B}(\ell)$ to STA A using the Calibration Measurement Message that contains the Channel Measurement Report.

7. STA A uses the estimates of $\mathbf{H}_{B\to A}(\ell)$ and $\mathbf{H}_{A\to B}(\ell)$ to compute the correction vectors $\mathbf{K}_A(\ell)$ and $\mathbf{K}_B(\ell)$.

8. STA A sends the quantized correction vectors $\mathbf{K}_B(\ell)$ to STA B using the Calibration Correction Vector Message that contains the Correction Vector element.

9. STA A and STA B now have correction vectors and are considered to be calibrated.

Once a STA has completed the calibration procedure, the correction vectors, $\mathbf{K}(\ell)$, are assumed to be available at the STA's transmitter, and are incorporated into the transmit spatial processing procedure for all subsequent communications.

This procedure needs to be performed only once for any STA that will participate in a beamforming exchange with another STA. For example, once an AP performs this procedure with one STA, it is calibrated and may participate in a beamforming exchange with any other calibrated STA. However, in many networks, the AP will be the primary agent for calibrating client STAs. Thus a typical AP will participate in many of these calibration procedures.

#### 11.2.2.3.4.3 Calibration procedure for Beamforming Rx-only STAs

STAs that have no transmit beamforming capabilities, but that still are capable of receiving beamforming transmissions, are referred to as Rx-only STAs. Such STAs must also participate in a calibration procedure similar to that described above. However, it is not necessary for such a STA to apply the calibration correction matrix on transmit. In this case, a STA A that wishes to transmit to a STA B using beamforming, must initiate the calibration sequence described above, with the exception that it does not execute step 8. Instead, STA A makes use of $\mathbf{K}_B(\ell)$ to precondition its channel estimate for the purposes of computing transmit steering vectors. This may be achieved by right-multiplying STA A's estimate of $\mathbf{H}_{B\to A}(\ell)$ by $\mathbf{K}_B(\ell)$.

#### 11.2.2.3.4.4 Calibration Processing

The MIMO calibration training sequence consists of $N_{\mathrm{CAL}} = N_{Tx}$ HT-LTFs. Each HT-LTF consists of an 800 ns guard interval followed by two periods of a 3.2 μs training symbol sequence, for a total duration of 7.2 μs. For details on the format of the HT-LTF, see section 11.2.1.3.4.

### 11.2.2.3.5 HT-Short Training Field in BF-MIMO mode

HT-STF is identical to basic MIMO case (refer to section 11.2.1.3.3). The HT-STF undergoes the same spatial steering as the DATA.

#### 11.2.2.3.6 HT-Long Training Field in BF-MIMO mode

HT-LTFs are identical to the basic MIMO case (refer to section 11.2.1.3.4). The HT-LTF undergoes the same spatial steering as the DATA.

##### 11.2.2.3.6.1 MCS field in BF-MIMO mode

MCS set for BF-MIMO is identical to that of basic MIMO, as described in section 11.2.1.4.2.2.

#### 11.2.2.3.7 Antenna streams / Transmitter architecture in BF-MIMO mode

The only difference in the transmitter architecture with respect to the basic MIMO mode is the introduction of the spatial steering matrix, as shown in Figure 71:

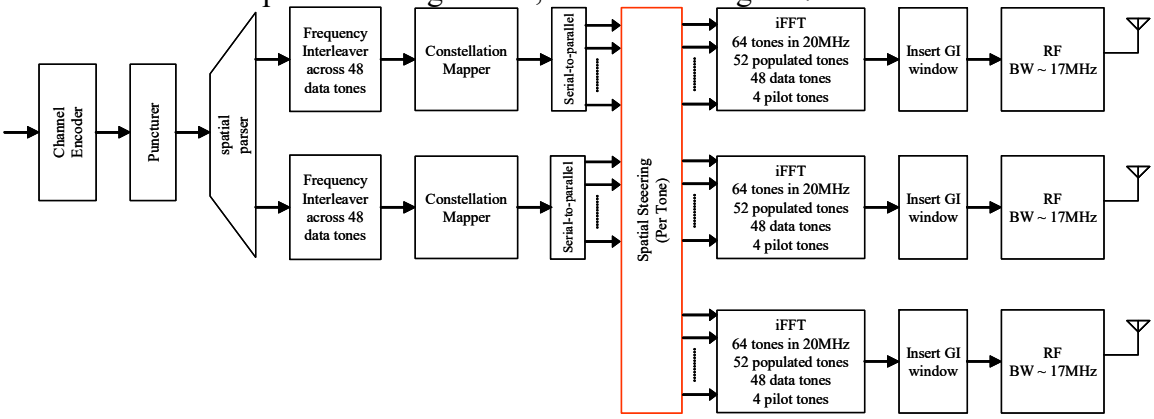



**Figure 71: Transmitter architecture for TX Beamforming for $N_{ss}$=2,and $N_{TX}$ = 3**

#### 11.2.2.3.8 Puncturing of Coded Data in BF-MIMO mode

TX Beamforming uses the same puncturing pattern as the basic MIMO mode, described in 11.2.1.5.6.

#### 11.2.2.3.9 MCS set in BF-MIMO mode

The MCS is identical for all spatials streams in basic TX beamforming, as is the case in the basic MIMO mode. The MCS set is described in Table 26.

### 11.2.3 Advanced Transmit Beamforming (Optional Mode)

In our proposal, there are two class of BF-MIMO. The first one is basic BF-MIMO (as described in section 11.2.2). When AP uses this mode, STA would receive a beamformed frame as a basic MIMO frame. No additional functionality is required at the STA, except for the ability of the STA to send a sounding-PPDU and support feedback calibration. An extension to the basic BF-MIMO mode is the advanced BF-MIMO mode, which includes the following highlights:

- Unequal power among the spatial streams
- Independent MCS for each spatial stream

- Support for bi-directional beamforming

#### 11.2.3.1 Required Capability for supporting of ABF-MIMO mode

In this mode, STA should support additional functionality to achieve better performance. These include:

- The receiving STA has to recognize a TRQ, and should be able to transmit a sounding PPDU as a response to it. (Common to basic BF-MIMO)
- Calibration support using MAC frame. (Common to basic BF-MIMO)
- Power level detection at each spatial stream to support unequal power loading
- Supporting unequal MCS at different spatial stream
- UD decomposition (or an equivalent method) to extract eigenvalues and eigenvectors of the channel matrix. Eigenvalues are used to determine the MCS at the receiver to support pairwise spoofing, and/or link adaptation. Eigenvectors in the U matrix allow bi-directional beamforming to be supported

##### 11.2.3.1.1 Power Loading of spatial streams in ABF-MIMO

In ABF-MIMO, additional performance gain is possible if different power levels are applied to different spatial streams. However, to decode the PPDU with different power levels on different spatial streams, the receiver requires knowledge of these power ratios.

In the case of an ABF-PPDU, the values of the power level of each spatial stream can be varied as long as the total output power is maintained constant. Mathematically this can be viewed as multiplying the data vector by an $N_{SS}$ x $N_{SS}$ diagonal matrix, P, where the entries on the diagonal matrix are positive and the sum of the squares of the diagonal entries is $N_{SS}$. In other words,

$$p_1^2 + p_2^2 + \ldots + p_{N_{SS}}^2 = N_{SS} \quad (53)$$

After the scaling of power ratios, the beamforming matrix, V, is applied. The operation of power scaling and beamforming is represented as,

$$\vec{y} = V \cdot P \cdot \vec{x} \quad (54)$$

Transmitter should determine the power levels for each spatial stream based on the channel estimates obtained from the sounding packet.

###### 11.2.3.1.1.1 Unequal power loading (Informative)

In order to decode the received ABF-PPDU, the receiver must estimate the power ratios between the spatial streams, which may not be equal to each other.

Once the streams of data have been separated at the receiver, the power ratios of the separated spatial streams can be estimated by estimating the power ratios of the pilot tones. The spatial streams of data can then be scaled using the estimate of the power ratios, derived from the power of the pilot tones.

#### 11.2.3.1.1.2 Extended MCS set for ABF-MIMO mode

ABF-MIMO would use different modulation/coding scheme at each spatial stream. As a result, MCS fields in ABF-MIMO mode have been extended, as shown in Table 29.

**Table 29: Extended MCS set for ABF-MIMO**

| ID# | Stream Count | Stream ID vs Modulation&Coding | | | | Full GI | | Half GI | |
|---|---|---|---|---|---|---|---|---|---|
| | | stream 1 | stream 2 | Stream 3 | stream 4 | Rate in 20MHz | Rate in 40MHz | Rate in 20MHz | Rate in 40MHz |
| 33 | 1 | 256QAM, 3/4 | N/A | N/A | N/A | 72 | 162 | 80 | 180 |
| 34 | 2 | QPSK, 3/4 | BPSK, 1/2 | N/A | N/A | 24 | 54 | 26.667 | 60 |
| 35 | 2 | QPSK, 3/4 | BPSK, 3/4 | N/A | N/A | 27 | 60.75 | 30 | 67.5 |
| 36 | 2 | 16QAM, 1/2 | QPSK, 1/2 | N/A | N/A | 36 | 81 | 40 | 90 |
| 37 | 2 | 16QAM, 3/4 | QPSK, 1/2 | N/A | N/A | 48 | 108 | 53.333 | 120 |
| 38 | 2 | 16QAM, 3/4 | QPSK, 3/4 | N/A | N/A | 54 | 121.5 | 60 | 135 |
| 39 | 2 | 64QAM, 2/3 | BPSK, 1/2 | N/A | N/A | 54 | 121.5 | 60 | 135 |
| 40 | 2 | 64QAM, 3/4 | QPSK, 3/4 | N/A | N/A | 72 | 162 | 80 | 180 |
| 41 | 2 | 64QAM, 2/3 | 16QAM, 1/2 | N/A | N/A | 72 | 162 | 80 | 180 |
| 42 | 2 | 256QAM, 3/4 | 16QAM, 1/2 | N/A | N/A | 96 | 216 | 106.67 | 240 |
| 43 | 2 | 256QAM, 3/4 | 16QAM, 3/4 | N/A | N/A | 108 | 243 | 120 | 270 |
| 44 | 2 | 256QAM, 3/4 | 256QAM, 3/4 | N/A | N/A | 144 | 324 | 160 | 360 |
| 45 | 3 | 16QAM, 3/4 | 16QAM, 1/2 | QPSK, 1/2 | N/A | 72 | 162 | 80 | 180 |
| 46 | 3 | 64QAM, 2/3 | QPSK, 3/4 | BPSK, 1/2 | N/A | 72 | 162 | 80 | 180 |
| 47 | 3 | 64QAM, 3/4 | 16QAM, 1/2 | QPSK 3/4 | N/A | 96 | 216 | 106.67 | 240 |
| 48 | 3 | 64QAM, 3/4 | 16QAM, 3/4 | QPSK, 3/4 | N/A | 108 | 243 | 120 | 270 |
| 49 | 3 | 64QAM, 3/4 | 64QAM, 2/3 | BPSK, 1/2 | N/A | 108 | 243 | 120 | 270 |
| 50 | 3 | 64QAM, 3/4 | 64QAM, 3/4 | 16QAM, 3/4 | N/A | 144 | 324 | 160 | 360 |
| 51 | 3 | 256QAM, 3/4 | 64QAM, 2/3 | 16QAM, 1/2 | N/A | 144 | 324 | 160 | 360 |
| 52 | 3 | 256QAM, 3/4 | 64QAM, 3/4 | QPSK 3/4 | N/A | 144 | 324 | 160 | 360 |
| 53 | 3 | 256QAM, 3/4 | 64QAM, 3/4 | 16QAM, 3/4 | N/A | 162 | 364.5 | 180 | 405 |
| 54 | 3 | 256QAM, 3/4 | 256QAM, 3/4 | QPSK 3/4 | N/A | 162 | 364.5 | 180 | 405 |
| 55 | 3 | 256QAM, 3/4 | 256QAM, 3/4 | 64QAM, 2/3 | N/A | 192 | 432 | 213.33 | 480 |
| 56 | 4 | 64QAM, 2/3 | 16QAM, 3/4 | BPSK, 1/2 | BPSK, 1/2 | 96 | 216 | 106.67 | 240 |
| 57 | 4 | 64QAM, 3/4 | 64QAM, 3/4 | 16QAM, 1/2 | QPSK, 1/2 | 144 | 324 | 160 | 360 |
| 58 | 4 | 256QAM, 3/4 | 64QAM, 3/4 | 64QAM, 2/3 | QPSK, 3/4 | 192 | 432 | 213.33 | 480 |
| 59 | 4 | 256QAM, 3/4 | 64QAM, 3/4 | 64QAM, 3/4 | QPSK, 1/2 | 192 | 432 | 213.33 | 480 |
| 60 | 4 | 256QAM, 3/4 | 256QAM, 3/4 | 16QAM, 3/4 | QPSK, 1/2 | 192 | 432 | 213.33 | 480 |
| 61 | 4 | 256QAM, 3/4 | 256QAM, 3/4 | 64QAM, 2/3 | 16QAM, 1/2 | 216 | 486 | 240 | 540 |
| 62 | 4 | 256QAM, 3/4 | 256QAM, 3/4 | 64QAM, 3/4 | QPSK, 3/4 | 216 | 486 | 240 | 540 |
| 63 | reserved | reserved | reserved | reserved | reserved | | | | |

#### 11.2.3.2 Transmitter Architecture in ABF-MIMO mode

The transmitter architecture for the ABF-MIMO mode includes the provision for independent MCS for each spatial stream. The Transmit datapath architecture is shown in Figure 72:

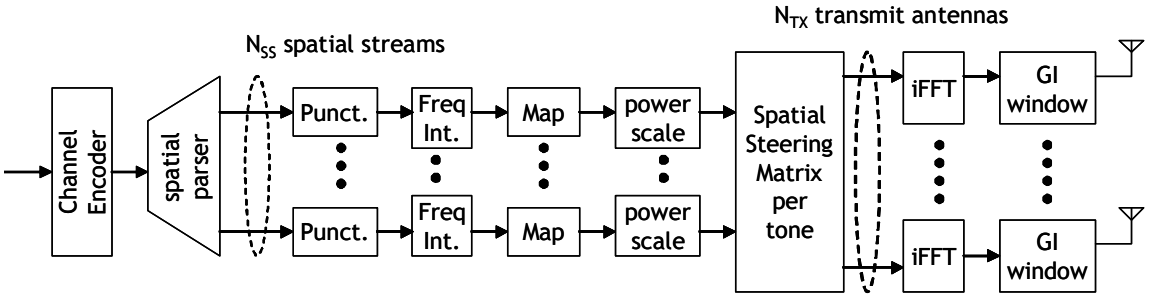



**Figure 72: Transmit Datapath Architecture for ABF-MIMO mode**

##### 11.2.3.2.1 Subcarrier Modulation Mapping in ABF-MIMO mode

256QAM is introduced in the ABF-MIMO mode. The normalization factor $K_{MOD}$ for 256QAM is $1/\sqrt{170}$ . For 256-QAM, $b_0b_1b_2b_3$ determines the I value and $b_4b_5b_6b_7$ determines the Q value, as illustrated in Table 30. The constellation mapping for 256QAM is as follows.

**Table 30: Constellation Mapping for 256-QAM in ABF-MIMO Mode**

| Input bits $b_0b_1b_2b_3$ | I-out |
|---|---|
| 0000 | -15 |
| 0001 | -13 |
| 0011 | -11 |
| 0010 | -9 |
| 0110 | -7 |
| 0111 | -5 |
| 0101 | -3 |
| 0100 | -1 |
| 1100 | 1 |
| 1101 | 3 |
| 1111 | 5 |
| 1110 | 7 |
| 1010 | 9 |
| 1011 | 11 |
| 1001 | 13 |
| 1000 | 15 |

| Input bits $b_4b_5b_6b_7$ | Q-out |
|---|---|
| 0000 | -15 |
| 0001 | -13 |
| 0011 | -11 |
| 0010 | -9 |
| 0110 | -7 |
| 0111 | -5 |
| 0101 | -3 |
| 0100 | -1 |
| 1100 | 1 |
| 1101 | 3 |
| 1111 | 5 |
| 1110 | 7 |
| 1010 | 9 |
| 1011 | 11 |
| 1001 | 13 |
| 1000 | 15 |

##### 11.2.3.2.2 Spatial Parsing with Unequal Puncturing Rates

Puncturing is performed after parsing, as shown in Figure 72 (which is different from basic BF-MIMO, as shown in Figure 71). Parsing is done in cycles. During each cycle, a block of coded bits is parsed to each spatial stream. These blocks are taken to be integer multiples of the puncture cycle of the code; that is, for a rate n/(n+1) puncturing, the puncture cycle is n trellis stages, or 2n un-coded bits (the mother code is rate ½). Parameters of the parser are selected to

yield the smallest parsing cycle length, hence ensure good mixing of spatial streams within the constraint length of the code.

### 11.2.4 Low-Density Parity-Check Coding (Optional Mode)

Optional Low-Density Parity-Check (LDPC) coding may be used with all MCS's from Table 26. Utilization of LDPC codes with the optional advanced transmit beamforming (clause 11.2.3) is TBD. When encoding specified in this clause is applied, convolutional encoder and associated puncturing and padding shall not be used.

#### 11.2.4.1 Code Rates and Codeword Lengths

Code rate (R) of the LDPC code may be selected from the set of code rates defined for mandatory convolutional codes (1/2, 2/3, 3/4 and 7/8 ). One of two codeword sizes is used to encode packets of length specified by HT-LENGTH parameter. Codeword size in bits, N, may be 576 or 1728, depending on the value of HT-LENGTH parameter, as follows:

If HT-LENGTH > 226 bytes, N = 1728 bits, otherwise N = 576 bits.

#### 11.2.4.2 PPDU Encoding using LDPC Codes

This subclause, which specifies the LDPC encoding, replaces corresponding procedure defined for mandatory convolutional codes.

LDPC codes are block codes that are specified by the parity check matrix of size MxN , which defines an LDPC block code (N,K), where K is the information block size in bits, N is the length of the codeword, and M is the number of parity check bits, M=N-K. Code rate is defined as R=K/N. The general characteristic of an LDPC parity check matrix is a low density of non-zero elements (1's in this case), which allows utilization of efficient decoding algorithms. LDPC parity check matrix is designed in a way that enables simple encoding as well. It can be represented in the following form:

$$\mathbf{H} = [\mathbf{H}^d \mid \mathbf{H}^p]$$

$\mathbf{H}^d$ is an MxK matrix and corresponds to the "data" bits of the codeword. The design of this matrix ensures high coding gain. $\mathbf{H}^p$ is an MxM modified "dual diagonal" matrix, which corresponds to the "parity" bits of the codeword. LDPC codes applied here are systematic and canonic block codes. Codewords have the following structure:

$$\mathbf{c} = \begin{bmatrix} \mathbf{d} \\ \mathbf{p} \end{bmatrix}$$

where $\mathbf{d} = [d_0, d_1, ..., d_{K-1}]^T$ is the block of (uncoded) data bits and $\mathbf{p} = [p_0, p_1, ..., p_{M-1}]^T$ are the parity bits. A codeword is any binary N-vector $\mathbf{c}$ that satisfies:

$$\mathbf{Hc} = \mathbf{H}^d\mathbf{d} + \mathbf{H}^p\mathbf{p} = \mathbf{0}.$$

Since the information packet size may not in general be a multiple of number of information bits per codeword, procedure for encoding is defined in this subclause. The encoding procedure uses the following parameters as input:

HT-LENGTH – the number of information octets to encode and transmit using selected MCS
MCS – modulation type and code rate set

Based on the MCS, following two parameters are derived first:

$N_{CBPS} = N_{BPSC} * N_{SD} * N_{SS}$, number of coded bits per OFDM symbol
$N_{DBPS} = N_{CBPS} * R$, number of information bits per OFDM symbol

where: $N_{BPSC}$ is the number of coded bits per sub-carrier, $N_{SD}$ is the number of data sub-carriers, and $N_{SS}$ is the number of spatial streams.

Both shortening (reduction of number of bits in the information portion of the codeword) and puncturing (reduction of number of bits in the parity portion of the codeword) may be applied in order to ensure minimum overhead without degrading performance. If $N_{DBPS}$ is above a pre defined threshold, only shortening is used. The procedure for encoding $N_{INFO\_BITS}$ = HT-LENGTH∗8 consists of the following steps:

a) Encoding parameters computation

Determine the number of codewords, $N_{CWORDS}$, to transmit. For each of the codewords of length $N_1 \le N$ determine amount of the information bits to encode, $K_1 \le K$, as well as the number of parity check bits to be transmitted, $M_1 \le M$ ($M_1 = N_1 - K_1$). This, in turn, determines by how many bits to shorten information portion of the codeword (number of zeros to pad the information field), $N_{PAD\_CW}$, as well as how many bits to puncture (remove bits from the parity portion of the codeword), $N_{PUNCTURE\_CW}$. In some cases it may be required that the last codeword has different number of data and parity bits, $K_{1\_LAST}$ and $M_{1\_LAST}$ , respectively, (and consequently $N_{PAD\_CW\_LAST}$ and $N_{PUNCTURE\_CW\_LAST}$) than the other codewords.

```
if NDBPS ≤ 216
        NOFDM = ceiling(NINFO_BITS /NDBPS) + 1
        NCWORDS = ceiling(NOFDM*NCBPS/N)
        N1 = floor(NOFDM*NCBPS/ NCWORDS)
        K1 = ceiling(NINFO_BITS/ NCWORDS)
        NPAD_CW = K - K1
        NPUNCTURE_CW = max(0,(N-N1- NPAD_CW))
        if NCWORDS > 1
                K1_LAST = NINFO_BITS - K1*(NCWORDS-1)
                NPAD_CW_LAST = K - K1_LAST
                N1_LAST = NOFDM*NCBPS - N1*(NCWORDS-1)
                NPUNCTURE_CW_LAST = max(0,(N-N1_LAST- NPAD_CW_LAST))
        end
else
        NCWORDS = ceiling(NINFO_BITS /K)
        K1 = ceiling(NINFO_BITS/ NCWORDS)
        NPAD_CW = K - K1
```

if $N_{CWORDS} > 1$
$K_{1\_LAST} = N_{INFO\_BITS} - K_1*(N_{CWORDS}-1)$
$N_{PAD\_CW\_LAST} = K - K_{1\_LAST}$
end
end

b) Last OFDM symbol padding field parameter computation

If the total number of coded bits, $N_{CODED\_BITS\_TOTAL}$, doesn't fit integer number of OFDM symbols, then additional padding (scrambled zeros) bits are added to the last OFDM symbol. Number of those bits, $N_{PAD\_OFDM\_LAST}$, is computed as follows:

if remainder($N_{CODED\_BITS\_TOTAL}$,$N_{CBPS}$) > 0
$N_{PAD\_OFDM\_LAST} = N_{CBPS}$ - remainder($N_{CODED\_BITS\_TOTAL}$,$N_{CBPS}$)

where $N_{CODED\_BITS\_TOTAL}$ is computed as follows:

if $N_{CWORDS} > 1$
$N_{CODED\_BITS\_TOTAL} = N_1*(N_{CWORDS}-1) + N_{1\_LAST}$
else
$N_{CODED\_BITS\_TOTAL} = N_1*N_{CWORDS}$
end

$N_{PAD\_OFDM\_LAST}$ zeros are appended to $N_{INFO\_BITS}$ from the input data buffer and passed to the scrambler.

c) LDPC encoding

Generate all $N_{CWORDS}$ codewords by applying any of the encoding methods, such that $\mathbf{Hc}_i = \mathbf{0}$, where i=0, 1, …, $N_{CWORDS}$-1 with shortening and puncturing as necessary. **H** is the parity check matrix for the selected codeword size and code rate. Only one **H** matrix is used for the entire packet. The information vector for the i-th codeword to be encoded is formed by concatenating $K_1$ scrambled information bits and $N_{PAD\_CW} = K - K_1$ zeros:

$$\mathbf{d}^i = [\underbrace{d^i_0, d^i_1, ..., d^i_{K_1-1}}_{K}, \overbrace{0,0,...,0}^{N_{PAD\_CW}}]^T$$

After the encoding, obtained codeword is punctured (if necessary) by removing the last $N_{PUNCTURE\_CW}$ parity bits:

$$\mathbf{c}^i = [\underbrace{d^i_0, d^i_1, ..., d^i_{K_1-1}}_{K}, \overbrace{0,0,...,0}^{N_{PAD\_CW}}, \underbrace{p^i_0, p^i_1, ..., p^i_{M_1-1}}_{M}, \overbrace{p^i_{M_1}, p^i_{M_1+1}, ..., p^i_{M-1}}^{N_{PUNCTURE\_CW}}]^T$$

Zeros used for padding data part and punctured bits are not transmitted over the air. Rather, a concatenation of $K_1$ data bits and $M_1$ parity bits is transmitted only:

$$\mathbf{c}^i_{transmit} = [\underbrace{d^i_0, d^i_1, ..., d^i_{K_1-1}}_{K_1}, \underbrace{p^i_0, p^i_1, ..., p^i_{M_1-1}}_{M_1}]^T$$

d) Codeword and the last OFDM symbol padding field concatenation

Concatenate $N_{CWORDS}$ codewords and $N_{PAD\_OFDM\_LAST}$ padding bits (denoted as q's below) to form a vector of bits to be transmitted:

$$\mathbf{c}_{transmit} = [d_0^0,...,d_{K_1-1}^0, p_0^0,..., p_{M_1-1}^0,.....,d_0^{N_{CWORDS}-1},...,d_{K_{1\_LAST}-1}^{N_{CWORDS}-1}, p_0^{N_{CWORDS}-1},..., p_{M_{1\_LAST}-1}^{N_{CWORDS}-1}, q_0,...,q_{N_{PAD\_OFDM\_LAST}-1}]^T$$

Bit $d_0^0$ is transmitted first.

### 11.2.4.3 Parity Check Matrices

Parity check matrices **H** used in Step c) of the encoding procedure, described in sub-clause 11.2.4.2, are derived from one of the "base" parity check matrices, $\mathbf{H_b}$, specified below. One base matrix is defined per code rate. Size of a base parity check matrix is denoted as $M_b$x$N_b$. $N_b$, the number of columns in the base matrix, is fixed for all code rates, $N_b$=24. $M_b$, the number of rows in the base matrix, depends on the code rate as follows: $M_b = N_b(1-R)$. Parity check matrix **H** of size MxN is generated by expanding the base matrix for the selected rate, $\mathbf{H_b}$, z-times: $z=N/N_b=M/M_b$. The expansion operation is defined by element values of the base matrix. Each non-negative base matrix element, s, is replaced by a zxz identity matrix, $\mathbf{I}_z$, cyclically shifted to the right $s'=s_{mod(z)}$ times. Each negative number (-1) in the base matrix is replaced by a zxz zero matrix, $\mathbf{0}_{zxz}$. For the codeword of size 576 bits, z = 24 and for the codeword of size 1728 bits, z = 72.

Base matrices specification

Rate 1/2: $M_b$x$N_b$ = 12x24

```
 0   0  -1   0  -1   0  -1  -1  -1   0  -1  -1   1   0  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1
29  -1   0  26  -1  -1   0  -1   0  -1  -1  -1  -1   0   0  -1  -1  -1  -1  -1  -1  -1  -1  -1
-1  -1  -1  21   0  -1  17  -1  -1  38  -1   0  -1  -1   0   0  -1  -1  -1  -1  -1  -1  -1  -1
43  -1  -1  30  -1  -1  -1   0  -1  41   0  -1  -1  -1  -1   0   0  -1  -1  -1  -1  -1  -1  -1
 5  -1   1  -1  -1  20  35  -1  -1   2  -1  -1  -1  -1  -1   0   0  -1  -1  -1  -1  -1  -1  -1
-1  46  -1  -1  -1  -1  22  -1  40   8  -1  -1   0  -1  -1  -1  -1   0   0  -1  -1  -1  -1  -1
-1  -1  -1   9  -1  -1  18  13  -1  35  -1  27  -1  -1  -1  -1  -1  -1   0   0  -1  -1  -1  -1
 2  -1  44  -1  -1  -1  27  -1  -1  25  18  -1  -1  -1  -1  -1  -1  -1  -1   0   0  -1  -1  -1
33  35  -1  29  -1  -1  16  -1  -1  -1  -1  30  -1  -1  -1  -1  -1  -1  -1  -1   0   0  -1  -1
-1  -1  -1   4   4  -1  -1  -1  15  17  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1   0   0  -1
 5  -1  -1  19  -1  14  -1  -1  -1  -1  11  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1   0   0
10  -1  -1  -1  21  -1  18   8  -1  -1  -1  -1   1  -1  -1  -1  -1  -1  -1  -1  -1  -1  -1   0
```

Rate 2/3: $M_b$x$N_b$ = 8x24

```
68  -1  -1  24  -1  -1  64  -1   2  -1  11  -1  -1  44  -1   3   1   0  -1  -1  -1  -1  -1  -1
-1  14  57  -1  -1  66  -1  -1  32  -1  13  -1  55  -1  67  -1  -1   0   0  -1  -1  -1  -1  -1
-1   4  -1  -1  20  -1  19  -1  -1  44  -1  19  -1  30  18  -1  -1  -1   0   0  -1  -1  -1  -1
-1  -1  26  -1  10  21  -1  -1  -1  -1  56  54  54  -1  -1  37  -1  -1  -1   0   0  -1  -1  -1
19  -1  -1  -1  31  -1  -1  50  27  -1  -1  40  -1   4  -1  -1   0  -1  -1  -1   0   0  -1  -1
-1  -1  37  18  -1  -1  -1  41  -1  68  -1  -1   2  -1  50   5  -1  -1  -1  -1  -1   0   0  -1
67  -1  -1  -1  -1   4  68  -1  -1  69  -1  34  -1  40  -1  61  -1  -1  -1  -1  -1  -1   0   0
-1  45  -1  26  -1  -1  -1  16  -1  35  26  -1   5  -1  68  -1   1  -1  -1  -1  -1  -1  -1   0
```

Rate 3/4: $M_b$x$N_b$ = 6x24

```
 0  23  -1  -1   0  47  53   1  -1   5  -1  13  66  34  -1  62  65  -1   1   0  -1  -1  -1  -1
14  57   7  11  -1  -1  69  -1  25  34  -1  25  13  -1  19  70  -1  35  -1   0   0  -1  -1  -1
59   3  -1  18  -1  43  48  58  -1  29  -1  54  49  -1  25   0  66  -1  -1  -1   0   0  -1  -1
15   1   2  -1  -1  39  19  -1  37  64  52  -1  28   4  -1  21  20  -1   0  -1  -1   0   0  -1
22  64  -1  48  60  -1  36  -1  15  62  68  -1  46  55  -1  41  -1   7  -1  -1  -1  -1   0   0
68  36  57  -1  55  -1  41  34  -1  45  46  -1   8  -1  37  44  -1  15  -1  -1  -1  -1  -1   0
```

Rate 7/8: $M_b x N_b = 3x24$

```
 34  61  67  67  12  35  62  61  37  18  51  23  22  31  67  32   7  63  67  14  57   1   0  -1
  1  62  14  71  17  42  50  39  33  27  43  33  15  10  61  38  53  53  16  70  46   0   0   0
  8  65  34   8   9  30  63  57  24   0  45  31  49  24  42  66  40  70   0  28  69   1  -1   0
```

(END)

# APPENDIX S

**IEEE P802.11**
**Wireless LANs**

# TGn Sync Proposal Technical Specification

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## Abstract


This document presents the technical specification for the
MAC and the PHY layer of the TGn Sync proposal to IEEE 802.11 TGn



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# 1 Executive Summary

The TGn Sync team respectfully submits its complete proposal. The team is comprised of 802.11 WG participants whose companies represent a broad range of markets, including, PC, Enterprise, Consumer Electronics, Handset, Semiconductor and Public Access. Since these companies are based in the US, Europe and Asia Pacific, the team has had the benefit of a worldwide perspective, both in terms of perceived market demand as well as regulatory concerns (including channel bandwidth limitations, limited channel access, restricted transmission times, etc.).

Our goal has been to align (or "sync" with) 802.11n members to a single set of core positions prior to the TGn down selection phase. By aligning before entrenched positions form, we hope to increase the possibility of a more rapid introduction of an 802.11n standard.

The team has worked as a technical group for many months to develop a TGn proposal, recognizing that whatever decisions were made had to ultimately survive the TGn process and therefore be based solely on technical merit. There were no signed agreements involved in joining the TGn Sync team. There was no attempt to develop joint IP and each company was expected to abide by the same reasonable and non-discriminatory terms that the IEEE bylaws require.

The technical approach balances market expectations with design practicality. The solution is a robust, scalable architecture targeting the least amount of complexity. In fact, the basic configuration delivers a maximum rate of 243 Mbps using only two antennas. This rate is consistent with the historical trend of 5x with each generation of 802.11 (802.11/2Mbps, 802.11b/11Mbps, and finally 802.11a/ 54Mbps). The proposal also incorporates options for rates up to 720 Mbps. This choice of higher peak data rates was seen as critical for future proofing this next generation of WLAN.

The PHY techniques used to achieve the higher data rates involve a MIMO evolution of 802.11 OFDM PHY with spatial division multiplexing of spatial streams, wider bandwidth options (either 20MHz or 40MHz) and an optimized interleaver for both the 20 MHz and 40MHz channelizations. Additionally, optional enhancements include advanced FEC coding techniques (LDPC), space time block coding (STBC), and transmit beamforming with negligible additional cost in the receiving client device and/or additional RF chains. These options provide extra scalability if additional robustness and/or throughput is required.

The TGn Sync proposal also offers seamless interoperability with 802.11 legacy devices. This interoperability is achieved with an enhanced 802.11 preamble design and efficient PHY and MAC level mechanisms, which also provide robustness and cost-effectiveness.

The features added to improve MAC efficiency – for higher throughput and overall system performance – include aggregation, bi-directional data flow, enhanced Block Ack, channel management (including a receiver assisted channel training protocol) and feedback mechanisms that enable rate adaptation. Protection mechanisms are also added to achieve the seamless

interoperability and coexistence with legacy devices mentioned above. The approach supports 802.11e and proposes new features for further enhancement.

## 1.1 Proposal Structure

The TGn Sync complete proposal meets the IEEE 802.11n PAR, meets all functional requirements, and addresses all mandatory requirements of the comparison criteria.

This document contains a technical specification of the proposed MAC and PHY enhancements.

[5] contains the presentation of the proposal in powerpoint format. (Please note that the summary presentation [4] is no longer up to date).

[6] contains a statement of compliance to the IEEE 802.11 TGn FRCC requirements.

[7] and [8] contain FRCC results (and others) for the PHY and MAC respectively.

[9] and [10] are Excel spreadsheets containing detailed FRCC results from MAC simulations, and [11] describes the methodology used in these simulations.

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[11] IEEE 802.11-04/895, "TGnSync Proposal MAC Simulation Methodology"

# 3 Definitions

**Aggregate:** A PSDU transported by the PHY with an aggregate attribute indicating that it contains multiple MPDUs.

**Extended PHY Protection:** A technique that uses the legacy signal field to protect from legacy transmission the contents of more than on HT format PPDU.

**Initiator:** A STA that holds a TXOP and transmits the first frame in a frame exchange sequence including aggregate PPDUs and/or aggregate control frames (IAC/RAC/MRAD).

**LongNAV:** A MAC-layer protection mechanism that protects multiple PPDUs exchanged within a TXOP

**OFDM Format:** Definition of subcarrier frequencies relative to the channel center frequency, and specification of data bearing and pilot subcarriers.

**Originator:** A QSTA that sends data using the Block ACK mechanism.

**Preamble: short and long:** Portions of the 802.11 HT PPDU used for PHY synchronization and channel estimation.

**Receiver:** Any STA receiving the current PPDU.

**Recipient:** A QSTA that receives data using the Block ACK mechanism.

**Responder:** A STA that responds to an initiator in a frame exchange sequence including aggregate PPDUs and/or aggregate control frames.

**Reverse Direction:** Data flow from a responder to an initiator.

**SIGNAL FIELD:** Portion of the 802.11 HT PHY PPDU that contains “Rate” and “Duration”, part of the PLCP header.

**Symbol:** Typically refers to an OFDM symbol, which is a collection of sub-carriers (or tones)

# 4 Abbreviations and acronyms

| Term | Description |
|---|---|
| ACK | Acknowledgement |
| AGC | Automatic Gain Control |
| AP | Access Point |
| BF-MIMO | Beamforming MIMO |
| CAP | Controlled Access Phase |
| CDD | Cyclic Delay Diversity |
| CRC | Cyclic Redundancy Check |
| CSI | Channel State Information |
| CSIT | Channel State Information at the Transmitter |
| CTS | Clear to Send |
| DLP | Direct Link Protocol |
| EPP | Extended PHY Protection |
| ERP | Extended Rate PHY |
| FCS | Frame Check Sequence |
| FPD | Following Packet Descriptor |
| HC | Hybrid Controller |
| HT | High Throughput |
| HT-LTF | High Throughput Long Training Field |
| HT-SIG | High Throughput Signal Field |
| HT-STF | High Throughput Short Training Field |
| ICB | Increase Channel Bandwidth MPDU |
| IE | Information Element |
| LAC | Link Adaptation Control |
| LLC | Logical Link Control |
| L-LTF | Legacy Long Training Field |
| L-SIG | Legacy Signal Field |
| L-STF | Legacy Short Training Field |
| MAC | Medium Access Controller |
| MCS | Modulation Coding Scheme – includes modulation order (BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM) and FEC code rate (1/2, 2/3, 3/4, 7/8) |

| | |
|---|---|
| MFB | MCS Feedback |
| MIMO | Multiple input, multiple output (Both transmitter and receiver have multiple antennas for signaling over a point-to-point link) |
| MISO | Multiple input, single output (transmitter has multiple antennas but receiver has a single antenna) |
| MMP | MRA Multi-poll |
| MPDU | MAC protocol data unit |
| MRA | Multiple Receiver Aggregate – an aggregate that contains MPDUs for multiple receiver addresses. |
| MRC | Maximum Ratio Combining (a technique to maximize received SNR using antenna signal combining). |
| MRQ | MCS Request |
| MSDU | MAC service data unit |
| NAV | Network Allocation Vector (a MAC-level carrier-sense) |
| $N_{RX}$ | Number of Receive Antennas |
| $N_{SD}$ | Number of Data Subcarriers |
| $N_{SS}$ | Number of Spatial Streams |
| $N_{STS}$ | Number of Space-Time Streams (created after STBC encoding) |
| $N_{TX}$ | Number of Transmit Antennas |
| OFDM | Orthogonal Frequency Division Multiplexing |
| PHY | Physical Layer |
| PLCP | PHY layer convergence protocol |
| PPDU | PHY protocol data unit |
| PSDU | PHY service data unit |
| Pure Mode | A mode of operation of a BSS in which there are no legacy devices |
| QAP | QoS access point |
| QoS | Quality of service |
| QSTA | QoS station |
| RAC | Royal Automobile Club |
| RDG | Reverse Direction Grant |
| RDR | Reverse Direction Request |
| RDTID | Reverse Direction Traffic Identifier |
| RPO | Response Period Offset |
| RR | Rate Recommendation |

| | |
|---|---|
| RSSI | Receive Signal Strength Indicator |
| RTS | Request to send |
| RX | Receiver |
| SAP | Service Access Point |
| SF | Signal Field |
| SIFS | Short inter-frame spacing |
| SIMO | Single input, multiple output (transmitter has a single antenna, receiver has multiple antennas) |
| SISO | Single input, single output (both transmitter and receiver have a single antenna) |
| SoP | Start of Packet (i.e. PPDU Packet) |
| SRA | Single Receiver Aggregate – an aggregate that contains MPDUs for a single receiver address. |
| STA | Station |
| SVD | Singular Value Decomposition: For an arbitrary matrix A = $USV^H$ |
| TC | Traffic Category |
| TGe | 802.11 Task Group e - Quality of Service |
| TGn | 802.11 Task Group n - Enhancements for Higher Throughput |
| TRQ | Training Request |
| TS | Traffic Stream |
| TSID | Traffic Stream Identifier |
| TSPEC | Traffic specification |
| TX | Transmitter |
| TXOP | Transmission opportunity |

1

2

# 5 Introduction

## 5.1 Purpose

This document defines proposed Enhancements for Higher Throughput within the scope of the Project Authorization Request (PAR) [3] formulated for IEEE 802.11 Task Group n.

## 5.2 General description of MAC enhancements

The proposed MAC enhancements assume a baseline specification defined by IEEE 802.11 standard [1] and its later amendments, including the draft IEEE 802.11e amendment [2]. The purpose of the enhancements is to significantly improve throughput, providing a maximum throughput of at least 100Mbps, as measured at the MAC data service access point (SAP).

The features supported by this TGn Sync MAC proposal are as follows:

- A Frame Aggregation format that allows aggregation of multiple Data and Control MPDUs in one PPDU. Note, an aggregate can also include a single management frame, in addition to multiple data and control frames per unicast receiver address. Aggregation is suported at the MSDU level and at the MPDU level.

- Aggregate frame exchange rules that control the exchange of multiple MPDUs per PPDU between an initiating STA and a responding STA.

- Multi receiver Multi-Poll (MMP) sequence rules that allow the exchange of multiple MPDUs between an AP and multiple responding STA and support enhanced power saving at the STA.

- A receiver assisted channel training protocol.

- A reverse direction data protocol that allows efficient channel access for single and multiple responders within a frame exchange sequence.

- Protection of the new frame exchange sequences may be provided through one of two mechanisms: a MAC-level mechanism based on NAV reservations, and a PHY-level mechanism using the legacy PLCP rate/length information.

- Mechanisms to manage coexistence of legacy and HT devices.

- Channel management and channel selection methods.

## 5.3 General description of PHY enhancements

With the aim to increase the maximum PHY layer data rate, we have introduced two primary techniques in our proposal:

- Transmission of Multiple Spatial Streams via Multiple Transmit Antennas. Our recommendation is to make 2 spatial streams mandatory, with the option to scale to 4 spatial streams.

- Extended Bandwidth signaling. 20MHz channelization shall be mandatory worldwide. Our recommendation is to support 40MHz channelization in regulatory domains that will permit wider bandwidth operation

We have also introduced several secondary techniques for increasing throughput. These include:

- Increasing the number of data tones to 52 in 20MHz.

- A reduced guard interval of 400ns (i.e. half-GI), channel dispersion permitting (e.g. TGn channel model B). Support for half-GI is optional.

- Higher channel coding rate of 5/6. Support for 5/6 is mandatory in 20MHz.

- Optional support for 256-QAM in the Transmit Beamforming mode.

Due to the susceptibility of a wireless link to multipath fading, especially in a MIMO channel, our proposal introduces three optional techniques for improving the robustness of the link between the transmitter and the receiver, with the aim to keep the client (station) configuration low-cost and low-power:

- Transmitter beamforming (TxBF).

- STBC (Space-Time Block Coding)

- Advanced channel coding. Our proposal includes LDPC as an option. LDPC codes exhibit a larger minimum free distance compared to the existing 802.11a convolutional code, and hence are able to better exploit the frequency and spatial diversity in the channel.

Our proposal supports full backwards compatibility with existing 802.11a/b/g standards. Our preamble design support PHY layer interoperability with the OFDM preamble from 802.11a/g, while providing a robust mechanism for synchronization of the high throughput data.

# 6 Frame Formats

This clause specifies the format of new HT frames.

Reserved fields and subfields shall be transmitted as zeroes and shall be ignored by an HT receiver

## 6.1 MPDU Header

### 6.1.1 Frame Control Field

The Order field of the Frame Control field is defined as following:

| Context | Description |
|---|---|
| non-QoS Data MPDU | As defined in 802.11 |
| QoS data, BAR and BA | RDG/More PPDU as defined below |

### 6.1.2 RDG / More PPDU Field

This meaning of this field depends upon the role of the device transmitting the frame as follows:

| Role | Value | Description |
|---|---|---|
| Initiator<br>"RDG Field" | 0 | No reverse grant |
| | 1 | A reverse grant is present, as defined by the Duration/ID field.<br><br>The response PPDU(s) shall fit within the duration defined in the Duration/ID field of the MPDU carrying the RDG |
| Responder<br>"More PPDU Field" | 0 | The PPDU carrying the MPDU is the last transmission by the responder. |
| | 1 | The PPDU carrying the MPDU is followed by another PPDU. |

The "More PPDU Field" shall be set to the same value in all MPDUs of type QoS Data, BAR and BA within the same response aggregate.

## 6.2 Control frames

This section defines new control frame subtypes as listed below:

| Control Frame Subtype | Name |
|---|---|
| LAC | Link adaptation control |
| MMP | Multiple receiver aggregate multi-poll |
| Calibration Training | Calibration Training frame |

### 6.2.1 Link Adaptation Control (LAC) MPDU

#### 6.2.1.1 Introduction

This MPDU supports control of MIMO training requests and exchange of link adaptation information. It may be sent by either initiator or recipient during an aggregation exchange. It may be sent by itself (in which case the response is another LAC frame, or aggregated in either direction).

There are a number of groups of fields (LAC elements), which perform specific purposes within the MPDU as described below:

| Element Name | Purpose of item |
|---|---|
| RTS – Request to Send | Detects collisions at the receiver<br>Tests state of NAV in the receiver<br>Sets NAV reservation near Transmitter (LongNAV) |
| CTS – Clear-to-Send | Response to RTS indicates that the medium is clear |
| TRQ – MIMO training request | Request to train the channel<br>Used for MIMO with implicit Feedback. |
| MRQ – MCS request | Request for MCS feedback |
| MFB – MCS Feedback | Closed loop channel adaptation feedback |

Note, although described as "elements", the structure of the LAC MPDU containing these elements is fixed.

#### 6.2.1.2 Format of LAC MPDU

This section defines the format of the LAC MPDU.
The LAC MPDU has a fixed structure. Fields that are not used are present, but reserved.

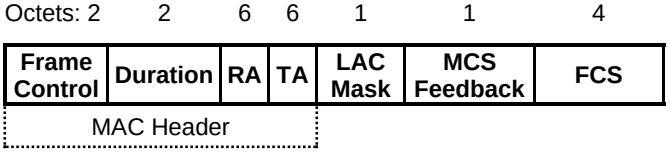


**Figure 1 – LAC MPDU**

| Field | Size (bytes) | Purpose |
|---|---|---|
| Frame Control | 2 | Type is control, subtype is LAC |
| Duration | 2 | |
| Receiver Address | 6 | |
| Transmitter Address | 6 | |
| LAC Mask | 1 | A bitmask indicating which LAC elements are present in the packet. |
| MCS Feedback | 1 | Contains a recommended MCS value.<br>Present when MFB is indicated, otherwise undefined. |
| FCS | 4 | |

#### 6.2.1.2.1 LAC Mask Field

This field indicates which logical elements are carried in the MPDU.

| LAC Mask Field bit | Position | Description |
|---|---|---|
| RTS | B0 | When set, indicates this is an RTS. The receiver should not generate any response if its NAV is non-zero. |
| CTS | B1 | When set, indicates this is a CTS. It is present in a LAC transmitted in response to a LAC containing the RTS flag set to 1. |
| TRQ | B2 | When set, indicates a request to train the channel.<br>Used for MIMO with implicit Feedback. |
| MRQ | B3 | When set, indicates a request for MCS feedback. |
| MFB | B4 | When set, indicates an MFB training response is present as defined by the MCS Feedback field. |

#### 6.2.1.2.2 Format of MCS Feedback Field

This field contains an MCS value and a selection for the Short GI.

The least significant 7 bits carry the MCS TXVECTOR parameter.
The most significant bit (bit7) carries the SHORT-GI TXVECTOR parameter.

### 6.2.2 Multiple Receiver Aggregate Multi-Poll (MMP) MPDU

#### 6.2.2.1 Introduction

The MMP frame is used to define multiple response periods, in combination with multiple-receiver aggregation.

The MMP frame may be transmitted in a separate PPDU, or may be aggregated with the first MRA of the MMP sequence. See section 7.1.4 (MMP exchange sequences).

#### 6.2.2.2 Format of MMP MPDU

This section defines the format of the MMP MPDU.

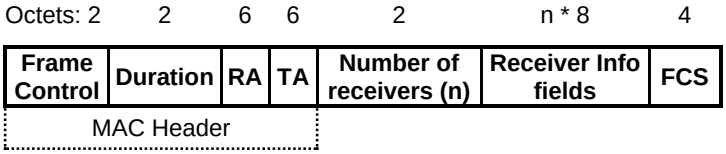



**Figure 2 – MMP MPDU**

| Field | Size (bytes) | Purpose |
|---|---|---|
| Frame Control | 2 | Frame type is Control, subtype MRAD |
| Duration | 2 | |
| Receiver Address | 6 | The RA field is the broadcast group address. |
| Transmitter Address | 6 | The TA field is the address of the STA transmitting the MRA aggregate. |
| Number of receivers | 2 | The number of receivers (n) for which MPDUs are included inside the MRA aggregate. |
| Receiver Info fields | n * 8 | n Receiver Info fields, one for each Receiver Address in the MRA aggregate. |
| FCS | 4 | |

The order of the Receiver Info fields is equal to the order in which MPDUs for the corresponding receivers appear in the MRA aggregate.

Each receiver info field carries the following information

| Subfield | Size | Purpose |
|---|---|---|
| AID | 2 bytes | Contains an association identifier that identifies the STA addressed by this record |
| TID | 4 bits | Defines the TID for transmissions by the STA |
| Reserved | 4 bits | |

| | | |
|---|---|---|
| Rx Offset | 10 bits | Defines the start of the PPDU containing the downlink data. Specified in units of 4us relative to the end of the MMP PPDU. Reserved if Rx Duration is zero. |
| Rx Duration | 10 bits | Locates the end of the downlink data [1] relative to the Rx Offset, in units of 4 us.<br>Contains zero if there is no downlink data for this AID. |
| Tx Offset | 10 bits | Defines the time when transmissions by this STA may start, in units of 4us relative to the end of the MMP PPDU.<br>Reserved if Tx Duration is zero. |
| Tx Duration | 10 bits | Defines the limit of transmission duration, in units of 4us.<br>Contains a zero if no transmission is scheduled. |

### 6.2.3 Block Ack (BA) MPDU

This section defines a compressed variant of the 802.11e BA MPDU. The variant is distinguished by setting the "Compressed" field of the BA Control field to 1.
The compression is achieved by removing fragmentation from the Block Ack mechanism, which reduces the bitmap size to 1 bit per MSDU.

The use of this mechanism is negotiated when the BA agreement is created through the exchange of ADDBA frames, and is constant for a BA agreement throughout its lifetime. This means that a BA for a particular BA agreement is always the same size.

#### 6.2.3.1 Format of BA MPDU

The frame format for the BA frame is defined as in Figure 3.

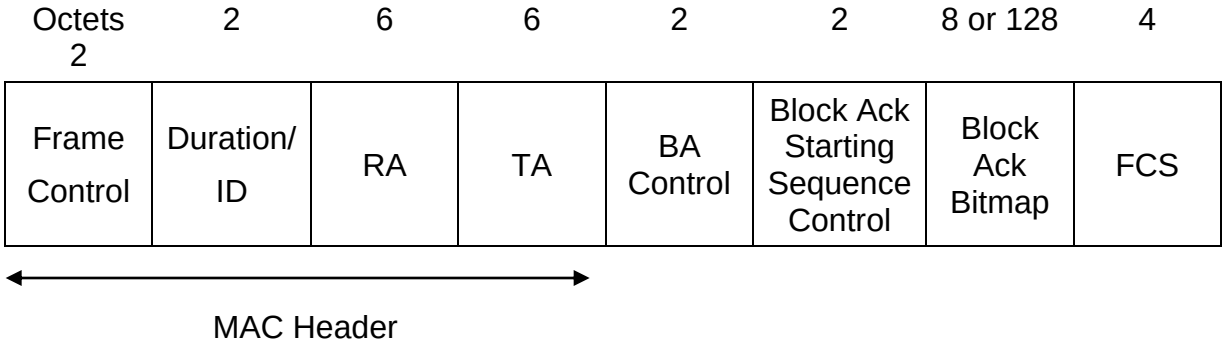



**Figure 3 – Compressed BA MPDU**

Only the BA control and Block Ack Bitmap fields are modified.

[1] Strictly: the end of the last symbol containing any data for this AID referenced to the start of the PPDU.

The BA Control Field is shown in Figure 4.

| B0 – B4 | B5 | B6 – B11 | B12 – B15 |
|---|---|---|---|
| Reserved | Compressed | NumMSDU_M1 | TID |
| Bits: 4 | 1 | 6 | 4 |

**Figure 4 – BA Control field**

The Compressed and NumMSDU_M1 are new fields.

The Compressed field selects between legacy 802.11e format and compressed format. When the Compressed field is set to 0, the BA is interpreted according to legacy 802.11e, with a 128-byte bitmap. When the Compressed field is set to 1, the BA is compressed, with an 8-byte bitmap.

The NumMSDU_M1 field defines the number of MSDUs that are acknowledged by the present bitmap, less one. For example, the NumMSDU_M1 field set as 0 indicates 1 MSDU is acknowledged by the bitmap and when it is 63, 64 MSDUs are acknowledged. The value of NumMSDU_M1 ranges from 0 to Buffer Size – 1, where Buffer Size is the ADDBA parameter that defines the BA window size.

The bitmap is interpreted according to the setting of the Compressed field, as defined in the following table.

**Table 1 – Interpretation of the BA Bitmap**

| Compressed | NumMSDU_M1 | Bitmap Length | Bitmap interpretation |
|---|---|---|---|
| 0 | 0 | 128 | Legacy 802.11e BA. |
| 1 | 0 to 63 | 8 | HT BA. Bit n acknowledges (if 1) or negatively acknowledges (if 0) an MSDU with Sequence Control = Block Ack Starting Sequence Control + 16*n. The first NumMSDU_M1 bits are valid; the remaining bits are ignored. |

### 6.2.4 Calibration Training MPDU

The frame format of the Calibration Training MPDU is defined in Figure 5.

| Octets: 2 | 2 | 6 | 6 | 1 | 1 | 4 |
|---|---|---|---|---|---|---|
| Frame Control | Duration | RA | TA | Calibration Control | Calibration Sequence | FCS |

**Figure 5 – Calibration Training MPDU**

The Calibration Control field contains:

- Number of antennas at the initiating STA *Ni* (2 bits)

- Number of antennas at the responding STA *Nr* (2 bits)
- Position (2 bits). This field is set to '0' by the STA transmitting the first frame that initiates the calibration training frame exchange sequence. The field is incremented in subsequent Calibration Training frame transmissions in the calibration training frame exchange sequence.
- *Reserved* (2 bits)

The Calibration Sequence field is incremented at the transmission of the Calibration Training frame that initiates the calibration procedure. The remaining frames in the same calibration procedure use the same Calibration Sequence value.

The Calibration Training frame is carried in a PPDU with attributes defined according to the value of the position field.

**Table 2 – PPDU attributes for Calibration Training MPDUs**

| Position Field | PPDU | TXVECTOR NLTF | TXVECTOR SOUNDING |
|---|---|---|---|
| 0 | Non-Aggregate | | 0 |
| 1 | Non-Aggregate, Sounding | Nr | 1 |
| 2 | Non-Aggregate, Sounding | Ni | 1 |

The Calibration Training frame shall be transmitted in a non-aggregate PPDU as part of the calibration training exchange defined in 8.3.

## 6.3 Management frame formats

### 6.3.1 HT Capabilities

Support for any optional features or behavior will be declared through a STA's capabilities or management elements.

**Table 3 –HT Capabilities**

| Capability | Location Size and Encoding | Contents |
|---|---|---|
| HT Supported | B0 1 bit<br>Set to 1 to indicate HT support, set to 0 otherwise. | Indicates that the device is an HT device, supporting all the mandatory features of this document.<br>This capability is indicated by the presence of the HT capability element. |
| Supported Channel Width Set | B1 1 bit<br>Set to 0 to indicate {20}, set to 1 to indicate {20,40} | Contains:<br>{20} for a device only capable of 20MHz operation<br>{20, 40} for a device capable of both 20MHz and 40MHz operation. |
| MMP Supported | B2 1 bit<br>Set to 1 to indicate MMP support, set to 0 otherwise. | When transmitted by a STA, indicates it is able to interpret the MMP frame and respond to a poll through the MMP mechanism (see section 7.1.4).<br>It also means that a STA is capable of receiving an MRA (see section 7.1.4).<br>When transmitted by an AP, indicates that it is able to transmit MMP frames. |
| Advanced Coding Capability | B3 1 bit<br>Set to 1 to indicate support for Advanced Coding. Set to 0 otherwise. | Advanced Coding Capability Indicates support for advanced coding.<br>This field has the same format as the advanced coding field defined in section **10.1.1.8**, where a bit set as one indicates that that coding type is supported. |
| Short GI Supported | B4 1 bit<br>Set to 1 to indicate support for Short GI as a receiver, set to 0 otherwise | Indicates that the STA can transmit and receive PPDUs using the SHORT GI Feature. |
| Calibration Supported | B5 1 bit<br>Set to 1 to indicate support for calibration exchanges as a responder, set to 0 | Indicates that the STA can participate in the calibration exchange defined in 8.3. |

<table>
<tr><th>Capability</th><th>Location Size and Encoding</th><th>Contents</th></tr>
<tr><td></td><td>otherwise</td><td></td></tr>
<tr><td>Number of Rx Antennas</td><td>B6-7 2 bits. Contains number of antennas less one</td><td>Indicates the number of Rx Antennas</td></tr>
<tr><td>Maximum Rx PSDU Length</td><td>B8-15 8 bits<br>Integer in range 15-18</td><td>Indicates the maximum PSDU size that can be received by the STA. See section 7.5</td></tr>
<tr><td>Supported MCS class</td><td>B16-31 16 bits<br>Used as follows:<br><table><tr><th>Bits</th><th>Capability</th></tr><tr><td>16-19</td><td>Tx 20MHz</td></tr><tr><td>20-23</td><td>Rx 20MHz</td></tr><tr><td>24-27</td><td>Tx 40MHz</td></tr><tr><td>28-31</td><td>Rx 40MHz</td></tr></table>If the supported channel bandwidth is only 20MHz, B24-B31 are reserved.</td><td>Defines the MCS capability supported by a STA.<br>MCS capability is specified independently for 20 MHz and 40 MHz.<br>See section 11.1.1.8.1 ??update for a list of MCS capability class.</td></tr>
</table>

### 6.3.1.1 HT Capability element

The HT Capability element contains a number of subfields that are used to advertise optional HT capabilities at an HT device. The HT Capability element is present in beacons, association and re-association request frames and in probe response frames. The presence of the HT Capability element indicates that the device is an HT device. The HT Capability element is defined in Figure 6.

| Octets: 1 | 1 | 4 |
|---|---|---|
| **Element ID** | **Length (2)** | **HT Capabilities Info** |

**Figure 6 – HT Capability element format**

### 6.3.2 Additional HT Information Elements

The AP will signal information in new information elements to manage the BSS. This information is defined in the table below.

### 6.3.2.1 HT Management Element

The AP will signal information in the HT Management Element defined here to manage the BSS, as shown in Figure 8. This element shall be present in all beacons and probe responses transmitted by a HT AP and by a HT STA in IBSS mode.

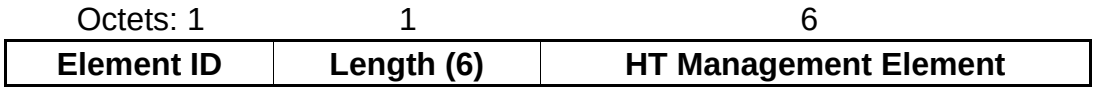



**Figure 7 – HT Management Element Format**

This information subfields in the HT Management Element field are defined in the table below.

**Table 4 – HT Management Element Subfields**

| Name | Description and Encoding |
|---|---|
| Legacy Protection | Indicates that legacy protection is required<br>B0 1 bit<br>Set 1 to to indicate legacy protection, set to 0 otherwise |
| HT20 Protection | Indicates that HT20 protection is required<br>B1 1 bit<br>Set to 1 to indicate HT20 Protection, set to 0 otherwise |
| Extension Channel Control | B2-3 2 bits<br>Values: 0-3<br>0 indicates {20, 40}20MHz transmissions only are permitted<br>Set to 0 1 indicates {20}that both 20MHz and 40MHz transmissions are permitted<br>2 indicates the 20MHz phase of 20MHz-base Managed operation as defined in section 8.1.2.3<br>3 indicates the 40MHz phase of 20MHz-base Managed operation as defined in section 8.1.2.3 |
| Extension Channel Offset | B3 1 bit<br>B4-5 Integer: 2 bits<br>Values: 0,–1, 1 indicate offset of the extension channel from the Extension Channel Offset information element.control channel.<br>Value of 0 indicates no extension channel is present. |
| Control Channel | Channel number of the control 20MHz channel<br>B6-15 Integer: 10 bits |
| Extension Channel Access Timeout | B16-23 8 bits<br>Integer |

| | |
|---|---|
| | It specifies a time limit (in TU) after which the AP gives up the transition to 40 MHz and the 40 MHz capable HT STA switches back to 20 MHz if it has not received CTS-to-self or Beacon on the extension channel.<br>Value = 0 otherwise |
| Basic MCS Capability | B24-31 8 bits<br>Indicates the required MCS capabilities to become a member of the BSS.<br>B24-27 indicate the required level of receive operation in 20MHz.<br>B28-31 indicate the required level of receive operation in 40MHz.<br>B28-31 are reserved if the Extension Channel Control is 0 |
| HT Basic Rate | B32-47 16 bits<br>Indicates the maximum rate that can be used to transmit protection and broadcast frames using a HT PPDU format |

### 6.3.2.2 TSF Synchronization Precision Capability Element

The TSF synchronization precision capability transmitted by an AP indicates the precision of its beacon transmission start time at the output of AP to the media relative to TSF timer updates. This value represents the amount of jitter present in the timestamp in the beacon relative to TSF timer update timing. It includes all jitter introduced in the process of beacon generation through both MAC and PHY.

This element is present in Association, Reassociation and Probe Response frames.

This information is used to inform other stations of the ability of the AP to support synchronization within a communicated precision.

The TSF Synchronization Precision Capability Element is given in Figure 8.

| Octets: 1 | 1 | 1 |
|---|---|---|
| **Element ID** | **Length (2)** | **SyncPrecision** |

**Figure 8 – TSF Synchronization Precision Capability Element**

The SyncPrecision field contains a non-negative integer in the range 0-20 representation that indicates the amount of synchronization of TSF at the output of AP is $2^{(-\text{SyncPrecision})}$ in units of μs.

### 6.3.3 Management Action Frames

These frames are defined to be action frames using the 802.11e Action frame format. They share a common category code "HT".

The frames using the "HT" category code are defined in Figure 9.

| Action Code | Meaning |
|---|---|
| 1 | Calibration Measurement |
| 2 | Calibration Correction |

**Figure 9 – Action codes for the HT action category**

#### 6.3.3.1 Calibration Measurement Action Frame

Calibration Measurement frame is a management action frame of category Calibration. It contains the following fields.

| Order | Information | Size |
|---|---|---|
| 1 | Calibration Control | 1 |
| 2 | Calibration Sequence | 1 |
| 3 | MCMR Segment Sequence | 1 |
| 4 | MIMO Channel Measurement Report | 3 × *Ns* × *Ni* × *Nr* |
| Where:<br>• *Ns* = Number of subcarriers in the Calibration Training symbols<br>• *Ni* = Number of antennas at the STA that transmitted the Calibration Request<br>• *Nr* = Number of antennas at the STA that is transmitting the Calibration Response | | |

All messages in the same calibration procedure use the same Calibration Sequence value. The Calibration Control field (1 octet) consists of:

- Number of antennas at the initiating STA *Ni* (2 bits)
- Number of antennas at the responding STA *Nr* (2 bits)
- Calibration Complete (1 bit). The Calibration Complete bit is set to '1' if the STA transmitting the Calibration Measurement frame declares the calibration procedure complete without requiring the other STA to transmit a Calibration Correction Vector frame.
- Reserved (3 bits)

The MCMR Segment Sequence (1 octet) contains the segment sequence number when the MIMO Channel Measurement Report has been segmented. The MCMR Segment Sequence of the first segment is 0. The complete MIMO Channel Measurement Report contains *Ns* × *Ni* × *Nr* complex coefficients.

Each complex coefficient (3 octets) is represented by its 12-bit signed real and 12-bit signed imaginary parts. Hence the total length of the complete MIMO Channel Measurement Report is $3 \times Ns \times Ni \times Nr$ octets. The order of channel coefficients is as follows:

40 MHz:
For each subcarrier in the following order: (-58, …-2, 2, …, +58), include
{
    For each of *Ni* antennas at the initiating STA in order: (1, …, *Ni*)
    {
        Include *Nr* complex coefficients one for each antenna at the receiving STA in order: (1, …, *Nr* )
    }
}

20 MHz:
For each subcarrier in the following order: (-28, …-1, 1, …, +28), include
{
    For each of *Ni* antennas at the initiating STA in order: (1, …, *Ni*)
    {
        Include *Nr* complex coefficients one for each antenna at the receiving STA in order: (1, …, *Nr* )
    }
}

The complete MIMO Channel Measurement Report may need to be transmitted using more than one MAC frame. In the mandatory configuration with *Ns* = 114, *Ni* = 2, *Nr* = 2, there will be 1368 octets (456 coefficients) in a single MIMO Channel Measurement Report element. The maximum length of the MIMO Channel Measurement Report field is 5472 octets (1824 coefficients) for the case with *Ns* = 114, *Ni* = 4, and *Nr* = 4. If the MIMO Channel Measurement Report is longer than 1368 octets, the first 1368 octets are included in the first frame (MCMR Segment Sequence = 0) and the remaining octets are included in subsequent frames (MCMR Segment Sequence = 1, 2, etc.).

### 6.3.3.2 Calibration Correction Action Frame

Calibration Correction frame is a management action frame of category Calibration Correction. It contains the following fields.

| Order | Information | Size |
|---|---|---|
| 1 | Calibration Control | 1 |
| 2 | Calibration Sequence | 1 |
| 3 | MIMO Correction Vector | $3 \times Ns \times Nr$ |
| Where:<br>• *Ns* = Number of subcarriers in the Calibration Training symbols<br>• *Nr* = Number of antennas at the STA that transmitted the Calibration | | |

Response

All frames in the same calibration procedure use the same Calibration Sequence value.
The Calibration Control field (1 octet) consists of:

- Number of antennas at the initiating STA *Ni* (2 bits)
- Number of antennas at the responding STA *Nr* (2 bits)
- Reserved (4 bits)

The MIMO Correction Vector contains *Ns* × *Nr* complex coefficients.
Each complex coefficient (3 octets) is represented by its 12-bit signed real and 12-bit signed imaginary parts. Hence the total length of the MIMO Correction Vector field is 3 × *Ns* × *Nr* octets. The order of correction vector coefficients is as follows:

40 MHz:
For each subcarrier in the following order: (-58, … -2, 2, …, +58), include
{
Include *Nr* complex coefficients one for each antenna at the receiving STA in order: (1, …, *Nr* )
}

20 MHz:
For each subcarrier in the following order: (-28, …-1, 1, …, +28), include
{
Include *Nr* complex coefficients one for each antenna at the receiving STA in order: (1, …, *Nr* )
}

The maximum length of the Correction Vector field corresponds to *Ns* = 114, *Nr* = 4 is 1368 octets.

### 6.3.4 Block Ack Parameter Set field

This section defines changes to the 802.11e Block Ack Parameter set field of the ADDBA frame.

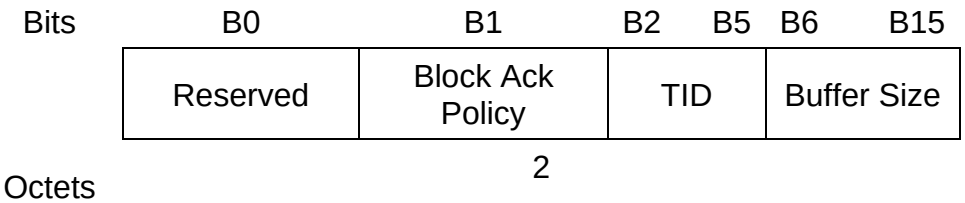



**Figure 10 - Block Ack Parameter Set fixed field**

The Block Ack Policy field is defined as Delayed Block Ack or Immediate Block Ack in 802.11e. The same field is redefined for HT stations, whereby the value of 0 corresponds to HT Partial State Block Ack, and the value of 1 corresponds to HT Immediate Block Ack. The details

of these enhanced BA mechanisms are described in section 2.4. An HT STA shall support the HT Partial State BA at a minimum

The Buffer Size field contains the number of buffers at the receiver. Its interpretation depends on the type of BA, as specified in the following table.

**Table 5 - Interpretation of the Buffer Size parameter**

| Block Ack Type | Buffer Size interpretation |
|---|---|
| Compressed | Buffer size contains the maximum number of MSDUs that can be sent within the BA window.<br>Maximum value is 64 |
| 802.11e | Buffer size contains the maximum number of MPDUs that can be sent within the BA window.<br>Maximum value is 1024 (*i.e.* 64 x 16) |

In an ADDBA request frame, the Buffer Size subfield is advisory and the recipient should select a value equal to or smaller than the initial value.

## 6.4 A-MPDU and A-MSDU aggregation formats

### 6.4.1 Introduction to Aggregation (Informative)

There are two types of aggregation defined in this specification: A-MSDU aggregation and A-MPDU aggregation.

A-MSDU aggregation joins together multiple MSDUs and creates a single larger MSDU that is transported in Data MPDUs.

A-MPDU aggregation joins multiple MPDUs together and transports them in a single PSDU.

Note, the term "aggregate" used elsewhere in this document refers to A-MPDU aggregation, unless specifically referring to A-MSDU aggregation.

The MAC interprets the PSDU as a single MPDU, or as an A-MPDU according to the A-MPDU TXVECTOR/RXVECTOR parameter, which is robustly transported in the PLCP header.

The Duration fields in the MAC Headers of all MPDUs in an aggregate carry the same value.

### 6.4.2 Aggregated MPDU format (A-MPDU)

An A-MPDU consists of a number of MPDU delimiters each followed by an MPDU. Except when it is the last MPDU, padding octets are appended (if needed) to make each section a multiple of 4 octets in length.

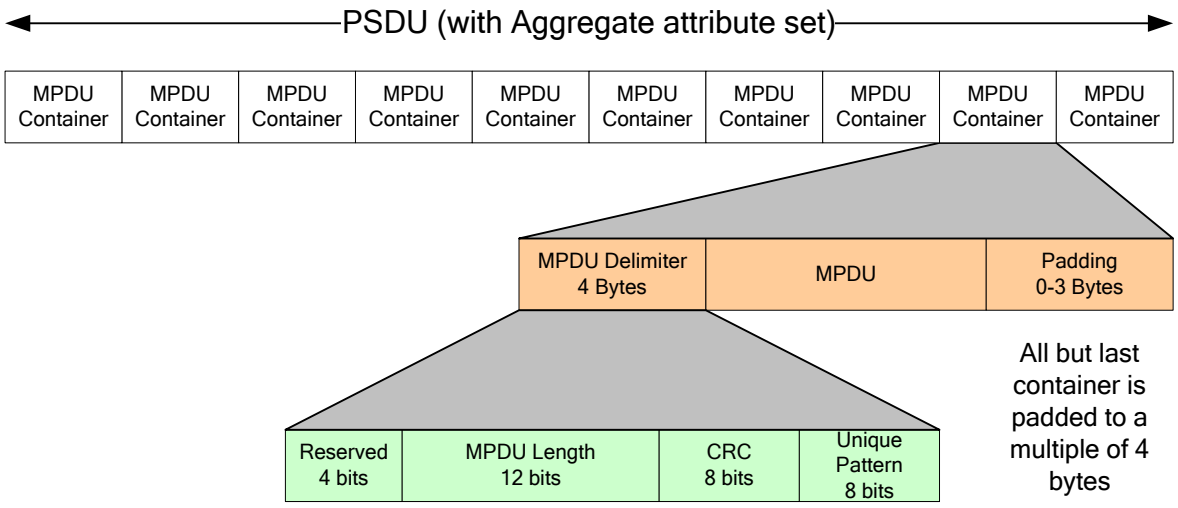



**Figure 11 – A-MPDU format**

The MPDU delimiter is 4 octets in length and contains the fields defined below:

**Table 6 – MPDU delimiter Fields**

| MPDU delimiter Field | Size (bits) | Description |
|---|---|---|
| Reserved | 4 | - |
| MPDU length | 12 | Length of the MPDU in octets |
| CRC | 8 | 8-bit CRC of the preceding 16-bits.<br>As defined in IEEE 802.11 section 14.3.2.2.3 |
| Unique pattern | 8 | Unique pattern that may be used to detect an MPDU delimiter when scanning for a delimiter.<br>The unique pattern is set to the ASCII value for character 'N'. |

The purpose of the MPDU delimiter is to robustly delimit the MPDUs within the aggregate. Robust in this case means that the structure of the aggregate can usually be recovered when one or more MPDU delimiters are received with errors. Individual delimiters have the same BER as the surrounding MPDUs, and so can be lost.

Note, a delimiter with MPDU length zero is valid. This can be used to introduce padding between MPDUs, or at the end of the A-MPDU.

### 6.4.3 Single receiver frame aggregation format

An A-MPDU aggregate is a sequence of MPDUs carried in a single PPDU with the TXVECTOR A-MPDU field set to 1.

In a single-receiver aggregate, all MPDUs are addressed to the same receiver address.

The aggregate contains MPDUs in the order defined below.

**Table 7 Single Receiver Aggregation MPDUs**

| MPDU | Multiplicity | Description |
|---|---|---|
| ACK | At most one | Contains an acknowledgement of at most one MPDU in the previous aggregate that required immediate acknowledgement. |
| BA | At most one per Block ACK agreement in the appropriate direction | Block ACK MPDUs |
| QoS Data | No limit, except as constrained by Block ACK protocol and TXOP duration | Data MPDUs sent under Block-ACK policy. |
| LAC | At most one | Link adaptation control<br>Used when it is necessary to include a logical element as described in section 7.1.5.<br>This MPDU may only occur anywhere within the aggregate after any response MPDUs (Ack, BA) and before any MPDUs requiring an immediate response. |
| BAR | At most one per Block ACK agreement. | Block ACK Requests |
| Any MPDU requiring an immediate response | At most one | At most one MPDU for which an Ack MPDU response may be transmitted.<br>This includes non-QoS Data MPDU and Management MPDU. BAR sent under Partial State Block Ack Policy may also generate an Ack MPDU response, but it is allowed to send multiple BARs as they will generate a single Ack MPDU. |

### 6.4.4 Multiple receiver frame aggregation format

A multiple-receiver aggregate (MRA) contains MPDUs that are addressed to multiple receivers.

An MRA may only be transmitted during an MMP sequence (as defined in section 7.1.4). A STA may only be addressed in an MRA if it has declared support for the MMP capability. Broadcast/Multicast frames shall not be transmitted in an MRA.

In the MRA, frames for each receiver address are grouped together. Each group shall contain the same MPDUs as a Single Receiver Aggregate (see section 6.4.3), addressed to the same receiver, in the order defined in Table 7. The order of (groups of) Data MPDUs for different receiver addresses is equal to the order of the matching Receiver Info fields in the previous MMP MPDU.

The RDG field shall be set to 0 in all MPDUs within an MRA. [2]

Data MPDUs can come from multiple TCs, provided that they comply with the TC policy of the current TXOP.

### 6.4.5 Aggregated MSDU Format (A-MSDU)

This section describes the format of Aggregated MSDU (A-MSDU). The purpose of the A-MSDU is to allow multiple MSDUs being sent to the same receiver to be aggregated and sent in a single MPDU, which improves the efficiency of the MAC layer, particularly when there are many small MSDUs such as TCP acknowledgements. Support for A-MSDU is mandatory at the receiver. However, the transmitter is free to use A-MSDU or not based on information such as traffic characteristics and link conditions. The maximum length of an A-MSDU is 3800 bytes.[3]

Figure 12: A-MSDU Strcuture shows the structure of a Data MPDU containing an A-MSDU, which is a sequence of *n* MSDU sub-frames. Each sub-frame consists of a sub-frame header followed by an MSDU and 0-3 bytes of padding. A sub-frame (except the last) is padded so that its length is a multiple of 4 bytes. The last sub-frame has no padding.

The sub-frame header contains three fields: Destination Address (DA), Source Address (SA), and Length. [4] The DA and SA fields are interpreted as described in Table 8 below. The length field contains the length in bytes of the MSDU.

[2] Any uplink direction data transmission during an MMP sequence is scheduled through the MMP.

[3] This figure is chosen so that the length of an MPDU containing an (unfragmented) A-MSDU does not exceed 3839 bytes. The figure of 3839 is chosen so that the maximum length MPDU containing an A-MSDU is 256B shorter than a common physical memory page size of 4KB, thereby allowing room for status and control information to be stored with the MPDU without forcing the use of multiple physical pages.

[4] Note, these fields are arranged in the same order as the 802.3 frame format.

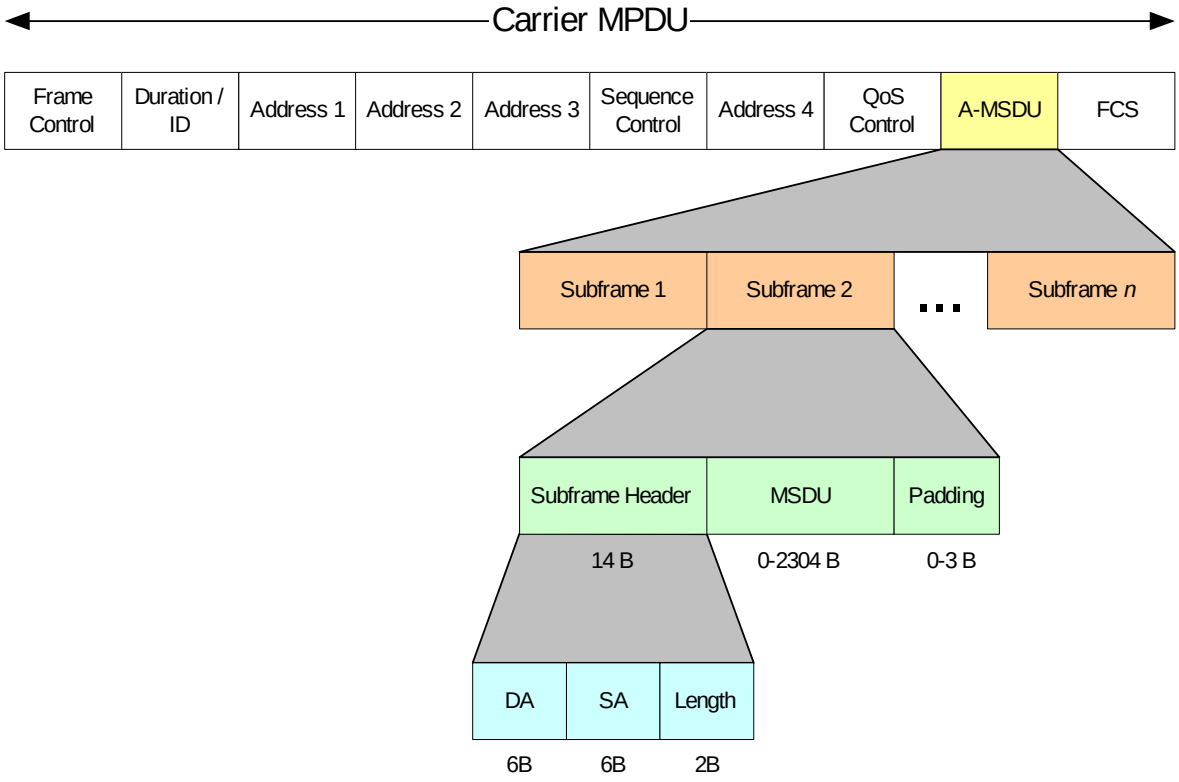



**Figure 12: A-MSDU Strcuture**

The MPDU containing the A-MSDU is one of the QoS data subtypes. The presence of the A-MSDU is signaled by setting bit 7 of the QoS control field to a 1.

The DA and SA are passed between the MAC and its service client in the MAC service primitives. The mapping of DA, SA to the addresses in the MPDU header is described by the following tables. It is possible to have different DA and SA in the same A-MSDU as long as they all map to the same receiver address.

**Table 8 – Address field contents**

| To DS | From DS | Address 1 | Address 2 | Address 3 | Address 4 | DA | SA |
|---|---|---|---|---|---|---|---|
| 0 | 0 | DA | SA | BSSID | X | - | - |
| 0 | 1 | DA | BSSID | - | X | - | SA |
| 1 | 0 | BSSID | SA | - | X | DA | - |
| 1 | 1 | RA | TA | - | - | DA | SA |

Notes:

X = not present

- = reserved

# 7 MAC sublayer functional description

## 7.1 Aggregation Exchange Sequences and related rules

### 7.1.1 Aggregation Exchanges

A STA that owns the TXOP may start an exchange of PPDUs. This STA is called the initiator.

The initiator STA may transmit PPDUs and obtain response PPDUs from one or more STA during the exchange. These STA are called responders.

A response may contain either:

- A singleton response PPDU containing one or more of the following response MPDUs: CTS, LAC, BA and Ack
- A response burst consisting of one or more PPDUs that may contain data as well as response MPDUs

In the case of a singleton response PPDU, all relevant MPDUs in the PPDU shall have the "More PPDU" field set to 0. In the case of a response burst, the last response PPDU shall have the "More PPDU" field set to 0 in all MPDUs of type: BA, BAR, QoS Data.

A response may be transmitted as defined in Table 9.

**Table 9 – Response Generation**

| Transmission by initiator | Response |
|---|---|
| An aggregate or non-aggregate PPDU containing one or more unicast frames addressed to the receiver with the RDG field set to 1. | A response burst starting a SIFS after the end of the initiator's transmission, and lasting no longer than the RDG duration (less a SIFS) |
| An aggregate or non-aggregate containing one or more frames addressed to the receiver that require a response, not transmitted as part of an MMP exchange sequence and not containing any frame with the RDG field set to 1 (i.e., not a reverse direction grant). | A singleton response PPDU containing only response MPDUs transmitted a SIFS after the end of the initiator's transmission |
| An MMP frame containing an entry for the responder with non-zero tx-duration | A response burst at the specified tx offset relative to the end of the MMP packet lasting no longer than the tx duration specified in the MMP packet. |

The initiator shall ensure that its PPDU transmission and any responses fit entirely within the current TXOP.

### 7.1.2 Bi-Directional Data Exchange Rules

Transmission of an MPDU by an initiator with the RDG flag set to 1 (either transmitted by itself, or as part of an aggregation) indicates that the period of time defined by the MPDU's Duration field is available for a response burst. The initiator is free to grant any RDG it wishes (compliant with the TXOP rules).

The responder may only transmit Data MPDUs of the same AC as the MPDU carrying the RDG.
The responder may only transmit MPDUs addressed to the Initiator, i.e., RA=Initiator.
The transmitted response burst shall last no longer than the granted duration.

After transmitting a PPDU containing a reverse direction grant, the initiator may transmit its next PPDU a SIFS after receiving a response PPDU with the "More PPDU" flag set to 0. It may transmit its next PPDU when the medium is sensed idle for PIFS.

### 7.1.3 Protection mechanisms

#### 7.1.3.1 LongNAV protection

When a STA has a TXOP, it may set a long NAV to protect multiple PPDUs using a single protection MAC layer protection exchange, e.g., RTS/CTS.

LongNAV protection is defined as selecting a duration value, limited by the remaining duration in the current TXOP and setting the NAV to this value using one of the MAC layer protection techniques.

In the case that a STA gains access to the channel using EDCA and uses LongNAV to protect a duration value, and then runs out of MPDUs to transmit, the STA may transmit a CF-End provided that the remaining duration is long enough to transmit this MPDU.
This shall be interpreted by HT STAs and is interpreted by legacy STAs as a NAV reset – i.e. they reset their NAV timer to zero at the end of the PPDU containing this MPDU.

#### 7.1.3.2 Extended PHY Protection

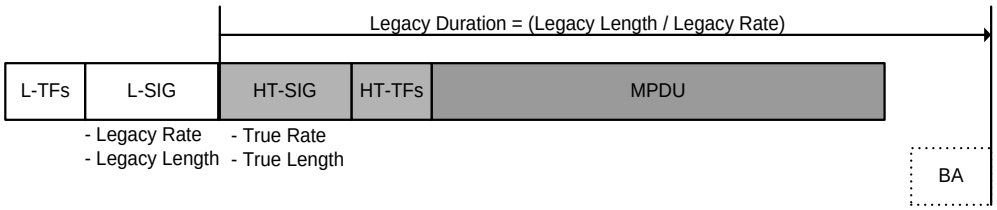



**Figure 13: Extended PHY protection**

A STA may use Extended PHY Protection (EPP) to provide protection of an exchange of packets, by utilizing the Legacy SIGNAL (L-SIG) portion of an HT PPDU. With EPP, the NAV Duration value is virtually carried in the Length and Rate Fields of the L-SIG.

EPP provides robust protection towards third party HT nodes along with legacy nodes with an HT PPDU, enabling protection packets to be sent in optimized MIMO PPDUs. EPP is also effective in providing protection towards 20MHz-only capable STAs because the L-SIG portion of a 40MHz PPDU is decodeable in both halves of the 40MHz channel.

When EPP is in operation, the Length and Rate Fields of the L-SIG is set so that the end point of Legacy Duration = (Legacy Length / Legacy Rate) is equivalent to the intended NAV Duration[5]. A legacy node that decodes these two fields will continue reception for (Legacy Length / Legacy Rate) time, preventing it to start transmission during this period.
An HT node that receives a PPDU examines the Rate and Length fields of the L-SIG and HT-SIG, from which it calculates Legacy and HT Durations. It determines that EPP is in operation if the Legacy Duration is longer than the HT Duration. When EPP is in operation, it shall set its NAV to the value of (Legacy Duration - HT Duration) [5] at the end of the received PPDU.

### 7.1.3.2.1 Extended PHY Protection with RTS/CTS

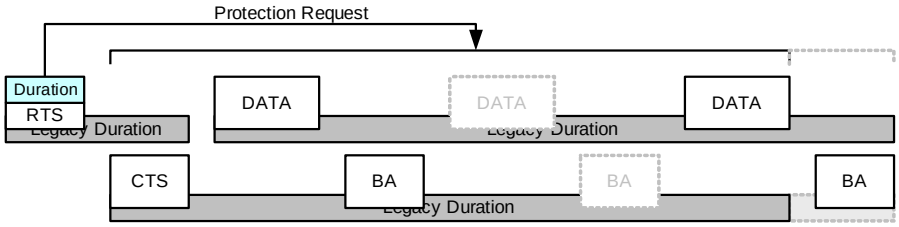



**Figure 14: Extended PHY protection with RTS/CTS**

A STA may use EPP to protect an exchange sequence to a single responder where an RTS/CTS handshake is necessary.

The EPP rules here are described in terms of an initial RTS/CTS exchange for convenience. The same rules shall be applied to any initial packet exchange, including a LAC/LAC exchange.

Extended PHY Protection with RTS/CTS - Rules at the Initiator
When the initiator intends to use EPP it may start a packet exchange with an RTS/CTS (or LAC/LAC equivalent) handshake. It shall set the Legacy Duration of the RTS PPDU so that it protects the expected response, the CTS.
In the RTS MPDU, the initiator shall notify the responder of the Protection Request Duration[5], which the responder will use to set the Legacy Duration of the CTS. The Protection Request shall be carried in the Duration Field of the MAC Header in the RTS MPDU. The duration of the Protection Request shall be set to at least one response frame (CTS), plus SIFS, plus one DATA PPDU, and may be extended to protect multiple DATA/ACK exchanges.

[5] (EIFS – DIFS) adjustment described in section 7.1.3.2.3 should be made

Upon reception of a CTS addressed to itself, the initiator shall start transmission of DATA PPDUs. The Legacy Duration of the first DATA PPDU from the initiator shall point to the end point of the CTS PPDU or may be set to a certain time beyond this end point. The duration of this extension of Legacy Duration at the initiator shall be the time equivalent to SIFS plus the duration of the expected final response from the responder.
When this extension of Legacy Duration is used, the initiator may choose to extend the EPP period by sending an RTS MPDU within the already established EPP period. The Protection Request Duration carried in the MAC Duration field of the RTS MPDU shall be set to the amount of extension to the EPP period.

After a STA transmits a PPDU using EPP it shall set the Legacy Duration value to the end of the EPP period on all the subsequent PPDU it transmits. The initiator shall wait until the end of the current EPP period before transmitting a PPDU that establishes a new EPP period[6].

Extended PHY Protection with RTS/CTS - Rules at the Responder
The responder, on receiving a RTS MPDU addressed to itself with EPP in operation, shall generate a response PPDU with the L-SIG set to duration equal to the Protection Request Duration.

After a STA transmits a PPDU using EPP it shall set the Legacy Duration value to the end of the EPP period on all the subsequent PPDU it transmits. The initiator shall wait until the end of the current EPP period before transmitting a PPDU that establishes a new EPP period[6].

### 7.1.3.2.2 Single Ended EPP

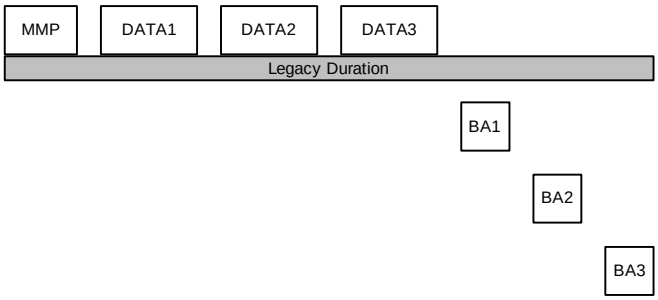



**Figure 15: Extended PHY protection for an MMP sequence**

STA may use Single Ended EPP to protect an exchange sequence where RTS/CTS protection is not necessary. This is especially effective in an MMP sequence where responses are expected from multiple responders.
The initiator should set the Legacy Duration of the initial PPDU, so that it protects to the end of the last response[5]. In case of a MMP sequence, the Legacy Duration of the MMP PPDU shall protect up to the end of the scheduled response.

[6] Because the L-SIG cannot be decoded by legacy while an EPP is active

#### 7.1.3.2.3 EIFS Rules for EPP

The EPP periods shall be set (EIFS- DIFS) shorter than the actual duration required for NAV protection. This is to avoid the unfairness towards legacy devices which will defer for EIFS upon reception of a PPDU using EPP, which will cause a CRC error. HT nodes shall add (EIFS-DIFS) to the EPP period when setting the NAV value set by a PPDU that uses EPP.
Upon sending a Protection Request in an RTS packet, it shall be the responsibility of the initiator to make the (EIFS- DIFS) adjustment in the request, so that the responder can simply set its Legacy Duration exactly as indicated in the Protection Request.

### 7.1.3.3 HT Device NAV and EIFS Rules

An HT device that receives a PPDU examines the legacy and HT rate and length fields from which it calculates legacy and HT durations.
It determines that EPPEPP is in operation if the legacy duration is not equal to the HT duration.
If EPPEPP is in operation, it shall set its NAV to the value of legacy duration + (EIFS – DIFS) – HT duration at the end of the received PPDU.

The following rule defines EIFS selection for an HT STA:
An HT STA that receives an MPDU with a bad CRC shall only use EIFS if its NAV is zero at the start of the PPDU containing the MPDU. The condition is never true during an aggregate exchange, but is true for isolated Data/ACK.

## 7.1.4 MMP Sequences

### 7.1.4.1 Introduction (Informative)

The MMP sequence is provided in response to two classes of comments on an earlier version of this proposal. One comment regarded the complexity of the response generation using the "reverse direction offset", which was mandatory in all STA, but there primarily to serve VoIP and similar applications. The second regarded the need to more effectively support power-saving in VoIP STA.

The MMP sequence addresses these requirements. The ability to participate in an MMP sequence is optional, but all STA are able to decode at least the MMP header.. The MMP frame contains addressing and timing information that allows a VoIP client to spend the minimum time awake during the MMP sequence. 3rd party STA, not participating in the sequence, or supporting the mechanism, can sleep through the entire sequence.

The existing 802.11e TSPEC mechanism is used to negotiate the creation of a periodic TSPEC. It is an option of the AP whether and how to group service intervals of STA into MMP sequences. It may use the MMP capability to determine that it can group STA together to service the TSPEC as part of an MMP sequence.

### 7.1.4.2 Definitions

An MMP sequence starts with the transmission of an unaggregated MMP frame, and ends when the last scheduled response contained in the MMP ends.

### 7.1.4.3 Rules at the AP

An AP shall only include a STA in an MMP if that STA declares support for MMP.

If the AP has grouped multiple STA to service under the MMP sequence, it shall transmit an unaggregated MMP frame at the start of the service interval containing a record for each STA that is to be serviced during the current service interval.

The MMP shall only contain records for STA that have declared support for MMP. The MMP shall contain at most one record per AID/TID combination.

During an MMP sequence, the AP shall only transmit frames addressed to STA identified in the MMP frame according to the schedule defined in the MMP frame.

The AP shall ensure that the first response period shall start no less than a SIFS after the end of the MMP PPDU. Typically the initiator will arrange that response periods are separated by SIFS, but there is no normative requirement for this to be the case.

#### 7.1.4.4 Rules at the STA

A STA receiving an MMP shall be enabled to receive during its indicated Rx period, and may transmit only during its indicated Tx period.

The STA shall only transmit frames for RA = AP.

If it transmitted any frames for which an immediate response is required, it shall wake to receive responses at the end of the current MMP exchange.

#### 7.1.4.5 Protection Rules for MMP

An MMP sequence may be protected using either LongNAV or EPP.

In the LongNAV case the NAV of all devices that can hear the initiator has already been set by transmission of a previous MPDU, such as a CTS-to-self. In this case, the PPDUs within the MMP sequence should not use EPP because it limits the ability of the initiator to recover unused RDG duration at the end of the response period.

The EPP case is applicable when there is no a-priori NAV setting. In this case the AP protects the duration of the entire sequence as shown in section 7.1.3.2.2.

In the case of LongNAV protection, the initiator may continue with a transmission a SIFS after the actual end of the last response PPDU. In the case of EPP, the initiator may continue its transmission a SIFS after the end of the last response period, regardless of the actual length of the response.

#### 7.1.4.6 Power-saving at the receiver of an MMP frame (informative)

Once it has decoded the MMP frame at the start of the service interval, the STA knows when it needs to be able to receive and when it can transmit. This may enable it to reduce power during some or all of the 3rd-party downlink and uplink.

The downlink may be contained in one or more PPDUs. The STA is given the start of the PPDU containing its downlink. The STA may also determine the starting offset of the data addressed to it relative to the start of the PPDU using the Rx Duration of the previous record in the MMP with a matching Rx Offset.
After acquisition, if the STA may be able to save power by disabling some of its receive mechanism, it can do so up to the first symbol containing its downlink data (MPDU). From that point, it decodes the data and scans for a valid MPDU delimiter. After it has received the indicated number of symbols of data defined in its receiver info record, it may sleep.

It also wakes to transmit at the time indicated in its receiver info field.

If it transmitted any frames requiring an immediate response, it shall wake at the end of the current MMP exchange to receive any responses.

#### 7.1.4.7 Power-saving at the 3rd-party receiver of an MMP frame (informative)

An HT STA that receives an MMP may sleep through the remaining duration of the MMP sequence on the following conditions:

- It does not support MMP
- It does support MMP, and the MMP does not contain its AID

### 7.1.5 MAC support for closed loop modes

#### 7.1.5.1 Closed-loop MCS training

Support for closed-loop MCS adaptation is provided by the exchange of MRQ (MCS Request) and MFB (MCS Feedback) elements carried in LAC control frames.
An MCS Request may be included in any LAC.
A STA receiving an MFB should use the information contained in it to adapt its transmission parameters.

A responder device that receives an unaggregated LAC shall respond with a LAC after a SIFS (assuming that the embedded RTS/CTS protocol (i.e., NAV setting) does not prevent such a response).

Assuming that the first LAC ("LAC1") transmitted by the initiator contains an MRQ, the second ("LAC2") transmitted by the responder may contain an MFB if the results are available quickly enough. Alternatively the responder may include a LAC ("LAC3") in a response aggregate at any time later once the results are available. In this case LAC2 does not contain an MFB element (indicating that no response is available yet), but LAC3 does.

When transmitted in an aggregate, a LAC frame only generates a response when the response contains at least one of the LAC elements. There is no need to acknowledge receipt of an aggregated LAC. This means that in the example above, if the MFB is not available immediately, LAC2 need not be included in the aggregate.

The MFB response is sent when it is available. That means that a device that can evaluate the MFB quickly may send it in the following PPDU. Other devices that evaluate it more slowly may send it in a later PPDU of the same sequence, or in a later sequence.

An STA sending an MRQ in a HT format PPDU shall set TXVECTOR SOUNDING to 1. If the transmission of segmented HT-LTFs is supported, it is also recommended that TXVECTOR NLTF be greater than the minimum value required for the current MCS, subject to a maximum value equal to the number of transmit antennas or 4, whichever is lower. The transmission of these additional HT-LTFs when sending an MRQ can aid MCS selection by the responder.

#### 7.1.5.2 Closed-loop MIMO training

Support for closed-loop MIMO adaptation is provided by the exchange of a TRQ (MIMO Training Request) element carried in LAC control frames and an HT sounding PPDU.
A TRQ can be included in any LAC (except a legacy unaggregated LAC). Its purpose is to request the peer STA to return an HT sounding PPDU that allows the requesting STA to use better parameters for subsequent transmissions to the peer STA.

Use of Closed-loop MIMO training is completely optional. A STA that does not support closed-loop MIMO will never send an LAC with the TRQ flag set. A STA that receives a TRQ does not have to send a sounding PPDU in response.

A STA sending a sounding PPDU in response to a TRQ shall set TXVECTOR SOUNDING to 1. If the transmission of segmented HT-LTFs is supported, it is also recommended that TXVECTOR NLTF be greater than the minimum value required for the current MCS, subject to a maximum value equal to the number of transmit antennas or 4, whichever is lower. The transmission of these additional HT-LTFs when sending a TRQ can increase the performance of beamformed transmissions.

## 7.2 MCS selection rules

### 7.2.1 MAC Protection Frames – basic rate and PPDU type

Any frame that is used to set or reset the NAV shall be transmitted using a rate and PPDU format as defined here.

When legacy devices are present, only rates in the legacy basic rate set and the legacy PPDU format may be used.

When HT20 devices are present, only 20MHz PPDU formats may be used.

During the 40MHz phase of 20MHz-base managed mixed mode, only 40MHz PPDU formats may be used.

The MCS for a 20MHz PPDU format is selected not to exceed the Basic MCS capability for 20MHz operation.

The MCS for a 40MHz PPDU format is selected not to exceed the Basic MCS capability for 40MHz operation.
HT format PPDUs shall be sent at a rate no higher than the HT Basic Rate specified in the HT Management Element.

### 7.2.2 Multicast

Multicast/broadcast frames in pure mode and control frames that need to be received by HT devices only shall be selected from the Basic MCS set.

### 7.2.3 MRA MCS Selection Rules

When a STA transmits a MRA to multiple receivers, it shall ensure that the MRA is sent using transmit parameters that should make the PPDU receivable by all receivers in the aggregate. It has to respect their receiver capabilities and select a "lowest common" set of parameters that should be consistent with reception at all these STAs.

### 7.2.4 Short GI

The SHORT GI TXVECTOR attribute shall only be set to 1 in unicast frames addressed to a peer that declares support of the Short GI in the HT capabilities element.

The SHORT GI TXVECTOR attribute shall be set to 0 in all broadcast frames, and all MAC protection frames.

## 7.3 Quality of Service (QoS)

### 7.3.1 802.11e Requirements

An HT device shall support the mandatory features of an 802.11e QSTA.
An HT device shall support the use of the Block ACK mechanism introduced in 802.11e.

Note: this document extends the 802.11e Block Ack by defining a compressed Block Ack frame format, and rules for Full State and Partial State Block Ack operations. These are defined in sections 6.2.3 and 2.4.

## 7.4 Enhanced Block Acknowledgment

### 7.4.1 Introduction (Informative)

This section specifies an enhancement to 802.11e Block Ack mechanism for use with HT frame aggregation. The enhancement, called Partial State BA, adds an immediate response mechanism to 802.11e Delayed BA, but without the complexity and scalability issue associated with 802.11e Immediate BA. An immediate BA response provides many benefits, including improved QoS, reduced buffering at both originator and recipient, and increased power saving by stations that use APSD, as a station's wake time is proportional to how long it has to wait for its data. The complexity and scalability issue of 802.11e Immediate BA arises from the requirement to keep persistent BA states on a per TID per destination basis, and have ready access to them to create immediate responses. This is especially problematic for QAPs, since they need to support many simultaneous QSTAs. Partial State BA resolves these issues by adding an entity that logically lies below the 802.11e Delayed BA, which handles immediate response but is less resource hungry.

### 7.4.2 Block Ack Negotiation

Block Ack session is established by exchanging the ADDBA request and response frames. The negotiation follows the same procedure as described by 802.11e, but use the Block Ack Parameter Set as defined in section 1.3.4.

If an HT recipient is capable of HT Immediate BA, it shall so indicate by setting the Block Ack Policy field in ADDBA response frame to 1. Otherwise, it shall set the Block Ack Policy field in ADDBA response frame to 0, which indicates that it is capable of HT Delayed BA with Immediate Partial State Response, as defined in this section. HT Delayed BA with Immediate Partial State Response is the minimum required BA capability for an HT STA.

An HT recipient shall use the Buffer Size field to indicate how many outstanding MSDUs it can accept. This defines the BA window size, which is fixed for the life time of the BA session. An HT originator must take care not to overflow the BA window, i.e., not to transmit sequence numbers that are later than (Buffer Size + the earliest unacknowledged sequence number). Within the BA window, an HT originator may send sequence numbers in arbitrary order.

Buffer Size also defines the maximum value of NumMSDU_M1 for compressed MPDU, which is (Buffer Size – 1). An HT STA shall always transmit a compressed BA MPDU to a HT STA. An HT STA shall never transmit a compressed BA MPDU to a non-HT STA.

### 7.4.3 Immediate BA Response

With the introduction of A-MPDU aggregation and MMP, the meaning of immediate BA response is modified as follows.

During an MMP sequence immediate BA responses, if any, are transmitted at the start of the scheduled response period for the recipient.

When multiple SIFS-separated PPDU are transmitted by the originator in a TXOP (not within an MMP sequence), BAR are only permitted in the final PPDU of the burst. The recipient responds with immediate BA responses if any, SIFS duration after the final PPDU.

### 7.4.4 Explicit and Implicit BAR

There are two methods that an HT originator can use to solicit BA response from an HT recipient. One is the same as 802.11e, which is to send QoS Data frames with Ack Policy field in the QoS Control header set to Block Ack, and send BAR frames to request a response from the HT recipient. This is the explicit BAR mechanism. BAR may be sent in the same A-MPDU as the QoS Data frames, or in a separate MPDU or A-MPDU. Multiple BAR for different TID may be sent in the same A-MPDU. When multiple SIFS-separated PPDU are transmitted by the originator in a TXOP (not within an MMP sequence), BAR are only permitted in the final PPDU of the burst. If multiple immediate BA responses are generated, for instance, due to reception of multiple BAR for different TID, they shall be sent in a single A-MPDU.

When an HT originator discards frames due to MSDU lifetime being exceeded, it shall advance the sequence number pass discarded frames. It should send an explicit BAR to resynchronize the starting sequence number of the BA window at the recipient. It may send new sequence numbers before or together with the explicit BAR.

The other method is used for QoS Data frames sent in an A-MPDU. QoS Data frames in an A-MPDU may be sent with Ack Policy field in the QoS Control header set to Normal Ack. If an HT recipient receives a QoS Data frame with Normal Ack policy in an A-MPDU, it shall interpret it as if there is an implicit BAR frame in the same A-MPDU for the same TID, and send a BA response accordingly. This is the implicit BAR mechanism, which is more robust than explicit BAR, as any valid frame received by the recipient will generate an immediate BA response. The HT originator should mark all QoS Data frames belonging to the same TID in an A-MPDU with the same Ack Policy. When multiple SIFS-separated PPDU are transmitted by the originator in a TXOP (not within an MMP sequence), implicit BAR are only permitted in the final PPDU of the burst.

Implicit BAR differs from explicit BAR in one aspect. Explicit BAR carries a Block Ack Starting Sequence Control, which indicates to the recipient that it must align the starting sequence number of its BA window. Implicit BAR carries no such information, therefore does not causes such alignment in the recipient.

Since the explicit BAR provides these additional capabilities, the originator is only permitted to include either an implicit or an explicit BAR but not both, for any delayed BA TID. Without this restriction, the originator cannot determine whether the immediate partial state BA response acknowledges the explicit BAR and thus whether the recipient has moved up the left edge of the BA window.

For immediate BA TID, the originator can determine whether the recipient has moved up the left edge of the BA window from the immediate full state BA response, so the originator is permitted to include both implicit and explicit BAR.
In this section, whenever BAR is mentioned, it shall be either explicit or implicit, unless a restriction is specifically stated.

### 7.4.5 Operation of HT Immediate BA

An HT STA that supports HT Immediate BA shall operate according to the 802.11e spec, with the additional rules regarding compressed BA and implicit BAR. It needs to keep a persistent BA state for each BA agreement that is accessible for creating immediate responses. When an HT recipient receives a BAR, it shall respond with a BA in SIFS time.

### 7.4.6 Operation of HT Delayed BA with Immediate Partial State Response

An HT recipient that supports Delayed BA maintains two logically separate BA states: (1) 16 (one per TID) partial state bitmaps for exactly one TA, which is used for generating immediate partial state BA response; (2) a persistent state for each BA agreement, on a per destination per TID basis, which is used for generating delayed full BA response as well as for duplicate detection. The partial state operates like a sliding window, just as the corresponding persistent state, except that the partial state is reset every time the HT recipient receives QoS Data frames from a different HT STA. An HT recipient shall record the TA of the last QoS Data frame received, regardless of TID, in order to check whether a matching partial state exists.

When an HT recipient receives QoS Data frames in an A-MPDU, it shall update both the partial state and the corresponding persistent state. If there is no matching partial state, e.g., the TA of

received frame is different from the last recorded TA; it shall reset the partial state first and then perform the update. The update procedure is a set of sliding window operations as described in 802.11e spec.

When an HT recipient receives a BAR corresponding to a Delayed BA TID, it shall check whether a matching partial state exists. If so, it shall send an immediate partial state BA response, after updating the partial state if necessary. Multiple BAR for different TID will generate multiple immediate BA responses, which shall be sent in a single A-MPDU. If no matching partial state exists, it shall send an ACK, and later send a delayed BA based on the persistent state. Multiple BAR for different TID will generate a single ACK and multiple delayed BA, which can be sent together in an A-MPDU or separately. The delayed BA shall be sent at the earliest opportunity using the highest priority access category, similar to 802.11e. Full state delayed BA when transmitted by the recipient shall be ACK-ed by the originator as in 802.11e.

The general rule at the HT recipient is to update BA states, then send response if required. It should be noted that an implicit BAR will always generate a BA response rather than an ACK, since the partial BA state will be recreated based on the received A-MPDU, even if no matching partial BA state is found.

An HT recipient shall not send immediate and delayed BA in the same A-MPDU. This allows an HT originator to distinguish the two kinds of BA responses. A BA that comes when a HT originator is waiting for a SIFS response is an immediate BA and shall not be acknowledged. A BA that comes when an HT originator is not waiting for a SIFS response is a delayed BA and shall be acknowledged.

When an HT recipient receives a non-aggregated QoS Data MPDU with Ack Policy in the QoS Control header set to Normal Ack, it shall update both partial and persistent states, and send an ACK after SIFS time.

## 7.5 PSDU Length Limit Rules

A STA shall declare the maximum PSDU size that it can receive using the Maximum Rx PDSU Length capability field. The STA shall be able to receive PSDUs of length less than the indicated limit. When it receives a PSDU of length greater than the limit, it shall receive the first $2^{\text{Maximum Rx PSDU Length}}$ bytes and discard any remainder.

A STA shall form an aggregate for transmission such that all the MPDUs within the aggregate that are intended to be received by a particular STA shall be within the first $2^{\text{Maximum Rx PSDU Length}}$ bytes of the PSDU, using the limit declared by that STA.

## 7.6 HT PHY-SAP service operation

The encoding of the HT-SF supports transmission of non-aggregate PSDUs up to a limit of 3071B.
The MAC may transmit single A-MSDU frames of length exceeding 3071B using an A-MPDU aggregate containing a single frame.

An A-MPDU aggregate shall be transmitted using a HT format PPDU with the A-MPDU TXVECTOR field set to 1.

On receiving a PSDU with the A-MPDU RXVECTOR field set to 1, the MAC shall use the A-MPDU aggregation format to unpack the component MPDUs. [7]

# 8 MAC sublayer management

## 8.1 Coexistence management

### 8.1.1 Receiver capabilities regarding legacy operation in the extension channel

An HT AP or IBSS STA should be able to detect activity in the extension channel without being able to receive legacy MPDUs in it. On detecting a possible legacy MPDU, the STA should enable itself to receive in that extension channel in order to determine if a legacy BSS has arrived on the extension channel. It is not necessary that this capability be available simultaneous with operation on the control channel.

### 8.1.2 Infrastructure BSS Operation

#### 8.1.2.1 This section defines rules for operation of an infrastructure HT BSS Operation

The AP controls the operating mode and protection requirements of its STA through information elements in the beacon.

When the HT AP detects a legacy STA in the control channel, it shall set the legacy protection flag in the beacon, enter 20 MHz-base managed mixed mode, or attempt to find an alternative channel using the procedures defined in section 8.2. When the HT AP detects a legacy STA in the extension channel, it shall enter 20 MHz-base managed mixed mode or attempt to find an alternative channel using the procedures defined in section 8.2.

When the HT AP detects a 20MHz-only capable HT device, it shall set the HT20 protection flag in the beacon, enter 20 MHz-base managed mixed mode, or attempt to find an alternative channel using the procedures defined in section 8.2.

The HT AP transmits its beacon containing an HT management element[8]. The beacon may be in either a 20MHz HT PPDU or a legacy PPDU type.

> Note, the use of a beacon in a 20MHz HT PPDU format with the legacy protection flag unset is only suitable for managed installations where management procedures ensure that legacy BSSs do not share the same channels as HT APs.

When the beacon is formatted as a legacy PPDU, the AP may receive association and probe requests from legacy STAs. The AP shall respond to a legacy probe request with a legacy probe

[7] Note, the PHY transports a whole number of symbols in an aggregate. The A-MPDU structure ensures that any trailing padding is discarded on reception.

[8] This will stop other co-channel HT APs from considering the AP to be a legacy AP.

response. It shall respond to a legacy association request with a legacy association response. The AP may choose to accept or deny the association request.

In the 20 MHz-base managed mixed mode, the AP transmits its beacon using the legacy PPDU type. The beacon is transmitted on the control channel but for the purpose of reserving the extension channel, an AP may send beacons also in the extension channel. Beacons in the extension channel may cause legacy STAs to attempt association but the HT AP shall deny association or may ignore those requests.

#### 8.1.2.2 Infrastructure STA Operation

The operation of an infrastructure STA is controlled by the extension channel control, the legacy protection flag and the HT20 flag contained in beacon or probe response frames.

A STA that is only capable of 20MHz operation ignores the extension channel control.

A STA that is capable of 40MHz operation uses the extension channel control to determine what transmission widths are permitted and whether 20MHz-base managed operation is required, as defined in section 8.1.2.3..

The legacy protection and HT20 protection flags read from the beacon affects the selection of a basic rate and PPDU type as defined in section 7.2..

#### 8.1.2.3 20 MHz-Base Managed Operation

This section describes a coexistence mechanism where a BSS operates in 20 MHz mode and switches to a 40 MHz phase under the control of an HT AP. The HT AP reserves the 20MHz control channel and the 20MHz extension channel in turn to start the 40 MHz phase and resets the NAV in the 20MHz channels in the opposite order to start the 20 MHz phase. The process is illustrated in Figure 16. Due to the protection of the 40 MHz period in both channels, it is tolerant of overlapping BSSs on both 20MHz halves of a 40MHz channel.

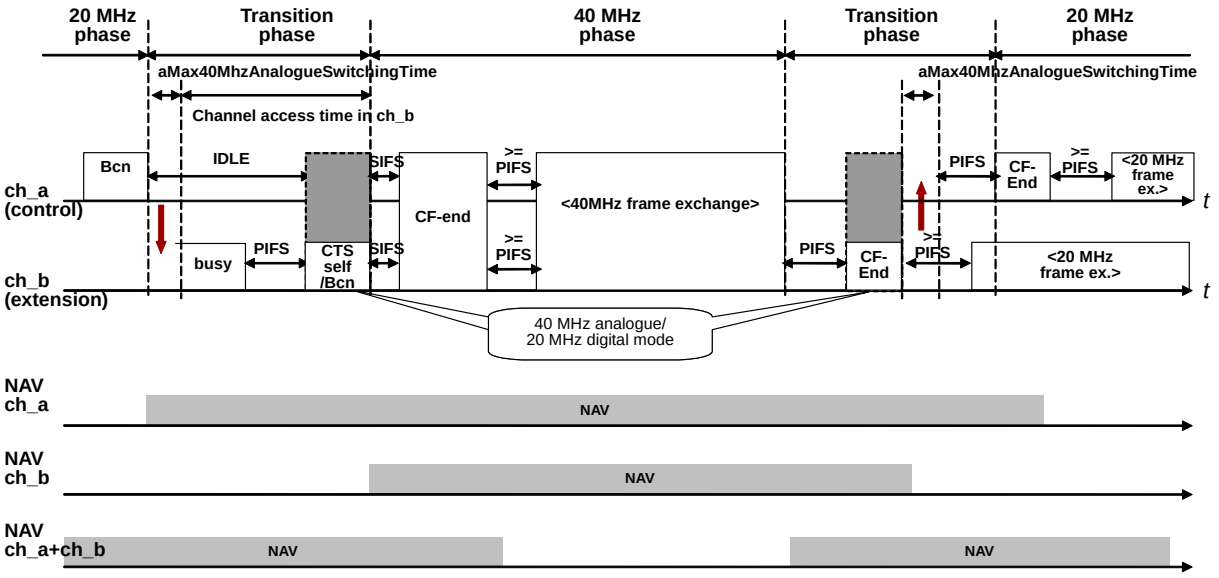



**Figure 16 – 20 MHz-Base Managed Mixed Mode**

#### 8.1.2.3.1 Assumptions

20 MHz STAs associated with the HT AP operate only on the control channel.

#### 8.1.2.3.2 Rules for Operation at HT AP

A CFP or a CTS-to-self NAV setting sent by an HT AP to reserve the medium for the 40 MHz phase shall include the transition periods between 20 and 40 MHz operation. If the HT AP intends to continue the CFP after the 40 MHz phase, it may do so by setting a longer duration for the CFP. To avoid an unexpectedly long channel access delay to the 40 MHz phase, the HT AP starts a timer with a timeout value equal to the extension channel access timeout after transmitting the beacon on the control channel. If the timer expires while attempting to reserve the extension channel, the AP shall abandon switching to the 40 MHz bandwidth by transmitting a CF-end frame on the control channel.

The AP shall wait for aMax40MhzAnalogueSwitchingTime + PIFS before sending a CTS to self or a beacon in the extension channel to start the 40MHz operating phase. Likewise, it waits for aMax40MhzAnalogueSwitchingTime + PIFS before sending out a CF-end in the control channel to start the 20 MHz operating phase (see Figure 17).

The HT AP exchanges frames with 40 MHz capable HT STAs using 40 MHz HT MCS in a 40 MHz phase. In a 20 MHz phase, it exchanges frames with legacy STAs using legacy rate and with both 20 MHz HT STAs and 40 MHz capable HT STAs using 20 MHz HT MCS. EDCA or HCCA channel access may be used in both phases.

#### 8.1.2.3.3 Rules for Operation at 40 MHz capable HT STAs

A 40 MHz capable HT STA associated with the HT AP extends its channel bandwidth to 40 MHz when it receives a beacon frame that contains an Extension Channel Control subfield set to

3, interpreting the NAV value as the remaining duration of the 40 MHz phase. To recover from unexpectedly long channel access delay to the 40 MHz phase, it shall start a timer associated with a timeout value equal to the extension channel access timeout when receiving the beacon. This timeout is reset when a 40MHz CF-End is received. When the 40 MHz phase ends or the timer associated with the extension channel access timeout expires before the 40 MHz NAV is reset, it shall set the NAV for 40 MHz mode operation to 65535 TU and may switch back to 20 MHz mode on the control channel to communicate in the 20 MHz phase.

A 40 MHz capable HT STA shall only transmit frames during the 40 MHz phase using 40 MHz HT PPDU type and shall only transmit frames during the 20 MHz phase using a 20 MHz (HT or legacy) PPDU type.

A 40 MHz capable HT STA including a HT AP that is attempting an EDCA channel access during a 40 MHz phase either freezes the backoff counter during 20 MHz operation and resumes the interrupted backoff during the next 40 MHz phase or selects a new random backoff at the start of the 40 MHz phase. If it is attempting a channel access during a 20MHz phase and a 40 MHz phase starts, it manages the backoff counter for the 20 MHz access likewise.

A 40MHz capable HT STA shall ignore the legacy protection and HT20 protection flags in the beacon during the 40MHz phase of 20 MHz-base managed mixed mode operation.

### 8.1.3 Ad-hoc (IBSS) Operation

Each STA maintains a table for STAs it can see according to the mode of operation of the STA. Stale entries in this table are removed by a timeout process. A STA can be classified as legacy if it is seen to transmit a legacy beacon without the HT elements (note, this also includes legacy APs). It is classified as a HT20 device according to its declared capabilities.
The IBSS beacon shall be transmitted using a legacy PPDU type. The beacon shall indicate what types of protection are required according to its own observations of legacy and HT20 STA types in its vicinity.

Its own observations, plus the protection requirements contained in received beacons shall be used to select the basic rates and PPDU types as defined in section 7.2.

## 8.2 Channel management

### 8.2.1 Channel Management at the AP

The AP transmits a beacon containing the Permitted Width Set, Control Channel Number, Extension Channel offset HT Management Element, as defined in section 6.3.2. This defines which channel is the control channel, which is the extension channel, and whether 40MHz operation is supported in this BSS.

An HT AP shall receive the beacons of other HT BSSs on its channel. If one of these indicates a that only 20MHz transmissions are permitted, the AP shall indicate that only 20MHz transmissions are permitted so that it matches or shall select a new operating channel.
HT BSSs shall only overlap HT BSSs with the same control channel and extension channel location. [9]

[9] This, together with the requirement for the same basic width set ensures that any pure-mode control frames sent in one BSS can be received in any overlapping HT BSS.

### 8.2.2 Channel Management at the STA

A STA shall only transmit 40MHz PPDUs when the Extension Channel Control is set to 1 (static 40MHz operation is permitted) or set to 3 (during the 40MHz phase of 20MHz-base managed mixed mode).

A STA shall only transmit an HT PPDU to a peer STA using a width that it knows the peer to support.

### 8.2.3 Channel Selection Rules for HT AP

The HT AP shall either be configured manually or configure itself automatically as described in this section.
The HT AP shall scan its environment before selecting channel parameters.
If the selected channel parameters overlap an existing HT BSS, then they must use the same control channel and extension channel offset and width (determined from the Extension Channel Control).
The AP shall reselect new channel parameters if an HT BSS that does not have the same control channel, extension channel offset and width starts operating on an overlapped channel.
Given a choice of 40MHz channel selections permitted by the previous rules, the AP should prefer a channel selection that aligns its 40MHz channel with the starting (i.e. lowest frequency) pair of adjacent 20MHz channels within any band or sub-band plus zero or more times 40MHz.

> Note: The purpose of this recommendation is to avoid introducing 20MHz "holes" between adjacent operating 40MHz BSS, thus making them unavailable for 40MHz operation.

## 8.3 Calibration

### 8.3.1 Introduction

Transmit beamforming can operate with or without calibration assistance from the receiver. Support for calibration is optional.

Differences in transmit and receive chains in a STA or AP destroy the inherent reciprocity of the over-the-air TDD channel. Calibration is helpful in order to remove differences in transmit and receive chains and enforce reciprocity in the observed baseband-to-baseband channels. A simple over-the-air calibration procedure effectively corrects for these differences. The calibration procedure ensures that the observed channel matrices in the two directions of the link are transposes of each other and thus renders the resultant channel reciprocal. Thus, if they are able to do so, STAs calibrate upon association. Calibration works for any square or non-square dimensionality, i.e., $N_{TX}$ and $N_{RX}$ greater than 1 and less than 5.

### 8.3.2 Procedure

A STA shall only initiate a calibration training frame exchange sequence with a device that has the "Calibration Supported" HT Capability set to 1.

The Calibration Training frame exchange sequence, illustrated in Figure 17: Calibration Procedure operates as follows:

- STA A transmits a Calibration Training MPDU (Position field = 0).

- In response, STA B transmits a Calibration Training MPDU (Position field = 1) after a SIFS interval, which includes the HT-LTF that allows STA A to estimate the channel matrices.
- In response, STA A transmits a Calibration Training MPDU (Position field = 2) after a SIFS interval, which includes the HT-LTF that allows a receiving STA B to estimate the channel matrices.

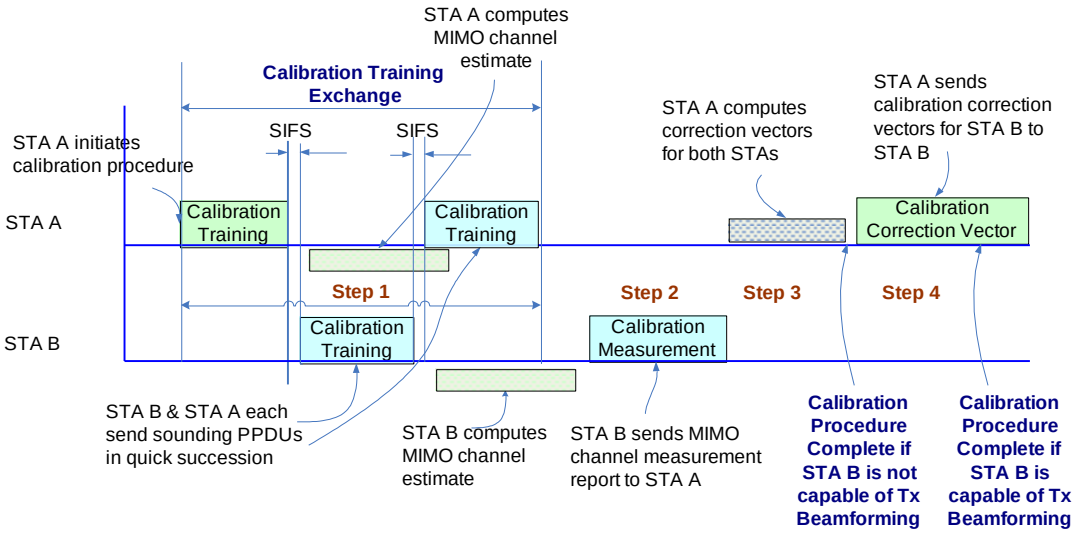



**Figure 17: Calibration Procedure**

The Calibration Training MPDUs are carried in non-aggregated sounding PPDUs. The last two steps must occur over a sufficiently short time interval so that the channel does not change over the interval. When used in a mixed BSS, this frame exchange sequence must be protected with an appropriate protection mechanism.

The remaining message exchange in the calibration procedure is not time critical.
When the channel measurements become available at STA B, STA B sends one or more Calibration Measurement action frames that contain the MIMO Channel Measurement Report. STA B sets the Calibration Complete bit to '1' in case it is not capable of transmit beamforming. In this case STA A will not send Calibration Correction frame.

In case that both STAs are capable of transmit beamforming, once STA A has the MIMO Channel Measurement Report from STA B, along with its local channel measurement measured from the Calibration Training frame transmitted by STA B, STA A can compute the correction vectors required for both itself and STA B. The Calibration Correction frame is transmitted to complete the calibration procedure by STA A. The message includes the MIMO Correction Vector for STA B.

## 8.4 Precise TSF synchronization

### 8.4.1 Precise TSF synchronization support at the AP

Jitter of the beacon transmission time relative to its timestamp is created by its passage through both MAC and PHY.

The optional "Precise TSF synchronization" function provides a means to improve the precision of synchronization of timestamps at a non-AP STA with those transmitted by the AP.

This is achieved by synchronizing the timing of the generation of PHY-TXSTART.request primitive used to transmit a beacon with the update events ("clock edge") of the TSF timer, and by minimizing the variation of PHY processing delay.

The amount of jitter between the TSF timer update and the on-the-air transmission time is assumed to be a constant, which is a characteristic of the AP design. It is signaled in the SyncPrecision field of the TSF Synchronization Precision Capability Element.

If Precise TSF synchronization is not supported, the AP shall not transmit the TSF synchronization precision capability element.

If Precise TSF synchronization is supported, the AP shall transmit a TSF synchronization precision capability element with the SyncPrecision field set to a non-zero value that is no less than the actual precision available.

### 8.4.2 Precise TSF synchronization support at the non-AP STA

The precision of oscillators used for the TSF timers in both AP and STA, the variation of multipath delay, as well as the transmission path jitter described in 8.4.1 are sources of jitter for synchronizing TSF timers.

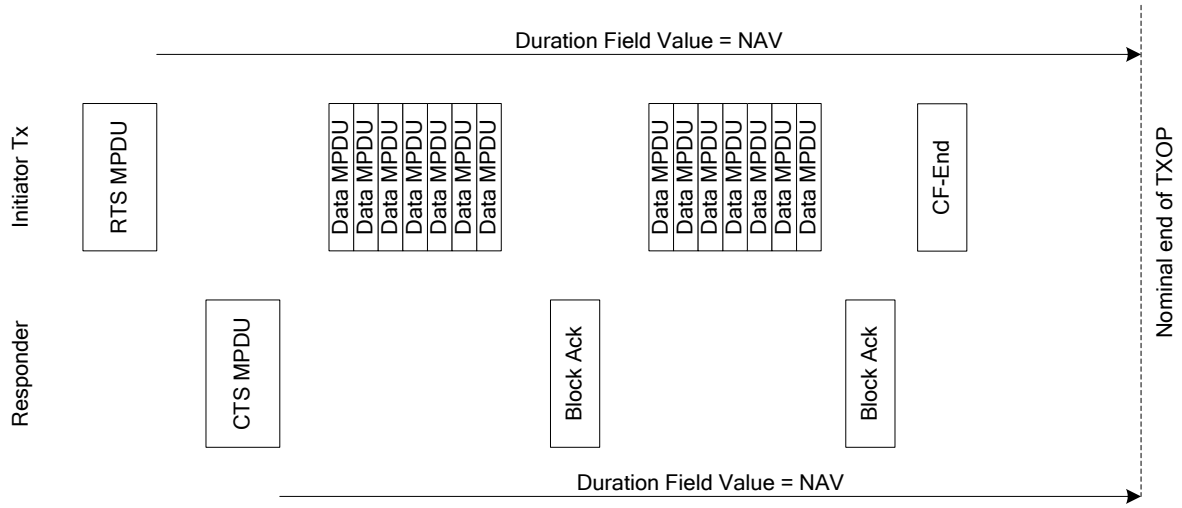
Transmission path jitter can be reduced at AP as described in 8.4.1. The Non-AP STA may maintain a precise TSF timer by filtering out the above jitters using a PLL.

The implementation detail of the PLL is out of a scope of this standard.

# 9 Background information and Examples (Informative)

## 9.1 Example Aggregation Exchanges

### 9.1.1 Simple Aggregation Exchange




The initiator transmits a non-aggregate RTS using a basic rate and PPDU type (as defined in section 7.2), and with a NAV value set to the nominal end of the TXOP (this is LongNAV protection).

The responder transmits a non-aggregate CTS after a SIFS interval using a basic rate and PPDU type.

The initiator transmits an A-MPDU containing a burst of Data MPDUs addressed to the responder.

The responder determines this is an SRA (not part of an MMP sequence) and transmits a response after SIFS carrying only mandatory response frames. In this case only a single BA is required, which is sent in an unaggregated MPDU.

This sequence of Data burst / BA continues until the initiator has run out of data, or the TXOP expires. In this case, the initiator runs out of data, and transmits a CF-End at a basic rate and PPDU type.

### 9.1.2 Aggregation Exchange with Reverse-Direction Data and slow link adaptation

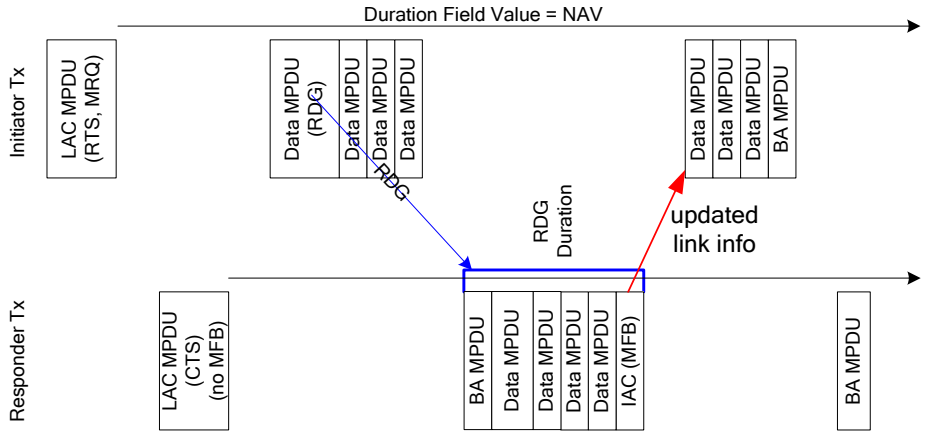



**Figure 18 – LongNAV Bi-Directional Example**

After an initial LAC (RTS)/LAC (CTS) MPDU exchange, the initiator transmits an aggregate containing one or more MPDUs with the RDG field set to 1. The duration value specifies a limit for the response burst. In this case the responder generates a single PPDU (with the More PPDU field set to 0 in all MPDUs) constrained by this duration, containing MPDUs addressed RA=initiator and containing QoS data AC matching that of the MPDU containing the RDG. The MRQ present in the first LAC generated no immediate response. The responder aggregated a LAC(MFB) later in the sequence in its response PPDU to contain updated link adaptation parameters.

### 9.1.3 MMP Sequence

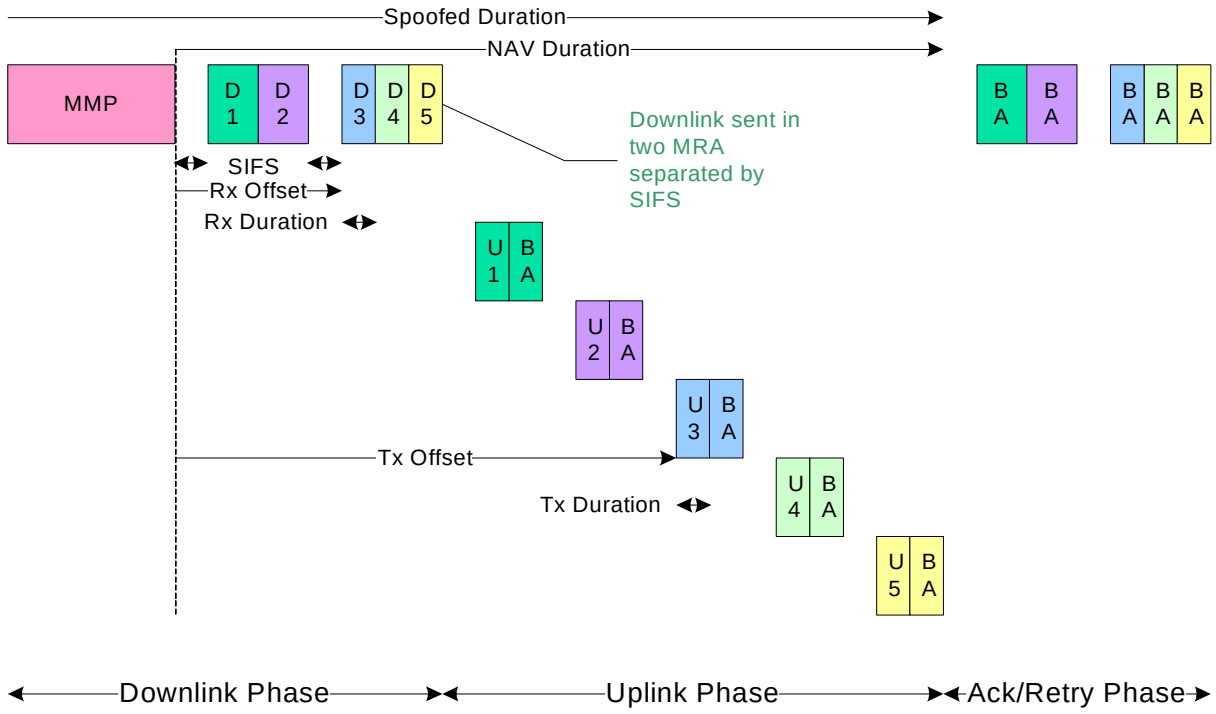


**Figure 19: Example of an MMP sequence**

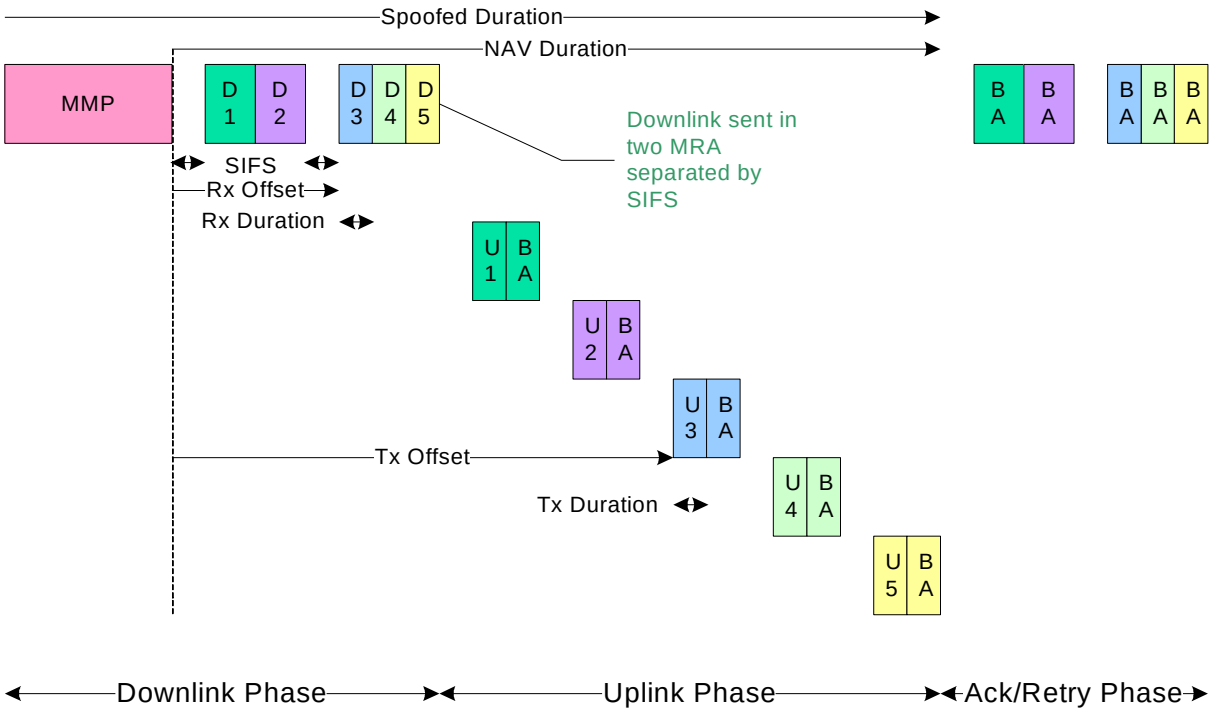



Figure 19: Example of an MMP sequence shows an example of the use of MMP, such as in support of VoIP handsets.

In this example, the AP has grouped together five handsets into one service interval. The five handsets all wake from sleep according to 802.11e periodic APSD. The AP transmits an MMP frame at the start of the service interval that locates the downlink (receive) and uplink (transmit) periods for each STA, identified through its association identifier.

In this case the downlink is split into two PPDUs containing five data MPDUs. STA with similar rates are grouped together to optimize the duration of the downlink. Each STA wakes to receive its downlink, and then wakes to transmit its uplink.

In this example, we show the use of data sent under a block ack agreement. So the transmitted data results in an implicit BAR, causing the uplink to contain data and acknowledgement to the downlink. It's also possible, in this example, to use normal ack policy because we are only transmitting at most one data frame for each receiver in each aggregate.

The five STA all awake at the end of the MMP sequence to receive the acknowledgements they are expecting to their uplink data (again, through the operation of the implicit BAR in this example). They stay awake until they receive their acknowledgements, or the service interval expires.

# 10 PHY-SAP service specification

The PHY service is provided to the MAC entry at an STA through the PHY service access point (PHY-SAP), as shown in Figure 11 of [1] and described in Clause 12 of that reference.

The amendments to the PHY-SAP parameters TXVECTOR and RXVECTOR are described in Sections 10.1.1 and 10.1.2 respectively.

## 10.1 PHY Specific Service Parameter List

The architecture of the IEEE 802.11 MAC is intended to be PHY independent. Some PHY implementations require PHY-dependent MAC state machines running in the MAC sublayer in order to meet certain PMD requirements. The PHY-dependent MAC state machine resides in a sublayer defined as the MAC sublayer management entity (MLME). In certain PMD implementations, the MLME may need to interact with the PLME as part of the normal PHY SAP primitives. These interactions are defined by the PLME parameter list currently defined in the PHY service primitives as TXVECTOR and RXVECTOR. The list of these parameters, and the values they may represent, are defined in the specific PHY specifications for each PMD. This subclause addresses the TXVECTOR and RXVECTOR for the MIMO-OFDM High Throughput (HT) PHY. The service parameters for TXVECTOR and RXVECTOR shall follow subclause 10.1.1 and 10.1.2.

### 10.1.1 TXVECTOR

The TXVECTOR is an array of fields sent from the MAC to the PHY instructing the PHY how to transmit the PPDU.

| Parameter | Associated Primitive | Value |
|---|---|---|
| PPDU FORMAT | PHY-TXSTART.request (TXVECTOR) | Legacy 20 in 20<br>HT 20 in 20<br>Legacy upper 20 in 40<br>Legacy lower 20 in 40<br>HT upper 20 in 40<br>HT lower 20 in 40<br>HT 40 in 40 |
| L-LENGTH | PHY-TXSTART.request (TXVECTOR) | 1 – 4095 |
| L-DATARATE | PHY-TXSTART.request (TXVECTOR) | 6, 9, 12, 18, 24, 36, 48, and 54 (Support of 6, 12, and 24 data rates are mandatory.) |
| L-SERVICE | PHY-TXSTART.request (TXVECTOR) | Scrambler initialization; 7 null bits + 9 reserved null bits |
| TX_PWR_LEVEL | PHY-TXSTART.request (TXVECTOR) | 1 – 8 |
| HT-LENGTH | PHY-TXSTART.request | 1 – 262143 |

| | | |
|---|---|---|
| | (TXVECTOR) | |
| MCS | PHY-TXSTART.request (TXVECTOR) | 0 – 126 |
| ADV CODING | PHY-TXSTART.request (TXVECTOR) | 0, 1 |
| SOUNDING | PHY-TXSTART.request (TXVECTOR) | 0, 1 |
| NLTF | PHY-TXSTART.request (TXVECTOR) | 1 – 4 |
| A-MPDU | PHY-TXSTART.request (TXVECTOR) | 0, 1 |
| SCRAMBLER-INIT | PHY-TXSTART.request (TXVECTOR) | 0, 1, 2, 3 |
| SHORT-GI | PHY-TXSTART.request (TXVECTOR) | 0, 1 |
| BEAMFORMED | PHY-TXSTART.request (TXVECTOR) | 0, 1 |
| BEAMFORM MATRIX | PHY-TXSTART.request (TXVECTOR) | $(N_{SD} + N_{SP})$ complex matrices of dimension $N_{TX} \times N_{LTF}$ |
| STBC | PHY-TXSTART.request (TXVECTOR) | 0, 1 |

**Table 10: Table of parameters for the TX Vector**

#### 10.1.1.1 TXVECTOR PPDU FORMAT

The PPDU FORMAT field specifies whether the PPDU is to be sent using a legacy PPDU format or using a high-throughput format. Legacy is interpreted to be 802.11g if operating in the 2.4 GHz band and 802.11a if operating in the 5 GHz band. Furthermore, it specifies the channel (i.e, the full 20MHz channel, the upper 20MHz sub-channel in the 40MHz channel, the lower 20MHz sub-channel in the 40MHz channel, or the full 40MHz channel) at which the PPDU is to be sent.

The value of this field affects the interpretation of several other TXVECTOR fields.

#### 10.1.1.2 TXVECTOR L-LENGTH

The allowed values for the L-LENGTH parameter are in the range of 1–4095.

In legacy format this parameter is used to indicate the number of octets in the MPDU which the MAC is currently requesting the PHY to transmit. This value is used by the PHY to determine the number of octet transfers that will occur between the MAC and the PHY after receiving a request to start the transmission. In high-throughput format this parameter (along with L-DATARATE) is used to protect the length of the current PPDU and possibly additional PPDUs.

#### 10.1.1.3 TXVECTOR L-DATARATE

In legacy format the L-DATARATE parameter describes the bit rate at which the PLCP shall transmit the PSDU. Its value can be any of the rates: 6, 9, 12, 18, 24, 36, 48, and 54. Data rates of 6, 12, and 24 shall be supported; other rates may also be supported. In high-throughput format this parameter (along with L-LENGTH) is use to protect the length of the current PPDU and possibly additional PPDUs. For legacy protection purposes, L-DATARATE in the L-SIG is set to 6Mbps.

#### 10.1.1.4 TXVECTOR L-SERVICE

In legacy format the L-SERVICE parameter consists of 7 null bits used for the scrambler initialization and 9 null bits reserved for future use. In HT format this parameter is Null.

#### 10.1.1.5 TXVECTOR TXPWR_LEVEL

The allowed values for the TXPWR_LEVEL parameter are in the range from 1–8. This parameter is used to indicate which of the available TxPowerLevel attributes defined in the MIB shall be used for the current transmission. In high-throughput format the transmit power is the aggregate of the power from all transmit antennas.

#### 10.1.1.6 TXVECTOR HT-LENGTH

The allowed values for this parameter are 1 – 264143. In HT format this parameter indicates the number of octets in the PSDU to be sent in the PPDU. In legacy format this parameter is Null.

#### 10.1.1.7 TXVECTOR MCS

The allowed values for this parameter are 0 – 126. In HT format this parameter indicates the modulation and coding scheme. The number is an index into the MCS table given in Table 17. In legacy format this parameter is Null.

#### 10.1.1.8 TXVECTOR ADV CODING

In HT format this parameter indicates whether advanced coding is used. A value of 0 indicates that advanced coding is not used. In legacy format this parameter is Null. A value of 1 indicates LDPC coding is used.

#### 10.1.1.9 TXVECTOR SOUNDING

In HT format this parameter indicates whether this PPDU is a sounding PPDU. A value of 0 indicates that it is not a sounding PPDU. A value of 1 indicates that it is a sounding PPDU. In legacy format this parameter is Null.

#### 10.1.1.10 TXVECTOR NLTF

In high-throughput format this parameter specifies the number of long training fields. In legacy format this parameter is Null.

#### 10.1.1.11 TXVECTOR A-MPDU

In high-throughput format this parameter indicates whether the PPDU contains an aggregated MPDU. A value of 0 indicates that the MPDU is not an aggregate and a value of 1 indicates that the MPDUs are aggregated. In legacy format this parameter is Null.

#### 10.1.1.12 TXVECTOR SCRAMBLER-INIT

In high-throughput format this is the scrambler initialization field. It is a two-bit field, which serves as a pointer to one of four 7-bit long scrambler initialization sequences. In legacy format this parameter is Null.

The 2 bits are mapped to the following four scrambler initialization sequences:

| |
|---|
| b'00 → step 15 b'0111100 |
| b'01 → step 84 b'0111101 |
| b'10 → step 103 b'0111110 |
| b'11 → step 127 b'0111111 |

**Table 11: Scrambler Initialization Sequence**

#### 10.1.1.13 TXVECTOR SHORT-GI

In high-throughput format this parameter indicates whether the data is sent with a short guard interval (400 ns). A value of zero indicates a full GI (i.e. 800ns) and a value of 1 indicates a short GI (i.e. 400 ns). In legacy format this parameter is Null.

#### 10.1.1.14 TXVECTOR BEAMFORMED

In high-throughput format this parameter indicates whether a beamforming matrix is applied to the data. A value of zero indicates that no beamforming is applied and a value of 1 indicates that beamforming is applied. In legacy format this parameter is Null.

#### 10.1.1.15 TXVECTOR BEAMFORM MATRIX

In high-throughput format this field specifies $\left(N_{SD} + N_{SP}\right)$ complex matrices of dimension $N_{TX} \times N_{LTF}$ which are used to beamform the PPDU. This field is only valid when the BEAMFORMED parameter is set to 1. In legacy format this parameter is set to Null.

#### 10.1.1.16 TXVECTOR STBC

In HT format this parameter indicates whether STBC is used. A value of 0 indicates that STBC is not used. A value of 1 indicates that STBC is used. In legacy format this parameter is set to Null.

### 10.1.2 RXVECTOR

The RXVECTOR is an array of fields sent from the PHY to the MAC providing information regarding the received PPDU.

| Parameter | Associated Primitive | Value |
|---|---|---|
| PPDU FORMAT | PHY-RXSTART.indicate (RXVECTOR) | Legacy 20 in 20<br>HT 20 in 20<br>Legacy upper 20 in 40<br>Legacy lower 20 in 40<br>HT upper 20 in 40<br>HT lower 20 in 40<br>HT 40 in 40 |
| L-LENGTH | PHY-RXSTART.indicate (RXVECTOR) | 1 – 4095 |
| RSSI | PHY-RXSTART.indicate (RXVECTOR) | 0 – RSSI maximum |
| L-DATARATE | PHY-RXSTART.indicate (RXVECTOR) | 6, 9, 12, 18, 24, 36, 48, and 54 |
| BW | PHY-RXSTART.indicate (RXVECTOR) | 20, 40 |
| HT-LENGTH | PHY-RXSTART.indicate (RXVECTOR) | 1 – 262143 |
| MCS | PHY-RXSTART.indicate (RXVECTOR) | 0 – 126 |
| ADV CODING | PHY-RXSTART.indicate (RXVECTOR) | 0, 1 |
| SOUNDING | PHY-RXSTART.indicate (RXVECTOR) | 0, 1 |
| NLTF | PHY-RXSTART.indicate (RXVECTOR) | 1 – 4 |
| A-MPDU | PHY-RXSTART.indicate (RXVECTOR) | 0, 1 |
| SHORT-GI | PHY-RXSTART.indicate (RXVECTOR) | 0, 1 |
| STBC | PHY-RXSTART.indicate (RXVECTOR) | 0, 1 |

**Table 12: Table of parameters for the RX Vector**

#### 10.1.2.1 RXVECTOR PPDU FORMAT

The PPDU FORMAT field specifies whether the received PPDU has a legacy PPDU format or a high-throughput format. Legacy is interpreted to be 802.11g if operating in the 2.4 GHz band and 802.11a if operating in the 5 GHz band. Furthermore, it specifies the channel (i.e, the full 20MHz channel, the upper 20MHz sub-channel in the 40MHz channel, the lower 20MHz sub-channel in the 40MHz channel, or the full 40MHz channel) at which the received PPDU was sent.

#### 10.1.2.2 RXVECTOR L-LENGTH

The allowed values for the L-LENGTH parameter are in the range of 1–4095. This parameter is used to indicate the value of the L-LENGTH field in received PPDU. If this was a legacy PPDU then this parameter is the actual length of the PPDU. If this is a HT PPDU then this parameter, along with the L-DATARATE parameter, is used to calculate the protected duration.

#### 10.1.2.3 RXVECTOR RSSI

The allowed values for the receive signal strength indicator (RSSI) parameter are in the range from 0 through RSSI maximum. This parameter is a measure by the PHY sub-layer of the energy observed at the antenna used to receive the current PPDU. RSSI shall be measured during the reception of the PLCP preamble. RSSI is intended to be used in a relative manner, and it shall be a monotonically increasing function of the received power. The value of RSSI is the maximum of the RSSI values from each receive antenna.

#### 10.1.2.4 RXVECTOR L-DATARATE

The allowed values for L-DATARATE are: 6, 9, 12, 18, 24, 36, 48, and 54. This parameter is used to indicate the value of the L-DATARATE field in the received PPDU. If this is a legacy PPDU this is the data rate at which the data was transmitted. If this is an HT PPDU then this parameter, along with L-LENGTH, is used to calculate the protected duration.

#### 10.1.2.5 RXVECTOR BW

In high-throughput format this parameter specifies whether the received PPDU is a 20 MHz bandwidth or 40 MHz bandwidth HT PPDU. In legacy format this parameter is Null.

#### 10.1.2.6 RXVECTOR HT-LENGTH

The allowed values for this parameter are 1 – 264143. In HT format this parameter indicates the value contained in the HT-LENGTH field. This parameter specifies the number of octets to be transferred from the PHY to the MAC sub-layer. In legacy format this parameter is Null.

#### 10.1.2.7 RXVECTOR MCS

The allowed values for this parameter are 0 – 126. The number is an index into the MCS table given in Table 17. In high-throughput format this parameter indicates the value of the MCS field in the PPDU HT-SIG. In legacy format this parameter is Null.

#### 10.1.2.8 RXVECTOR ADV CODING

In HT format this parameter indicates whether advanced coding was used in the PPDU. A value of 0 indicates that advanced coding is not used. In legacy format this parameter is Null. A value of 1 indicates that LDPC coding is used.

#### 10.1.2.9 RXVECTOR SOUNDING

In HT format this parameter indicates whether this PPDU is a sounding PPDU. A value of 0 indicates that it is not a sounding PPDU. A value of 1 indicates that it is a sounding PPDU. In legacy format this parameter is Null.

#### 10.1.2.10 RXVECTOR NLTF

In high-throughput format this parameter specifies the number of long training fields. In legacy format this parameter is Null.

#### 10.1.2.11 RXVECTOR A-MPDU

In high-throughput format this parameter indicates whether the PPDU contains an aggregated MPDU. A value of 0 indicates that the MPDU is not an aggregate and a value of 1 indicates that the MPDUs are aggregated. This value is used by the MAC sub-layer to indicate whether de-aggregation is required. In legacy format this parameter is Null.

#### 10.1.2.12 RXVECTOR SHORT-GI

In high-throughput format this parameter indicates whether the data was sent with a short guard interval (400 ns). A value of zero indicates a full GI (800 ns) and a value of 1 indicates a short GI (400 ns). In legacy format this parameter is Null.

#### 10.1.2.13 RXVECTOR STBC

In high-throughput format this parameter indicates whether STBC is used. A value of zero indicates that STBC is not used and a value of 1 indicates that STBC is used. In legacy format this parameter is set to Null.

# 11 MIMO-OFDM HT PHY specification

## 11.1 Overview

### 11.1.1 Introduction (Informative)

The PHY layer introduces several techniques for increasing the rate and reliability of the wireless link, as shown in Table 13:

| Feature | Mandatory | Optional |
|---|---|---|
| Number of Spatial Streams | 1 and 2 | 3 and 4 |
| Number of Transmit Antennas | 2 | Greater than 2 |
| Channelization bandwidth | 20MHz | 40MHz |
| Number of Occupied Subcarriers | 56 in 20MHz | 114 in 40MHz |
| Number of Data Subcarriers | 52 | 108 |
| Number of Pilot Subcarriers | 4 | 6 |
| Modulation Order | BPSK, QPSK, 16-QAM, 64-QAM | 256-QAM |
| Code Rate | 1/2, 2/3, 3/4, 5/6 | |
| Guard Interval | 800ns | 400ns |
| Convolutional Coding | R=1/2, K=7, ($g_1=133_8$, $g_2=171_8$) | |
| LDPC | | TX and RX Optional |
| TX Beamforming | | TX and RX Optional |
| STBC | | TX and RX Optional |

**Table 13: PHY Feature Set**

#### 11.1.1.1 Frequency Bands of Operation

Our proposal supports operation of devices in 2.4GHz, 5GHz, and 4.9GHz. Operation in 4.9GHz shall conform to 802.11j rules.

#### 11.1.1.2 MIMO Data Path Overview

The general data path for MIMO transmission is shown in Figure 20.

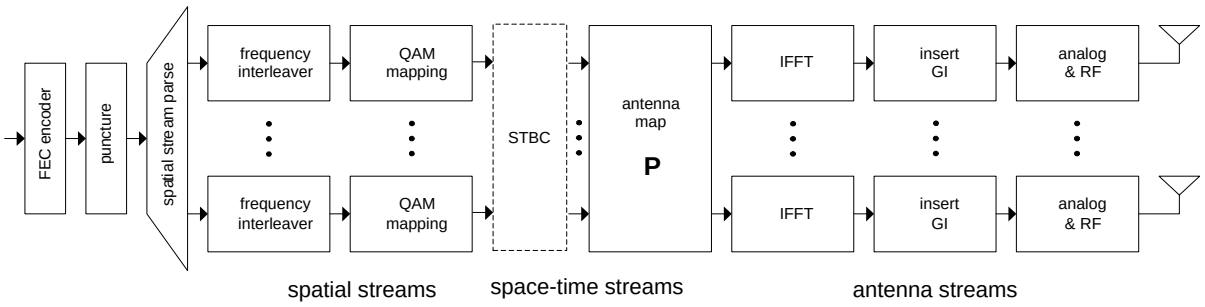



**Figure 20: MIMO data path.**

The FEC architecture has a single encoder. For the convolutional code (CC), the mother code is rate 1/2. Encoded bits may be punctured to produce code rates 2/3, 3/4 or 5/6. For the LDPC code different code rates are produced within the encoder and external puncturing is not applied. Processing of bits following encoding/puncturing is identical for both CC and LDPC.

The punctured bits are then distributed to $N_{SS}$ spatial streams via the spatial stream parser. For each spatial stream, blocks of bits that map to a single OFDM symbol are interleaved. This interleaving step is called "frequency interleaving" because it results in bit interleaving across subcarriers. The frequency interleaver is similar to the 802.11a interleaver. The combination of the spatial stream parser and the frequency interleavers results in space-time interleaving.

Interleaved bits are then mapped to QAM constellation points. The mapping may be BPSK, QPSK, 16 QAM, 64 QAM or 256 QAM.

If STBC is in use, the modulation symbols from the $N_{SS}$ spatial streams are encoded into $N_{STS} = 2N_{SS}$ space-time streams. If STBC is not used, the $N_{STS}$ space-time streams are equal to $N_{SS}$ spatial streams. The number of space-time streams is defined as

$$N_{STS} = \begin{cases} N_{SS} & \text{STBC is not used} \\ 2N_{SS} & \text{STBC is used} \end{cases}.$$

Antenna transformation maps $N_{STS}$ space-time streams to $N_{Tx}$ transmit antenna streams. Note that MIMO transmission requires $N_{SS} \le \min\{N_{Tx}, N_{Rx}\}$ where $N_{Rx}$ is the number of active receiving antennas at the receiving STA. In addition, we must always have $N_{STS} \le N_{Tx}$ in the transmit data path. This transformation is generically represented by the matrix **P**. In general, there may be a different $N_{Tx} \times N_{STS}$ transformation for each subcarrier. Our proposal supports three standard types of **P**-transformations, which are described in the subsections below.

Next, some mathematical notation for the antenna map transformations is provided. Let $\mathbf{P}^{(k)}$ denote the $N_{Tx} \times N_{STS}$ matrix that defines the antenna map for subcarrier *k*. We shall use the notation $\mathbf{p}_j^{(k)}$ to denote the $j^{\text{th}}$ column of $\mathbf{P}^{(k)}$, and $p_{i,j}^{(k)}$ to denote the $i,j^{\text{th}}$ element of $\mathbf{P}^{(k)}$. When convenient and when it is clear in context we shall often drop the subcarrier index superscript.

For an $N \times N$ matrix $\mathbf{A}$, the notation $[\mathbf{A}]_M$ shall denote the $N \times M$ matrix consisting of the first $M$ columns of $\mathbf{A}$.

Steering matrices are orthonormal matrices. This means that the columns $\mathbf{p}_0 \cdots \mathbf{p}_{N_{STS}-1}$ have Euclidean norm 1 and are orthogonal to each other. Mathematically, the orthonormal property is equivalent to $\mathbf{P}^H\mathbf{P} = \mathbf{I}_{N_{STS} \times N_{STS}}$. In the case $N_{Tx} = N_{STS}$ an orthonormal matrix is said to be unitary, in which case we also have $\mathbf{P}\mathbf{P}^H = \mathbf{I}_{N_{Tx} \times N_{Tx}}$.

It is noted that non-singular MIMO transmission requires $N_{SS} \leq \min\{N_{Tx}, N_{Rx}\}$ where $N_{Rx}$ is the number of active receive antennas at the receiving STA.

The PPDU has two parts. The legacy compatible part includes the L-STF, L-LTF, L-SIG and HT-SIG. The HT part includes the HT-STF, the HT-LTFs and the HT-Data. The antenna mapping for these two parts may be different. For example, the legacy compatible part may be direct map MIMO, while the HT part may employ spatial spreading or Tx beamforming. Indeed, both parts may employ spatial spreading, but with different cyclic delays.

To distinguish between different antenna map transformations, the notation $\mathbf{P}^{(k)}$ shall always denote the antenna map used during the HT part. The legacy compatible part always has only one spatial stream. Thus, we use a column vector $\mathbf{p}^{L(k)}$ to denote the antenna mapping for the legacy compatible part, and $p_{i_{Tx}}^{L(k)}$ is the element that defines the mapping to antenna $i_{Tx}$ (= 0, …, $N_{Tx}$).

After the antenna map, antenna streams are transformed to the time domain via the IFFT. The cyclically extended GI (guard interval) is added. Finally, time domain windowing (not shown in Figure 20) is applied to create a continuous time-domain signal, and analog and RF processing yields the signals that are applied to transmit antennas.

Table 10 summarizes the OFDM parameters for 20 and 40 MHz channels in comparison to the legacy 802.11 a/g formats.

| | 802.11a/g (20 MHz) | 20 MHz Channel (Mandatory) | 40 MHz Channel (Optional) |
|---|---|---|---|
| FFT size | 64 | 64 | 128 |
| Number of data subcarriers | 48 | 52 | 108 |
| Number of pilot subcarriers | 4 | 4 | 6 |
| Subcarrier separation | 312.5 kHz | 312.5 kHz | 312.5 kHz |
| Approx. Bandwidth | 16.25 MHz | 17.5 MHz | 36.6 MHz |

**Table 14: Summary of OFDM parameters**

#### 11.1.1.2.1 Basic MIMO Overview

##### 11.1.1.2.1.1 Direct Map MIMO Overview

Direct map MIMO is the simplest antenna mapping transformation. The **P** matrix is simply the identity mapping, i.e. each spatial stream maps to one antenna. Hence, there is a one-to-one correspondence between spatial streams and transmit antennas. Figure 21 illustrates the simplified data path for direct map MIMO.

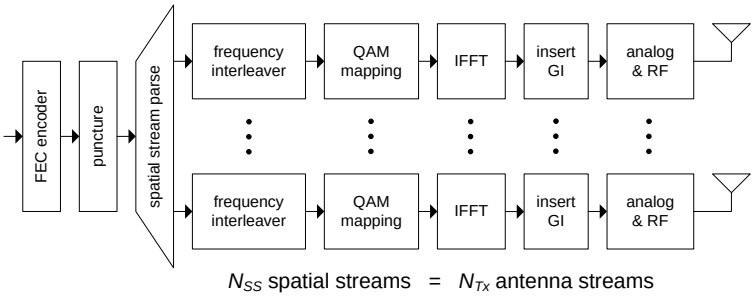



**Figure 21: Direct Map MIMO.**

For the direct map case, the **P** matrix is simply $\mathbf{P}^{(k)} = \left[\mathbf{I}_{N_{Tx}\times N_{Tx}}\right]_{N_{SS}}$; that is, we use the first $N_{SS}$ columns of the $N_{Tx} \times N_{Tx}$ identity matrix. Notice that for $N_{SS} < N_{Tx}$, the bottom $N_{Tx} - N_{SS}$ rows of $\mathbf{P}^{(k)}$ are all zero, which means that $N_{Tx} - N_{SS}$ transmit chains are not active.

For the legacy compatible part, the direct map antenna map vector is just $\mathbf{p}^{L(k)} = \left[1\,0\cdots 0\right]^T$, which simply means the entire legacy compatible part is transmitted on the first antenna.

##### 11.1.1.2.1.2 Spatial Spreading

Direct map MIMO only utilizes as many antennas as there are spatial streams; that is $N_{SS} = N_{Tx}$. Spatial spreading is one way to map spatial streams when the number of spatial streams is less than the number of transmitting antennas; that is $N_{SS} \le N_{Tx}$.

The basic spatial spreading function is achieved using the first $N_{SS}$ columns of a fixed $N_{Tx} \times N_{Tx}$ unitary matrix **W**. The same matrix **W** is used for all subcarriers. Typically one uses the Walsh matrix for $N_{Tx}$ = 2 and 4, or the Fourier matrix for $N_{Tx}$ = 3. A problem with this basic spatial spreading function is that it can result in undesired beamforming effects. To mitigate this effect, time-domain cyclic delays are applied to OFDM symbols prior to GI insertion. The first antenna is not delayed. Linearly increasing cyclic delays are then applied to the remaining antennas. In addition to mitigating undesired beamforming, the cyclic delays can also yield some performance improvement via transmit diversity. Thus, the method is referred to as Cyclic Delay Diversity (CDD). Since the unitary spatial spreading matrix is typically the Walsh matrix, this method is often called "Walsh+CDD."

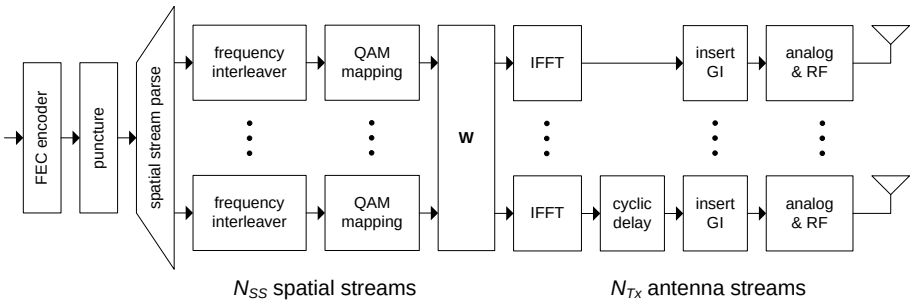



**Figure 22: Time domain implementation of spatial spreading cyclic delay.**

It is noted that since the **W** matrix is constant across subcarriers, yet another equivalent implementation would be to interchange the **W** matrix and the IFFT blocks.

At first, the spatial spreading method described above may seem to be a deviation to the general structure of Figure 20. However, there is a mathematical equivalence. The time domain cyclic delays are equivalent to a frequency dependent phase shift in the frequency domain. Each antenna has a different phasing due to the different cyclic delays. The result is that spatial spreading with time domain cyclic delays is mathematically equivalent to Figure 20 with **P** = **ΦW** where **Φ** is a frequency dependent diagonal phasing matrix.

Some mathematical notation for the antenna map transformations is provided. The frequency domain representation of the spatial spreading antenna map is

$$\mathbf{P}^{(k)} = \mathbf{\Phi}^{(k)} \left[ \mathbf{W}_{N_{Tx} \times N_{Tx}} \right]_{N_{SS}} \quad (1)$$

The matrix $\mathbf{\Phi}^{(k)}$ is an $N_{Tx} \times N_{Tx}$ diagonal unitary matrix that captures the frequency domain equivalent of cyclic delays in the time domain. Let $D$ denote the per antenna cyclic delay. The delay applied to antenna $i_{Tx}$ is $(i_{Tx} - 1)D$. Then

$$\mathbf{\Phi}^{(k)} = \text{diag}\left(1, \exp(-j2\pi k \Delta_F D), \ldots, \exp(-j2\pi k (N_{Tx} - 1)\Delta_F D)\right). \quad (2)$$

The matrix $\mathbf{W}_{N_{Tx} \times N_{Tx}}$ is the unitary spreading matrix. For $N_{Tx}$ = 2 or 4 these are Walsh-Hadamard matrices:

$$\mathbf{W}_{2\times 2} = \frac{1}{\sqrt{2}} \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix} \text{ and } \mathbf{W}_{4\times 4} = \frac{1}{2} \begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{bmatrix}. \quad (3)$$

For $N_{Tx}$ = 3 we use the Fourier matrix

$$\mathbf{W}_{3\times 3} = \frac{1}{\sqrt{3}} \begin{bmatrix} +1 & +1 & +1 \\ +1 & e^{j2\pi/3} & e^{-j2\pi/3} \\ +1 & e^{-j2\pi/3} & e^{j2\pi/3} \end{bmatrix}. \quad (4)$$

The unitary matrices in (3) and (4) are presented as typical solutions for construction of spatial spreading antenna map. In theory, any unitary matrix is sufficient. However, a significant advantage of these matrices is that each element has the constant complex modulus (= $1/\sqrt{N_{Tx}}$). The significance of this property is that each spatial stream maps equal energy to each antenna. Thus equal power is delivered to each antenna.

For the legacy compatible part, the spatial spreading antenna map vector is

$$\mathbf{p}^{L(k)} = \Phi^{(k)}(D)\ \frac{1}{\sqrt{N_{Tx}}}\begin{bmatrix}1\\ \vdots \\ 1\end{bmatrix} = \frac{1}{\sqrt{N_{Tx}}}\begin{bmatrix}1\\ \vdots \\ \exp(-j2\pi k(N_{Tx}-1)\Delta_F D)\end{bmatrix}. \quad (5)$$

This corresponds to a cyclic delay of $i_{Tx}D$ applied to antennas $i_{Tx} = 0, \ldots, N_{Tx}-1$.

#### 11.1.1.2.2 Space Time Block Coding

##### 11.1.1.2.2.1 STBC with direct map MIMO

STBC with direct map MIMO only utilizes as many antennas as processed; that is $N_{Tx} = N_{STS}$. The **P** matrix is simply the identity mapping, i.e. each space-time stream maps to one antenna. Hence, there is a one-to-one correspondence between space-time streams and transmit antennas. Figure 23 illustrates the simplified data path for STBC with direct map MIMO.

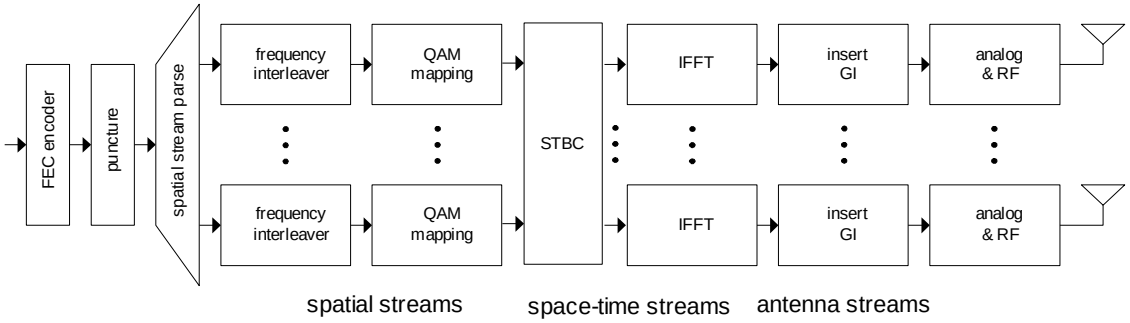



**Figure 23: STBC with direct map MIMO**

For the STBC with direct map case, the **P** matrix is simply $\mathbf{P}^{(k)} = \left[\mathbf{I}_{N_{Tx}\times N_{Tx}}\right]_{N_{STS}}$; that is, we use that first $N_{STS}$ columns of the $N_{Tx}\times N_{Tx}$ identity matrix. Notice that for $N_{STS} < N_{Tx}$, the bottom $N_{Tx} - N_{STS}$ rows of $\mathbf{P}^{(k)}$ are all zero, which means that $N_{Tx} - N_{STS}$ transmit chains are not active.

For the legacy compatible part, the direct map antenna map vector is just $\mathbf{p}^{L(k)} = \left[1\,0\cdots 0\right]^T$, which simply means the entire legacy compatible part is transmitted on the first antenna.

##### 11.1.1.2.2.2 STBC with spatial spreading

Spatial spreading is one way to map space-time streams to transmit antennas when the number of space-time streams is less than the number of transmitting antennas; that is $N_{STS} \le N_{Tx}$. The

basic spatial spreading function is achieved using the first $N_{STS}$ columns of a fixed $N_{Tx} \times N_{Tx}$ unitary matrix **W**, which is described in Section 11.1.1.2.1.2.

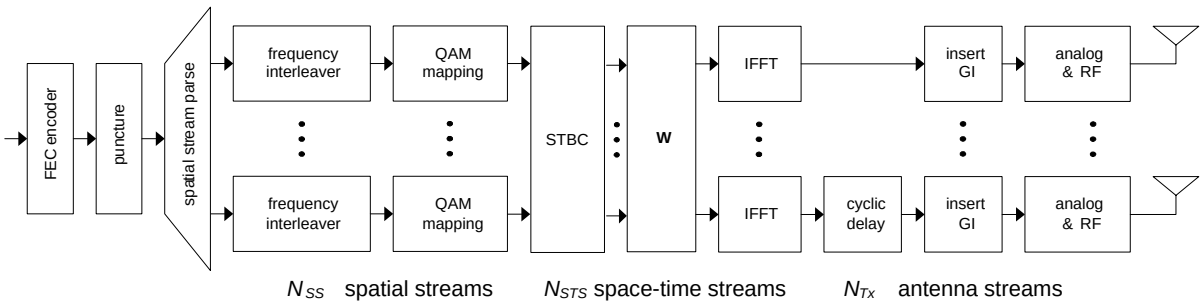



**Figure 24: STBC with spatial spreading**

The frequency domain representation of the spatial spreading antenna map is

$$\mathbf{P}^{(k)} = \mathbf{\Phi}^{(k)} \left[ \mathbf{W}_{N_{Tx} \times N_{Tx}} \right]_{N_{STS}} \quad (6)$$

The rest of the mathematical notation for the STBC with spatial spreading antenna map transformations is identical to that described in Section 11.1.1.2.1.2.

### 11.1.1.2.3 Transmit Beamforming

In this case, the P-transformation is designed specifically to pre-emphasize the dominant modes of transmission of the random MIMO channel. The optimal beamforming transformation is created from the right singular vectors of the SVD (singular value decomposition) of the observed channel. Our proposal provides full capability to implement SVD beamforming, as well as other types of beamforming such as constant amplitude phasing or constant beamforming matrices across all subcarriers. In these cases, the optimized beamforming matrix is the P-transformation.

Transmit beamforming is a technique that attempts to adjust the antenna map transformation to maximize the received energy at the receiver of each transmitted spatial stream. There are many ways to calculate beamforming matrices, which is largely left as an implementation option in this proposal. For informative purposes we briefly describe the optimal method based on the singular value decomposition (SVD) of the channel.

Let $\mathbf{H}^{(k)}$, which is an $N_{Rx} \times N_{Tx}$ matrix, denote the equivalent frequency domain channel for subcarrier *k*. Define $N = \min\{N_{Tx}, N_{Rx}\}$. Then the SVD is

$$\mathbf{H}^{(k)} = \mathbf{U}^{(k)} \mathbf{\Sigma}^{(k)} \mathbf{V}^{(k)H} \quad (7)$$

where $\mathbf{\Sigma}^{(k)} = \mathrm{diag}(\sigma_0, \ldots, \sigma_{N-1})$ is a diagonal matrix of "singular values," $\mathbf{U}^{(k)}$ is an $N_{Rx} \times N$ orthonormal matrix, and $\mathbf{V}^{(k)}$ is an $N_{Tx} \times N$ orthonormal matrix. (Thus, $\mathbf{U}^{(k)}$ is unitary if $N_{Rx} = N$, and likewise $\mathbf{V}^{(k)}$ is unitary if $N_{Tx} = N$.) The singular values are non-negative real numbers. We may always assume (by permutation of columns of $\mathbf{U}^{(k)}$ and $\mathbf{V}^{(k)}$) that $\sigma_0 \geq \sigma_1 \geq$

$\ldots \geq \sigma_{N-1}$. Given this ordering, the optimal beamforming transformation for $N_{SS} \leq N$ spatial streams is

$$\mathbf{P}^{(k)} = \left[\mathbf{V}^{(k)}\right]_{N_{SS}} . \quad (8)$$

#### 11.1.1.3 PPDU Format for Basic MIMO Transmission

The generic PPDU format is shown in Figure 25:




**Figure 25: PPDU Format**

The L-STF (Legacy Short Training Field), the L-LTF (Legacy Long Training Field), L-SIG (Legacy Signal Field) and HT-SIG (High Throughput Signal Field) comprise the legacy compatible part of the PPDU preamble. HT-STF, the HT-STFs and HT-Data symbols comprise the HT-Part of the PPDU.

In the 40MHz bandwidth, there are two 20MHz wide sub-channels. The upper sub-channel spans from 0 to +63, and the lower sub-channel spans from -64 to -1, as shown in Figure 26. A 40MHz-HT device receiving a 20MHz-only transmission shall indicate to the MAC which sub-channel is currently active.

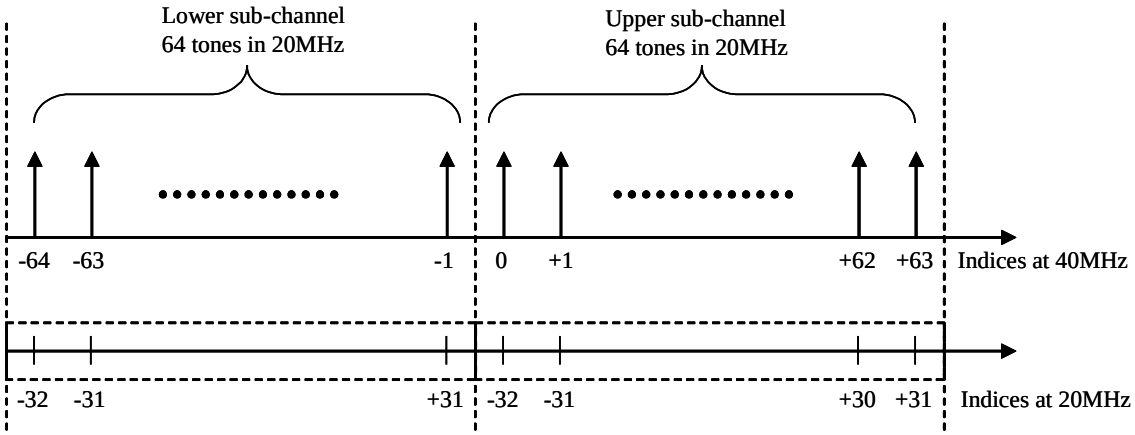



**Figure 26: Upper and Lower sub-channel specification in 40MHz**

The PPDU format from two transmit antennas, each 40MHz wide, is shown in Figure 27.

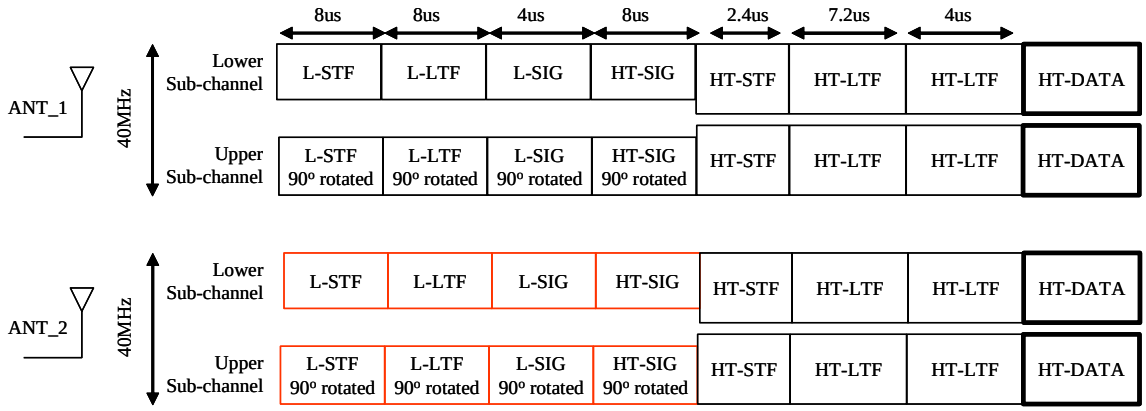



**Figure 27: PPDU Format for 2x40 Basic MIMO Transmission[10]**

The legacy part of the HT preamble (i.e. L-STF to L-SIG) and HT-SIG may either be transmitted from one antenna or both antennas. If transmitted from both antennas, the mapping of this single spatial stream to two antennas has to be such that beamforming in the far-field is mitigated. One method for achieving this is to use a cyclical delay diversity (CDD) mapping, as mentioned in 11.1.1.2.1.2. The optional part of the PPDU, corresponding to the CDD format, is shown in red color in Figure 27.

### 11.1.1.4 HT PCLP Preamble for Synchronization and Legacy Interoperability

The functions performed by the preamble include:

1. Start-of-Packet (SoP) detection
2. AGC
3. Coarse Frequency Offset Estimation
4. Coarse Timing Offset Estimation
5. Fine Timing Offset Estimation
6. Fine Frequency Offset Estimation
7. Channel Estimation

The High Throughput (HT) preamble in our proposal is a concatenation of the legacy preamble (identical to 802.11a/g) and a HT-specific preamble, as shown in Figure 28:

[10] 40MHz operation by an HT device shall only be permitted in those regulatory domain that allow it.

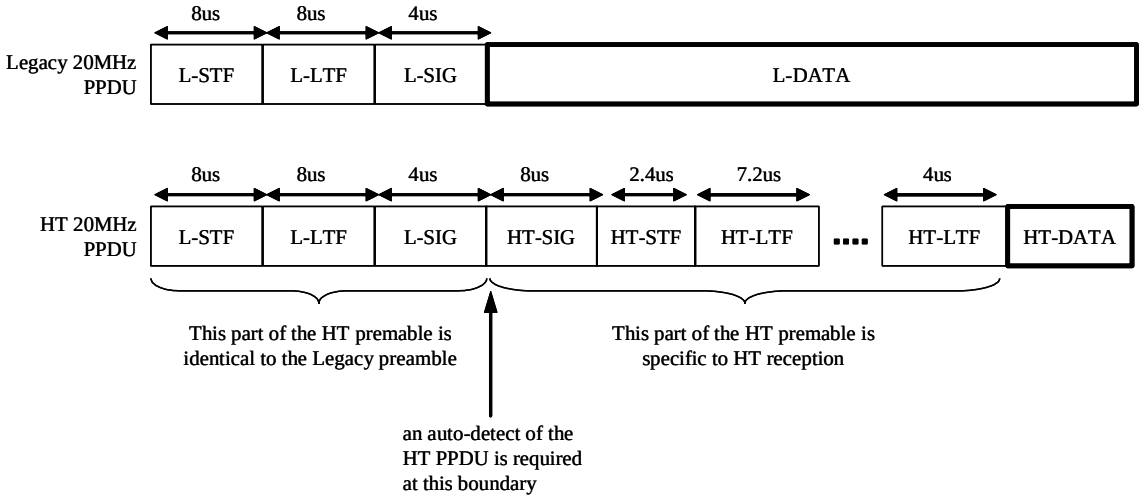



**Figure 28: HT Preamble format**

Concatenation of the legacy preamble allows PHY layer interoperability with 802.11a and ERP-802.11g modems.

A HT receiver does not know *a priori* whether it is receiving a legacy PPDU or a HT PPDU. Hence, a HT receiver has to perform an auto-detect after the legacy signal field (L-SIG) as to whether a HT-SIG is being received or legacy data (L-DATA). Our preamble format includes two provisions for auto-detecting the HT-SIG: (a) transmitting the HT-SIG as a BPSK signal on the quadrature axis instead of the in-phase axis, and (b) inverting the pilot polarity in going from the L-SIG to the HT-SIG.

The legacy part of the HT preamble allows a legacy receiver to properly decode the L-SIG. A HT receiver shall also perform functions 1 through 7 (SoP to Channel Estimation) to successfully decode the HT-SIG. It is anticipated that functions 1 through 4 (and perhaps function 5) are performed by the legacy short training field (L-STF), and functions 5 through 7 are performed by the legacy long training field (L-LTF).

Since a HT device (in our proposal) shall support multiple transmit antennas, the legacy part of the preamble can either be transmitted from one antenna or from multiple antennas. If more than one antenna is used for transmission, it is recommended that the signal be shifted in a cyclical fashion across the transmit antenna array. This technique introduces cyclical delay diversity (CDD), and it tends to reduce the "effective" length of the guard interval, as seen by a legacy device. Hence, the total shift across the transmit antenna array should be limited to 50ns.

In the 40MHz mode, the L-STF in the lower sub-channel is identical to legacy, whereas the L-STF in the upper sub-channel is a 90 degree phase rotation of the legacy STF. This rotation is performed to keep the PAPR of the STF low (see Figure 26 and Figure 27)

Since a legacy OFDM RX is not expected to "understand" any transmission after the L-SIG, the RATE and LENGTH fields in the L-SIG are selected such that a legacy OFDM RX can defer for the correct period of time.

The HT-SIG contains information needed to correctly de-map and decode the HT data field (i.e. the MIMO-OFDM symbols). It also contains fields for supporting advanced techniques that are described next.

Since the L-STF does not provide a sufficiently accurate power measurement for MIMO AGC purposes, a HT-STF has been introduced after the HT-SIG. The HT-STF is tone-interleaved symbol across the transmit antenna array. The HT short training symbol uses 24 tones in 20MHz (L-STF uses 12 tones in a 20 MHz channel). The choice of 24 tones permits accurate AGC measurements across 4 transmit antennas. In the 40 MHz channel, 48 tones are used in the HT-STF. The 24 (48) tones are interleaved across the antennas, i.e., 6 (12) tones are used per antenna if there are 4 transmitter antennas, and likewise 12 (24) are used per antenna if there are 2 transmitter antennas. The length of the HT-STS is 1.6μs. Since, the purpose of HT-STF is purely for AGC purposes, only one STS is needed. Together with the 0.8μs guard interval, the total length of the HT-STF is 2.4μs. The GI of the HT-STF, i.e. the first 0.8us, would contain echoes from the previous symbol. Hence, a clean measurement of power is made in the 1.6us portion of the HT-STF. It is anticipated that the RF transient settling after the AGC switch would occur in the GI of the HT-LTF that follows the HT-STF.

After the AGC has been "fine-tuned" for HT reception, channel estimation and fine frequency offset estimation are performed using the HT Long Training Symbols. In the basic MIMO modes, as in beamforming mode, the number of HT-LTFs sent must be at least equal to the number of streams sent, and at most equal to the number of transmit antennas. For example, when one spatial stream is transmitted using two transmit antennas, at least one HT-LTF must be sent, and under some conditions two HT-LTFs may be sent. However, if two spatial streams are sent using two transmit antennas, two HT-LTFs must be sent.

When the number of HT-LTFs that are sent is greater than the number of data streams, the resulting set of HT-LTFs is referred to as a segmented HT-LTF, and the additional HT-LTFs are referred to as extension HT-LTFs. In this case the tone interleaving is arranged so that the first $N_{SS}$ HT-LTFs sound the MIMO channel used by the $N_{SS}$ data streams, and the extension HT-LTFs sound the remaining dimensions of the MIMO channel. This is covered in more detail in 11.2.1.5.4.

The HT-LTF is also tone interleaved to minimize the power fluctuation with respect to the AGC setting (obtained via the HT-STF). Therefore, one HT-LTF would cover half of the tones in the two antenna case. Remaining tones are covered in the second HT-LTF. The first HT-LTF consists of two Long Training Symbols (LTS) as in 802.11a/g and a regular guard interval of 0.8 μs, giving a total length of 7.2μs. When present, the second, third and fourth HT-LTFs each consist of a single HT-LTS with a regular guard interval of 0.8 μs, giving a total length of 4μs.

### 11.1.1.5 Duplicate 6Mbps mode

The lowest data rate in the 40MHz mode would be 13.5Mbps (= 6Mbps x 2.25), if independent information bits are mapped to the upper and lower sub-channels. A 6Mbps mode in 40MHz is obtained by duplicating the data from the lower sub-channel to the upper sub-channel. For the 6Mbps mode in 40MHz, the MPDU is encoded, punctured, interleaved, and constellation-

mapped as a 6Mbps transmission in 20MHz. The duplication is performed just prior to the iFFT sub-carrier mapping, as shown in Figure 29.

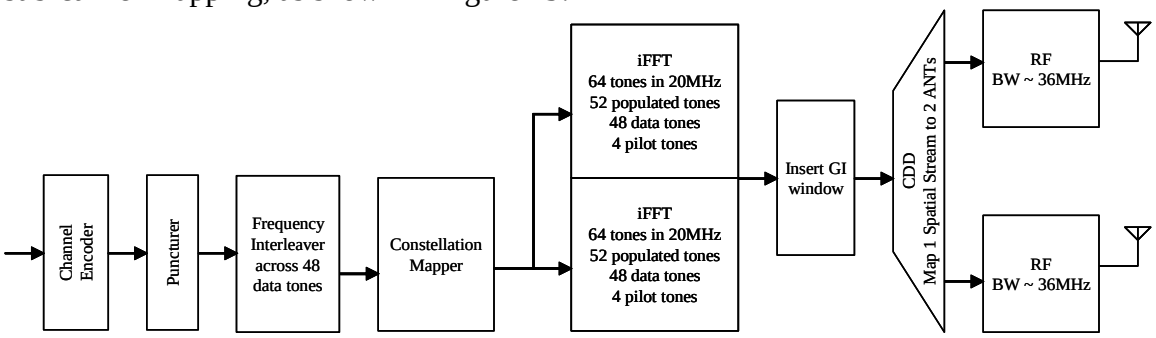



**Figure 29: Transmitter configuration for 6Mbps in 40MHz[11]**

Since the 6Mbps duplicate mode comprises of 1 spatial stream, only 1 HT-LTF is needed. Also note that there is no tone-fill past the HT-SIG, unlike the regular 40MHz PPDU format show in Figure 27. The PPDU format for the 6Mbps duplicate mode is shown in Figure 30:

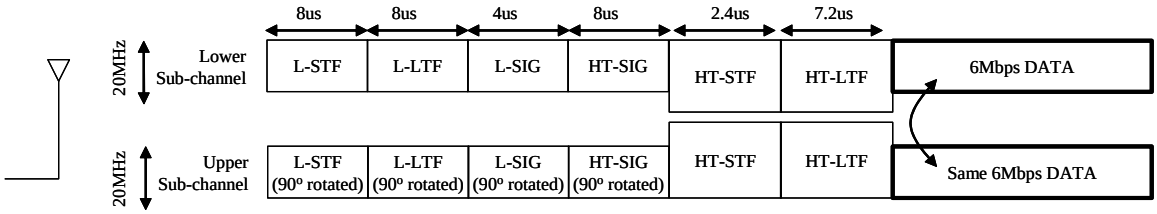



**Figure 30: PPDU format for 6Mbps duplicate mode**

Pilot locations in the duplicate mode follow the pilot locations in the 20MHz mode. The duplicate 6Mbps mode (in 40MHz) is signaled as mode 32 in the MCS set (see Table 17).

### 11.1.1.6 Feedback Mechanisms

Our proposal consists of several feedback mechanisms, supported at the MAC layer, as shown in Table 15.

| Nature of Feedback | Device Requirement | Type of Feedback | Description |
|---|---|---|---|
| Implicit feedback | Mandatory in device | Binary Response packet | • This only provides information to the TX whether its choice of the modulation-coding mode was supported by the channel.<br>• Does not provide any information to help perform spatial shaping<br>• Used when transmitting to legacy devices |
| Implicit Feedback | Optional | Binary Response packet sent as a sounding packet | • Allows the Initiator to estimate the physical channel in the reverse link. If reciprocity can be assumed, and if the number of TX and RX antennas are identical at the recipient, the TX can use the derived CSI to perform spatial shaping (e.g. in the style of BF-MIMO) |

[11] 40MHz operation by an HT device shall only be permitted in those regulatory domain that allow it.

| | | | |
|---|---|---|---|
| Explicit Feedback | Mandatory | RR (Rate Recommendation) Response packet | • The response packet contains a rate recommendation to the TX<br>• Since spatial shaping at the initiator is not desired, HT-LTFs are not appended |
| Explicit Feedback | Mandatory | RR Response packet sent as a sounding packet | • The response packet contains a rate recommendation to the TX<br>• Response packet does not contain forward link Channel State Information (CSIT)<br>• However, the sounding packet allows reverse link channel estimation. And, assuming reciprocity and equal number of TX RX antennas at the recipient, the initiator can perform spatial shaping. |

**Table 15: Feedback Mechanisms**

### 11.1.1.7 Comparison among MIMO transmission modes

Our proposal supports three classes of MIMO Transmissions Modes, as outlined in Table 16:

| MIMO Modes | Characteristic | Extent of TX adaptation |
|---|---|---|
| Basic MIMO (mandatory) | • Antenna mapping: direct map or spatial spreading | • No adaptation is performed in the spatial domain<br>• MCS selection (adaptation) is based upon either: (1) binary feedback (i.e. ACK/noACK), or (2) recommendation from the RX, or (3) availability of CSI at the TX |
| TX Beamforming (Optional) | • All spatial streams are spatially shaped via a beamforming matrix that may be different for each subcarrier.<br>• Enhanced performance can be obtained through the use of optional MCSs which support different data rates across spatial streams. | • CSI is required at the TX<br>• Sounding packet from the recipient to the initiator is required to estimate the CSI at the transmitter<br>• RF calibration at transmitter side is required since reciprocity is used to perform TX beamforming<br>• It is not mandated at devices which don't support Tx BF that they should be involved in calibration sequence. |
| Space Time Block Coding (Optional) | • All spatial streams undergo space-time block coding<br>• STBC output streams undergo antenna mapping: direct map or spatial spreading | • HT-Data field must contain an even number of OFDM symbols<br>• MCS selection (adaptation) is based upon either: (1) binary feedback (i.e. ACK/noACK), or (2) recommendation from the RX, or (3) availability of CSI at the TX |

**Table 16: MIMO Transmission options**

### 11.1.1.8 "Modulation-Coding Scheme" (MCS) Sets

Our proposal augments the 802.11a MCS set through the use of multiple spatial streams and bandwidth extension. A set of MCSs is defined to take full advantage of the availability of multiple spatial streams and extended bandwidth. The complete set is shown in Table 17. Our proposal supports a mandatory data rate of 130 Mbps using two spatial streams in 20MHz channelizations. And, with an eye towards the future, our proposal introduces scalability to 4 spatial streams and 40MHz channelization, offering data rates in excess of 700Mbps.

The first 33 MCSs (MCS 0 through MCS 32) consist of 8 modulation/code rate combinations supporting 1, 2, 3, and 4 spatial streams, plus a 6 Mbps duplicate mode for 40 MHz operation. All of these MCSs have equal code rate and modulation on all active spatial streams. Support of MCS 0 through MCS 15 is mandatory. Support of the remaining MCSs is optional.

In order to match per stream code rates and modulations as closely as possible to channel conditions on each spatial stream in BF MIMO, it is necessary to include MCSs with different data rates on each spatial stream. This may also be useful for basic MIMO. BF MIMO also can benefit from the use of 256-QAM, which is not used in MCSs 0 – 32. MCSs 33 – 126 have unequal modulation and/or 256-QAM. In order to simplify channel encoding and spatial parsing, a single channel coding rate with different modulations is used across spatial stream. All of these MCSs are optional.

**Table 17: MCS set**

| MCS Index | Code Rate | Stream Modulations | | | | 20 MHz Rates | | 40 MHz Rates | |
|---|---|---|---|---|---|---|---|---|---|
| | | M0 | M1 | M2 | M3 | Full GI | Half GI | Full GI | Half GI |
| 0 | 1/2 | BPSK | **OFF** | **OFF** | **OFF** | 6.50 | 7.22 | 13.50 | 15.00 |
| 1 | 1/2 | QPSK | **OFF** | **OFF** | **OFF** | 13.00 | 14.44 | 27.00 | 30.00 |
| 2 | 3/4 | QPSK | **OFF** | **OFF** | **OFF** | 19.50 | 21.67 | 40.50 | 45.00 |
| 3 | 1/2 | 16-QAM | **OFF** | **OFF** | **OFF** | 26.00 | 28.89 | 54.00 | 60.00 |
| 4 | 3/4 | 16-QAM | **OFF** | **OFF** | **OFF** | 39.00 | 43.33 | 81.00 | 90.00 |
| 5 | 2/3 | 64-QAM | **OFF** | **OFF** | **OFF** | 52.00 | 57.78 | 108.00 | 120.00 |
| 6 | 3/4 | 64-QAM | **OFF** | **OFF** | **OFF** | 58.50 | 65.00 | 121.50 | 135.00 |
| 7 | 5/6 | 64-QAM | **OFF** | **OFF** | **OFF** | 65.00 | 72.22 | 135.00 | 150.00 |
| | | | | | | | | | |
| 8 | 1/2 | BPSK | BPSK | **OFF** | **OFF** | 13.00 | 14.44 | 27.00 | 30.00 |
| 9 | 1/2 | QPSK | QPSK | **OFF** | **OFF** | 26.00 | 28.89 | 54.00 | 60.00 |
| 10 | 3/4 | QPSK | QPSK | **OFF** | **OFF** | 39.00 | 43.33 | 81.00 | 90.00 |
| 11 | 1/2 | 16-QAM | 16-QAM | **OFF** | **OFF** | 52.00 | 57.78 | 108.00 | 120.00 |
| 12 | 3/4 | 16-QAM | 16-QAM | **OFF** | **OFF** | 78.00 | 86.67 | 162.00 | 180.00 |
| 13 | 2/3 | 64-QAM | 64-QAM | **OFF** | **OFF** | 104.00 | 115.56 | 216.00 | 240.00 |
| 14 | 3/4 | 64-QAM | 64-QAM | **OFF** | **OFF** | 117.00 | 130.00 | 243.00 | 270.00 |
| 15 | 5/6 | 64-QAM | 64-QAM | **OFF** | **OFF** | 130.00 | 144.44 | 270.00 | 300.00 |
| | | | | | | | | | |

| MCS Index | Code Rate | Stream Modulations | | | | 20 MHz Rates | | 40 MHz Rates | |
|---|---|---|---|---|---|---|---|---|---|
| | | M0 | M1 | M2 | M3 | Full GI | Half GI | Full GI | Half GI |
| 16 | 1/2 | BPSK | BPSK | BPSK | **OFF** | 19.50 | 21.67 | 40.50 | 45.00 |
| 17 | 1/2 | QPSK | QPSK | QPSK | **OFF** | 39.00 | 43.33 | 81.00 | 90.00 |
| 18 | 3/4 | QPSK | QPSK | QPSK | **OFF** | 58.50 | 65.00 | 121.50 | 135.00 |
| 19 | 1/2 | 16-QAM | 16-QAM | 16-QAM | **OFF** | 78.00 | 86.67 | 162.00 | 180.00 |
| 20 | 3/4 | 16-QAM | 16-QAM | 16-QAM | **OFF** | 117.00 | 130.00 | 243.00 | 270.00 |
| 21 | 2/3 | 64-QAM | 64-QAM | 64-QAM | **OFF** | 156.00 | 173.33 | 324.00 | \360.00 |
| 22 | 3/4 | 64-QAM | 64-QAM | 64-QAM | **OFF** | 175.50 | 195.00 | 364.50 | 405.00 |
| 23 | 5/6 | 64-QAM | 64-QAM | 64-QAM | **OFF** | 195.00 | 216.67 | 405.00 | 450.00 |
| | | | | | | | | | |
| 24 | 1/2 | BPSK | BPSK | BPSK | BPSK | 26.00 | 28.89 | 54.00 | 60.00 |
| 25 | 1/2 | QPSK | QPSK | QPSK | QPSK | 52.00 | 57.78 | 108.00 | 120.00 |
| 26 | 3/4 | QPSK | QPSK | QPSK | QPSK | 78.00 | 86.67 | 162.00 | 180.00 |
| 27 | 1/2 | 16-QAM | 16-QAM | 16-QAM | 16-QAM | 104.00 | 115.56 | 216.00 | 240.00 |
| 28 | 3/4 | 16-QAM | 16-QAM | 16-QAM | 16-QAM | 156.00 | 173.33 | 324.00 | 360.00 |
| 29 | 2/3 | 64-QAM | 64-QAM | 64-QAM | 64-QAM | 208.00 | 231.11 | 432.00 | 480.00 |
| 30 | 3/4 | 64-QAM | 64-QAM | 64-QAM | 64-QAM | 234.00 | 260.00 | 486.00 | 540.00 |
| 31 | 5/6 | 64-QAM | 64-QAM | 64-QAM | 64-QAM | 260.00 | 288.89 | 540.00 | 600.00 |
| 32[1] | 1/2 | BPSK | **OFF** | **OFF** | **OFF** | | | 6.00 | 6.67 |
| | | | | | | | | | |
| 33 | 3/4 | 256-QAM | **OFF** | **OFF** | **OFF** | 78.00 | 86.67 | 162.00 | 180.00 |
| | | | | | | | | | |
| 34 | 1/2 | 16-QAM | QPSK | **OFF** | **OFF** | 39.00 | 43.33 | 81.00 | 90.00 |
| 35 | 1/2 | 64-QAM | QPSK | **OFF** | **OFF** | 52.00 | 57.78 | 108.00 | 120.00 |
| 36 | 1/2 | 64-QAM | 16-QAM | **OFF** | **OFF** | 65.00 | 72.22 | 135.00 | 150.00 |
| | | | | | | | | | |
| 37 | 3/4 | 16-QAM | QPSK | **OFF** | **OFF** | 58.50 | 65.00 | 121.50 | 135.00 |
| 38 | 3/4 | 64-QAM | QPSK | **OFF** | **OFF** | 78.00 | 86.67 | 162.00 | 180.00 |
| 39 | 3/4 | 64-QAM | 16-QAM | **OFF** | **OFF** | 97.50 | 108.33 | 202.50 | 225.00 |
| 40 | 3/4 | 256-QAM | QPSK | **OFF** | **OFF** | 97.50 | 108.33 | 202.50 | 225.00 |
| 41 | 3/4 | 256-QAM | 16-QAM | **OFF** | **OFF** | 117.00 | 130.00 | 243.00 | 270.00 |
| 42 | 3/4 | 256-QAM | 64-QAM | **OFF** | **OFF** | 136.50 | 151.67 | 283.50 | 315.00 |
| 43 | 3/4 | 256-QAM | 256-QAM | **OFF** | **OFF** | 156.00 | 173.33 | 324.00 | 360.00 |
| | | | | | | | | | |
| 44 | 1/2 | 16-QAM | QPSK | QPSK | **OFF** | 52.00 | 57.78 | 108.00 | 120.00 |
| 45 | 1/2 | 16-QAM | 16-QAM | QPSK | **OFF** | 65.00 | 72.22 | 135.00 | 150.00 |
| 46 | 1/2 | 64-QAM | QPSK | QPSK | **OFF** | 65.00 | 72.22 | 135.00 | 150.00 |
| 47 | 1/2 | 64-QAM | 16-QAM | QPSK | **OFF** | 78.00 | 86.67 | 162.00 | 180.00 |
| 48 | 1/2 | 64-QAM | 16-QAM | 16-QAM | **OFF** | 91.00 | 101.11 | 189.00 | 210.00 |

| MCS Index | Code Rate | Stream Modulations | | | | 20 MHz Rates | | 40 MHz Rates | |
|---|---|---|---|---|---|---|---|---|---|
| | | M0 | M1 | M2 | M3 | Full GI | Half GI | Full GI | Half GI |
| 49 | 1/2 | 64-QAM | 64-QAM | QPSK | **OFF** | 91.00 | 101.11 | 189.00 | 210.00 |
| 50 | 1/2 | 64-QAM | 64-QAM | 16-QAM | **OFF** | 104.00 | 115.56 | 216.00 | 240.00 |
| 51 | 1/2 | 256-QAM | QPSK | QPSK | **OFF** | 78.00 | 86.67 | 162.00 | 180.00 |
| 52 | 1/2 | 256-QAM | 16-QAM | QPSK | **OFF** | 91.00 | 101.11 | 189.00 | 210.00 |
| 53 | 1/2 | 256-QAM | 16-QAM | 16-QAM | **OFF** | 104.00 | 115.56 | 216.00 | 240.00 |
| 54 | 1/2 | 256-QAM | 64-QAM | QPSK | **OFF** | 104.00 | 115.56 | 216.00 | 240.00 |
| | | | | | | | | | |
| 55 | 3/4 | 16-QAM | QPSK | QPSK | **OFF** | 78.00 | 86.67 | 162.00 | 180.00 |
| 56 | 3/4 | 16-QAM | 16-QAM | QPSK | **OFF** | 97.50 | 108.33 | 202.50 | 225.00 |
| 57 | 3/4 | 64-QAM | QPSK | QPSK | **OFF** | 97.50 | 108.33 | 202.50 | 225.00 |
| 58 | 3/4 | 64-QAM | 16-QAM | QPSK | **OFF** | 117.00 | 130.00 | 243.00 | 270.00 |
| 59 | 3/4 | 64-QAM | 16-QAM | 16-QAM | **OFF** | 136.50 | 151.67 | 283.50 | 315.00 |
| 60 | 3/4 | 64-QAM | 64-QAM | QPSK | **OFF** | 136.50 | 151.67 | 283.50 | 315.00 |
| 61 | 3/4 | 64-QAM | 64-QAM | 16-QAM | **OFF** | 156.00 | 173.33 | 324.00 | 360.00 |
| 62 | 3/4 | 256-QAM | QPSK | QPSK | **OFF** | 117.00 | 130.00 | 243.00 | 270.00 |
| 63 | 3/4 | 256-QAM | 16-QAM | QPSK | **OFF** | 136.50 | 151.67 | 283.50 | 315.00 |
| 64 | 3/4 | 256-QAM | 16-QAM | 16-QAM | **OFF** | 156.00 | 173.33 | 324.00 | 360.00 |
| 65 | 3/4 | 256-QAM | 64-QAM | QPSK | **OFF** | 156.00 | 173.33 | 324.00 | 360.00 |
| 66 | 3/4 | 256-QAM | 64-QAM | 16-QAM | **OFF** | 175.50 | 195.00 | 364.50 | 405.00 |
| 67 | 3/4 | 256-QAM | 64-QAM | 64-QAM | **OFF** | 195.00 | 216.67 | 405.00 | 450.00 |
| 68 | 3/4 | 256-QAM | 256-QAM | QPSK | **OFF** | 175.50 | 195.00 | 364.50 | 405.00 |
| 69 | 3/4 | 256-QAM | 256-QAM | 16-QAM | **OFF** | 195.00 | 216.67 | 405.00 | 450.00 |
| 70 | 3/4 | 256-QAM | 256-QAM | 64-QAM | **OFF** | 214.50 | 238.33 | 445.50 | 495.00 |
| 71 | 3/4 | 256-QAM | 256-QAM | 256-QAM | **OFF** | 234.00 | 260.00 | 486.00 | 540.00 |
| | | | | | | | | | |
| 72 | 1/2 | 16-QAM | QPSK | QPSK | QPSK | 65.00 | 72.22 | 135.00 | 150.00 |
| 73 | 1/2 | 16-QAM | 16-QAM | QPSK | QPSK | 78.00 | 86.67 | 162.00 | 180.00 |
| 74 | 1/2 | 16-QAM | 16-QAM | 16-QAM | QPSK | 91.00 | 101.11 | 189.00 | 210.00 |
| 75 | 1/2 | 64-QAM | QPSK | QPSK | QPSK | 78.00 | 86.67 | 162.00 | 180.00 |
| 76 | 1/2 | 64-QAM | 16-QAM | QPSK | QPSK | 91.00 | 101.11 | 189.00 | 210.00 |
| 77 | 1/2 | 64-QAM | 16-QAM | 16-QAM | QPSK | 104.00 | 115.56 | 216.00 | 240.00 |
| 78 | 1/2 | 64-QAM | 16-QAM | 16-QAM | 16-QAM | 117.00 | 130.00 | 243.00 | 270.00 |
| 79 | 1/2 | 64-QAM | 64-QAM | QPSK | QPSK | 104.00 | 115.56 | 216.00 | 240.00 |
| 80 | 1/2 | 64-QAM | 64-QAM | 16-QAM | QPSK | 117.00 | 130.00 | 243.00 | 270.00 |
| 81 | 1/2 | 64-QAM | 64-QAM | 16-QAM | 16-QAM | 130.00 | 144.44 | 270.00 | 300.00 |
| 82 | 1/2 | 64-QAM | 64-QAM | 64-QAM | QPSK | 130.00 | 144.44 | 270.00 | 300.00 |
| 83 | 1/2 | 64-QAM | 64-QAM | 64-QAM | 16-QAM | 143.00 | 158.89 | 297.00 | 330.00 |
| 84 | 1/2 | 256-QAM | QPSK | QPSK | QPSK | 91.00 | 101.11 | 189.00 | 210.00 |

| MCS Index | Code Rate | Stream Modulations | | | | 20 MHz Rates | | 40 MHz Rates | |
|---|---|---|---|---|---|---|---|---|---|
| | | M0 | M1 | M2 | M3 | Full GI | Half GI | Full GI | Half GI |
| 85 | 1/2 | 256-QAM | 16-QAM | QPSK | QPSK | 104.00 | 115.56 | 216.00 | 240.00 |
| 86 | 1/2 | 256-QAM | 16-QAM | 16-QAM | QPSK | 117.00 | 130.00 | 243.00 | 270.00 |
| 87 | 1/2 | 256-QAM | 16-QAM | 16-QAM | 16-QAM | 130.00 | 144.44 | 270.00 | 300.00 |
| 88 | 1/2 | 256-QAM | 64-QAM | QPSK | QPSK | 117.00 | 130.00 | 243.00 | 270.00 |
| 89 | 1/2 | 256-QAM | 64-QAM | 16-QAM | QPSK | 130.00 | 144.44 | 270.00 | 300.00 |
| 90 | 1/2 | 256-QAM | 64-QAM | 16-QAM | 16-QAM | 143.00 | 158.89 | 297.00 | 330.00 |
| 91 | 1/2 | 256-QAM | 64-QAM | 64-QAM | QPSK | 143.00 | 158.89 | 297.00 | 330.00 |
| 92 | 1/2 | 256-QAM | 256-QAM | 16-QAM | QPSK | 143.00 | 158.89 | 297.00 | 330.00 |
| 93 | 1/2 | 256-QAM | 256-QAM | 64-QAM | QPSK | 156.00 | 173.33 | 324.00 | 360.00 |
| 94 | 1/2 | 256-QAM | 256-QAM | 256-QAM | QPSK | 169.00 | 187.78 | 351.00 | 390.00 |
| | | | | | | | | | |
| 95 | 3/4 | 16-QAM | QPSK | QPSK | QPSK | 97.50 | 108.33 | 202.50 | 225.00 |
| 96 | 3/4 | 16-QAM | 16-QAM | QPSK | QPSK | 117.00 | 130.00 | 243.00 | 270.00 |
| 97 | 3/4 | 16-QAM | 16-QAM | 16-QAM | QPSK | 136.50 | 151.67 | 283.50 | 315.00 |
| 98 | 3/4 | 64-QAM | QPSK | QPSK | QPSK | 117.00 | 130.00 | 243.00 | 270.00 |
| 99 | 3/4 | 64-QAM | 16-QAM | QPSK | QPSK | 136.50 | 151.67 | 283.50 | 315.00 |
| 100 | 3/4 | 64-QAM | 16-QAM | 16-QAM | QPSK | 156.00 | 173.33 | 324.00 | 360.00 |
| 101 | 3/4 | 64-QAM | 16-QAM | 16-QAM | 16-QAM | 175.50 | 195.00 | 364.50 | 405.00 |
| 102 | 3/4 | 64-QAM | 64-QAM | QPSK | QPSK | 156.00 | 173.33 | 324.00 | 360.00 |
| 103 | 3/4 | 64-QAM | 64-QAM | 16-QAM | QPSK | 175.50 | 195.00 | 364.50 | 405.00 |
| 104 | 3/4 | 64-QAM | 64-QAM | 16-QAM | 16-QAM | 195.00 | 216.67 | 405.00 | 450.00 |
| 105 | 3/4 | 64-QAM | 64-QAM | 64-QAM | QPSK | 195.00 | 216.67 | 405.00 | 450.00 |
| 106 | 3/4 | 64-QAM | 64-QAM | 64-QAM | 16-QAM | 214.50 | 238.33 | 445.50 | 495.00 |
| 107 | 3/4 | 256-QAM | QPSK | QPSK | QPSK | 136.50 | 151.67 | 283.50 | 315.00 |
| 108 | 3/4 | 256-QAM | 16-QAM | QPSK | QPSK | 156.00 | 173.33 | 324.00 | 360.00 |
| 109 | 3/4 | 256-QAM | 16-QAM | 16-QAM | QPSK | 175.50 | 195.00 | 364.50 | 405.00 |
| 110 | 3/4 | 256-QAM | 16-QAM | 16-QAM | 16-QAM | 195.00 | 216.67 | 405.00 | 450.00 |
| 111 | 3/4 | 256-QAM | 64-QAM | QPSK | QPSK | 175.50 | 195.00 | 364.50 | 405.00 |
| 112 | 3/4 | 256-QAM | 64-QAM | 16-QAM | QPSK | 195.00 | 216.67 | 405.00 | 450.00 |
| 113 | 3/4 | 256-QAM | 64-QAM | 16-QAM | 16-QAM | 214.50 | 238.33 | 445.50 | 495.00 |
| 114 | 3/4 | 256-QAM | 64-QAM | 64-QAM | QPSK | 214.50 | 238.33 | 445.50 | 495.00 |
| 115 | 3/4 | 256-QAM | 64-QAM | 64-QAM | 16-QAM | 234.00 | 260.00 | 486.00 | 540.00 |
| 116 | 3/4 | 256-QAM | 64-QAM | 64-QAM | 64-QAM | 253.50 | 281.67 | 526.50 | 585.00 |
| 117 | 3/4 | 256-QAM | 256-QAM | QPSK | QPSK | 195.00 | 216.67 | 405.00 | 450.00 |
| 118 | 3/4 | 256-QAM | 256-QAM | 16-QAM | QPSK | 214.50 | 238.33 | 445.50 | 495.00 |
| 119 | 3/4 | 256-QAM | 256-QAM | 16-QAM | 16-QAM | 234.00 | 260.00 | 486.00 | 540.00 |
| 120 | 3/4 | 256-QAM | 256-QAM | 64-QAM | QPSK | 234.00 | 260.00 | 486.00 | 540.00 |
| 121 | 3/4 | 256-QAM | 256-QAM | 64-QAM | 16-QAM | 253.50 | 281.67 | 526.50 | 585.00 |

| MCS Index | Code Rate | Stream Modulations | | | | 20 MHz Rates | | 40 MHz Rates | |
|---|---|---|---|---|---|---|---|---|---|
| | | M0 | M1 | M2 | M3 | Full GI | Half GI | Full GI | Half GI |
| 122 | 3/4 | 256-QAM | 256-QAM | 64-QAM | 64-QAM | 273.00 | 303.33 | 567.00 | 630.00 |
| 123 | 3/4 | 256-QAM | 256-QAM | 256-QAM | QPSK | 253.50 | 281.67 | 526.50 | 585.00 |
| 124 | 3/4 | 256-QAM | 256-QAM | 256-QAM | 16-QAM | 273.00 | 303.33 | 567.00 | 630.00 |
| 125 | 3/4 | 256-QAM | 256-QAM | 256-QAM | 64-QAM | 292.50 | 325.00 | 607.50 | 675.00 |
| 126 | 3/4 | 256-QAM | 256-QAM | 256-QAM | 256-QAM | 312.00 | 346.67 | 648.00 | 720.00 |
| 127[2] | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

[1]MCS 32 is used for 40 MHz duplicate mode to provide robust 6 Mbps operation in 40 MHz.
[2]The MCS index value 127 (binary value 1111111) is reserved to indicate a NULL response in the MCS field of an MFB.

### 11.1.1.8.1 MCS Capability Classes

A set of MCS capability classes is defined. These capability classes are used to specify which MCSs a STA supports on receive. MCS capability is specified independently for 20 MHz and 40 MHz. The capability classes are hierarchical in the number of streams supported: a capability class that supports *n* streams also supports 1 to *n*-1 streams.

The MCS capability classes are specified by a 4-bit field, $b_3b_2b_1b_0$, where:

- $b_3$ is set to 1 if MCSs that use 256-QAM are included, otherwise it is set to 0
- $b_2$ is set to 1 if MCSs with unequal modulations across spatial streams are included, otherwise it is set to 0
- $b_1b_0$ indicates the maximum number of spatial streams supported;
  - 00: maximum 1 stream
  - 01: maximum 2 streams
  - 10: maximum 3 streams
  - 11: maximum 4 streams

The capability classes are defined in Table 18 below.

**Table 18: MCS capability classes**

| $b_3b_2b_1b_0$ | Max Number of Streams | MCS | Description |
|---|---|---|---|
| 0000 | 1 | 0 – 7 | Constant modulation MCS only w/o 256-QAM, up to 1 stream |
| 0001 | 2 | 0 – 15 | Constant modulation MCS only w/o 256-QAM, up to 2 streams |
| 0010 | 3 | 0 – 23 | Constant modulation MCS only w/o 256-QAM, up to 3 streams |
| 0011 | 4 | 0 – 31 | Constant modulation MCS only w/o 256-QAM, up to 4 streams |
| 0101 | 2 | 0–15; 34–39; | All MCS w/o 256-QAM, up to 2 streams |
| 0110 | 3 | 0–23; 34–39; 44–50; | All MCS w/o 256-QAM, up to 3 streams |

| | | | |
|---|---|---|---|
| | | 55–61 | |
| 0111 | 4 | 0–31; 34–39; 44–50; 55–61; 72–83; 95–106 | All MCS w/o 256-QAM, up to 4 streams |
| 1000 | 1 | 0–7; 33 | All MCS w/256-QAM, up to 1 stream |
| 1101 | 2 | 0–15; 33–43 | All MCS w/ 256-QAM, up to 2 streams |
| 1110 | 3 | 0–23; 33–71 | All MCS w/ 256-QAM, up to 3 streams |
| 1111 | 4 | 0–31; 33–126 | All MCS w/ 256-QAM, up to 4 streams |
| 0100, 1001–1100 | -- | N/A | RSVD |

For 40MHz, all MCS capability class should include MCS 32.

Capability classes 0000 and 1000 specify MCSs with only one stream. While this proposal currently does not support single-stream devices, these single-stream capability classes are provided in anticipation of future support of single-stream devices.

Support of any MCS capability class requires support of all of the MCSs contained in that capability class.

## 11.2 PLCP Sublayer

### 11.2.1 Basic MIMO Mode

As described in Table 16, the basic MIMO mode does not involve any spatial steering. The basic MIMO mode can operate in both 20MHz and 40MHz channel bandwidths.

#### 11.2.1.1 Basic MIMO PPDU format

The HT Physical layer defines a PPDU format that provides interoperability and coexistence with 802.11a stations and with ERP-OFDM stations of 802.11g at the link level without protection mechanisms. Figure 31 shows the PPDU format for the basic MIMO mode:

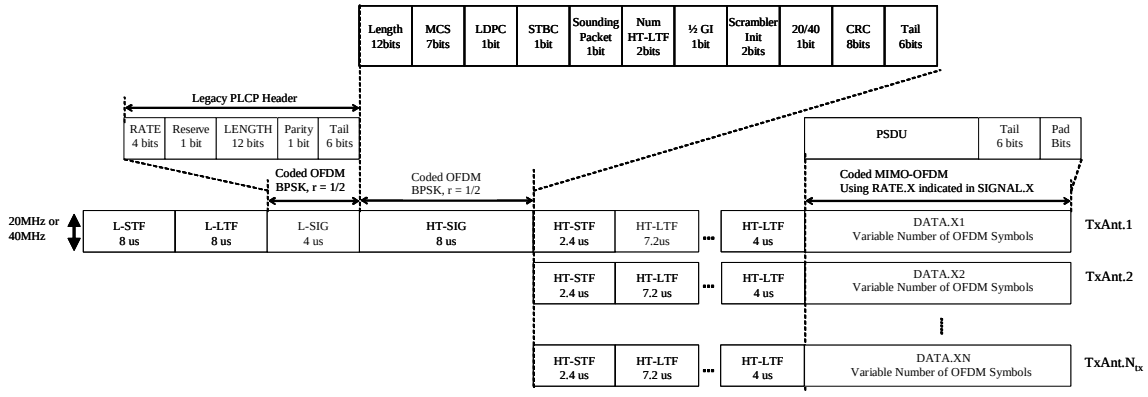



**Figure 31: PPDU Format for $N_{TX}$ antennas**

L-STF is the Legacy Short Training Field. Details of the L-STF symbols can be found in clause 11.2.1.5.1. The HT-STF is specific for HT. Details can be found in 11.2.1.5.3

L-LTF stands for Legacy Long Training Field. Details of the L-LTF symbols can be found in clause 11.2.1.5.2**.** The HT-LTFs are specific for HT and the details can be found in clause 11.2.1.5.4

L-SIG is based on the Legacy SIGNAL field as defined in clause 17.3.4 in [1]. The modulation and coding procedure also follows the steps of 17.3.4 in [1]. The RATE and LENGTH fields in L-SIG are defined in accordance with procedures described in 7.1.3.2 and 11.2.1.6.1.

The HT-SIG field is the signal field dedicated to the HT mode. The structure of this field is the same as the L-SIG. Since our proposal supports interoperability between HT devices and legacy OFDM devices at the PHY layer, a HT receiver will not know *a priori* whether a legacy packet or an HT packet is being received. That determination can only be made after the L-SIG. Our proposal supports two mechanisms for signaling a HT transmission: (a) send the HT-SIG as a BPSK signal on the quadrature axis, instead of on the in-phase axis, and (b) invert the polarity of the pilots in the HT-SIG with respect to the pilots in the L-SIG. These two mechanism allow an auto-detect of a HT transmission. Note that the pilots in the HT-SIG are not transmitted on the Quadrature axis. The definition of the contents of HT-SIG is specified in 11.2.1.6.2.

The L-STF, L-LTF, L-SIG, and HT-SIG should be transmitted from the antenna array such that an omni-directional beam pattern is created in the far field. This reduces the probability of creating hidden nodes in the BSS. One way to create an omni-beam is to transmit these fields from strictly one antenna. However, if the transmitter is power-amplifier limited, array gain can be derived by transmitting on multiple antennas. Since transmitting the same signal from multiple antennas invariably creates beamforming, one way to mitigate beamforming is to phase shift (i.e. time delay) the signal across the transmit antenna array. For an OFDM symbol, the delay can be introduced cyclically. Since delaying the same signal introduces frequency selectivity at the receiver, such a transmission is commonly referred to as “cyclical delay diversity” or CDD. This transmission format is shown in Figure 32:

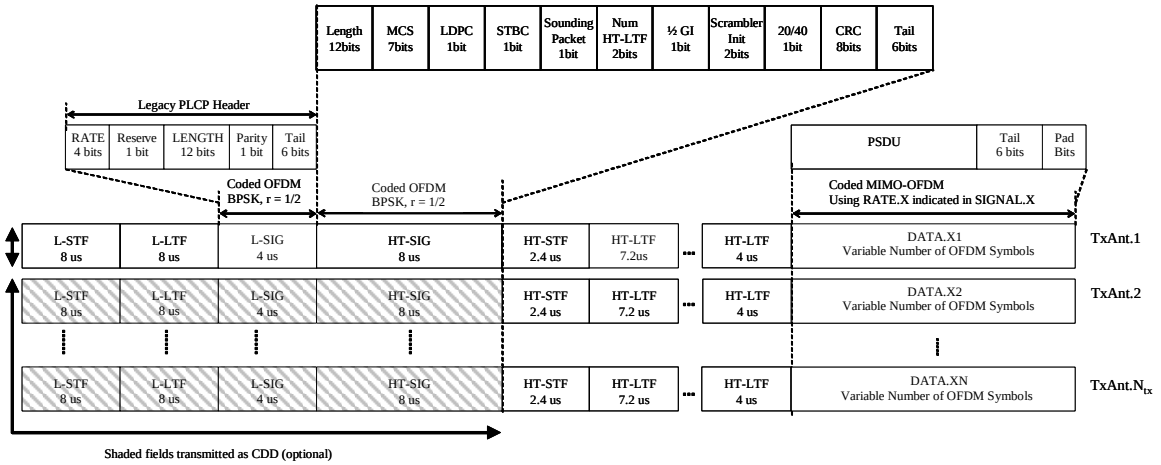



**Figure 32: PPDU format leveraging CDD transmission**

### 11.2.1.2 Legacy Protection

All MIMO transmissions are protected against legacy OFDM devices at the physical layer, and protected against legacy CCK/DSSS devices at the MAC layer.
The legacy short training field, the legacy long training field and the legacy signal field are transmitted such that a legacy OFDM receiver (802.11g or 802.11a) is able to "understand" these fields. In the basic MIMO mode, the transmitter selects the Modulation Coding Scheme either based on conventional rate selection heuristics or via implicit or explicit feedback. Thus, the RATE and LENGTH fields in the legacy signal field can be used to allow the legacy OFDM receivers to correctly set their NAV.

RTS/CTS or CTS-to-self mechanism may be used to protect against legacy CCK/DSSS devices in an 802.11n BSS.

### 11.2.1.3 Timing related parameters

| Parameter | Value for 20 MHz Channel | Value for 40 MHz Channel |
|---|---|---|
| $N_{SD}$ : Number of data subcarriers | 52 | 108 |
| $N_{SP}$ : Number of pilot subcarriers | 4 | 6 |
| $N_{SN}$ : Number of center null subcarriers | 1 (tone = 0) | 3 (tones = -1,0,+1) |
| $N_{SR}$ : Subcarrier range (index range) | 28 (-28 … +28) | 58 (-58 … +58) |
| $\Delta_F$ : Subcarrier frequency spacing | 0.3125 MHz (= 20 MHz / 64) | 0.3125 MHz (= 40 MHz / 128) |
| $T_{FFT}$ : IFFT/FFT period | 3.2 µsec | 3.2 µsec |
| $T_{GI}$ : GI duration | 0.8 µsec | 0.8 µsec |
| $T_{ShortGI}$ : Short GI duration | 0.4 µsec | 0.4 µsec |
| $T_{GI2}$ : Legacy LongTraining symbol GI duration | 1.6 µsec | 1.6 µsec |
| $T_{SYM}$ : Symbol interval | 4 µsec | 4 µsec |
| $T_{L-STF}$ : Legacy STF duration | 8 µsec | 8 µsec |
| $T_{L-LTF}$ : Legacy LTF duration | 8 µsec | 8 µsec |
| $T_{L-SIG}$ : Legacy Signal Field duration | 4 µsec | 4 µsec |
| $T_{HT-SIG}$ : HT Signal Field duration | 8 µsec | 8 µsec |
| $T_{HT-STF}$ : HT Short training field duration | 2.4µsec | 2.4µsec |
| $T_{HT-LTF1}$ : HT Long training field duration | 7.2µsec | 7.2 µsec |
| $T_{HT-LTF2}$ : HT Long training field duration | 4 µsec | 4 µsec |
| $T_S$ : Nyquist sampling interval | 50nsec | 25nsec |

**Table 19: Timing Related Parameters**

### 11.2.1.4 Mathematical Representation of Time Domain Signals

The transmitted signals will be described using the complex baseband signal notation. The transmitted signal at RF, $r_{RF}(t)$, is related to the complex baseband signal by the following relationship:

$$r_{RF}(t) = \mathrm{Re}\left\{ r(t)\exp\left( j2\pi f_c t\right)\right\} \quad (9)$$

where

$\mathrm{Re}\{\cdot\}$ represents the real part of a complex variable;

$f_c$ denotes the center frequency of the carrier.

The transmitted baseband signal consists of several subframes. The timing boundaries for the various subframes are shown in Figure 33.

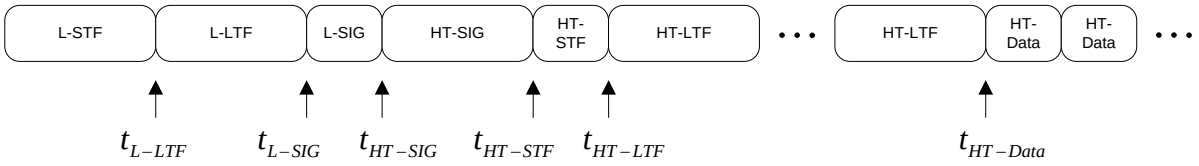



**Figure 33: Timing boundaries for PPDU Fields**

The signal transmitted on antenna $i_{Tx}$ is

$$\begin{aligned} r_{PPDU}^{(i_{Tx})}(t) = {} & r_{L-STF}^{(i_{Tx})}(t) + r_{L-LTF}^{(i_{Tx})}\left(t - t_{L-LTF}\right) \\ & + r_{L-SIG}^{(i_{Tx})}\left(t - t_{L-SIG}\right) \\ & + r_{HT-SIG}^{(i_{Tx})}\left(t - t_{HT-SIG}\right) \\ & + r_{HT-STF}^{(i_{Tx})}\left(t - t_{HT-STF}\right) \\ & + r_{HT-LTF1}^{(i_{Tx})}(t - t_{HT-LTF1}) \\ & + \sum_{i_{LTF}=1}^{N_{LTF}-1} r_{HT-LTF2}^{(i_{Tx},i_{LTF})}\left(t - t_{HT-STF} - T_{HT-LTF1} - i_{LTF}T_{HT-LTF2}\right) \\ & + r_{HT\ DATA}^{(i_{Tx})}(t - t_{HT\ DATA}) \end{aligned} \quad (10)$$

where

$$t_{L-LTF} = T_{L-STF}, \quad (11)$$

$$t_{L-SIG} = t_{L-LTF} + T_{L-LTF}, \quad (12)$$

$$t_{HT-SIG} = t_{L-SIG} + T_{L-SIG},$$

$$t_{HT-SIG} = t_{L-SIG} + T_{L-SIG}, \quad (13)$$

$$t_{HT-STF} = t_{HT-SIG} + T_{HT-SIG},$$

$$t_{HT-LTF} = t_{HT-STF} + T_{HT-STF} \quad (14)$$

and

$$t_{HT-Data} = t_{HT-LTF} + T_{HT-LTF1} + (N_{LTF} - 1)T_{HT-LTF2}. \quad (15)$$

The time offsets $t_{Field}$ determines the starting time of the corresponding subframe.

Each baseband waveform $r_{Field}^{(i_{Tx})}(t)$ is defined via the discrete Fourier transform as

$$r_{Field}^{(i_{Tx})}(t) = \frac{1}{\sqrt{N_{Field}^{Tone}}} w_{Field}(t) \sum_k X_k^{(i_{Tx})} \exp( j2\pi k\Delta_F t ) \quad (16)$$

This general representation holds for all fields, which are L-STF, L-LTF, L-SIG, HT-SIG, HT-STF, HT-LTF and HT-Data. The frequency domain symbols $X_k^{(i_{Tx})}$ define the field, as shall be specified in the following subsections. We adopt the convention that:

$$\sum_{i_{Tx}=0}^{N_{Tx}} E\left[ | X_k^{(i_{Tx})} |^2 \right] = 1 \quad (17)$$

With this convention, the $1/\sqrt{N_{Field}^{Tone}}$ scale factor in (16) ensures that the total power of the time domain signal as summed over all transmit antennas is 1. The following table summarizes the various values of $N_{Field}^{Tone}$.

**Table 20: Number of tones for different fields.**

| Field | $N_{Field}^{Tone}$ | |
|---|---|---|
| | 20 MHz | 40 MHz |
| L-STF | 12 | 24 |
| L-LTF | 52 | 104 |
| L-SIG | 52 | 104 |
| HT-SIG | 52 | 104 |
| HT-STF | 24 | 48 |
| HT-LTF | 56 | 114 |
| HT-Data | 56 | 114 |
| HT-Data 40 MHz Dup. Format | - | 104 |

The windowing function $w_{Field}(t)$ defines the time duration of the waveform. The windowing roll is not specified, although raised-cosine is typical. This function is illustrated in

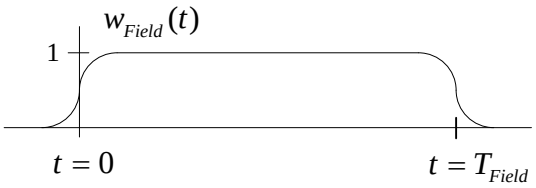



**Figure 34: Illustration of time-domain windowing function.**

#### 11.2.1.5 Training symbols specification

The training fields are used for synchronization purposes.

##### 11.2.1.5.1 Legacy Short Training Field

The L-STS is identical to the 802.11a short training symbol. The legacy short training OFDM symbol in the 20MHz mode is the L-STS is

$$S_{-26,26} = \sqrt{1/2}\,\{0,0,1+j,0,0,0,-1-j,0,0,0,1+j,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,\\ 0,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0\} \quad (18)$$

The normalization factor $\sqrt{1/2}$ is the QPSK normalization.

The legacy short training OFDM symbol in 40MHz mode is:

$$S_{-58,58} = \sqrt{1/2}\{0,0,1+j,0,0,0,-1-j,0,0,0,1+j,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,\\ 0,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,0,0,\\ 0,0,0,0,0,0,0,0,0,0,j-1,0,0,0,-j+1,0,0,0,j-1,0,0,0,-j+1,0,0,0,-j+1,0,0,0,j-1,\\ 0,0,0,0,0,0,0,-j+1,0,0,0,-j+1,0,0,0,j-1,0,0,0,j-1,0,0,0,j-1,0,0,0\} \quad (19)$$

The tones in the upper subchannel (see Figure 26) are obtained by phase rotating the 802.11a short OFDM training symbol tones by 90 degrees, whereas the tones in the lower subchannel are identical to the 802.11a short training OFDM symbol tones. The 90° rotation helps keep the PAPR of the STF in 40MHz comparable to that in 20MHz.
The L-STF is

$$r_{L-STF}^{(i_{TX})}(t) = \frac{1}{\sqrt{N_{L-STF}^{Tone}}}\, w_{L-STF}(t) \sum_{k=-N_{SR}}^{N_{SR}} p_{i_{Tx}}^{L(k)} S_k \exp\left( j 2\pi k \Delta_F t \right) \quad (20)$$

where we recall that $\mathbf{p}^{L(k)}$ is the column vector that defines the antenna map for the legacy compatible part. Observe that equation (20) is identical to the general expression (16) with $X_k^{(i_{Tx})} = p_{i_{Tx}}^{L(k)} S_k$.

The L-STS has a period of 0.8 μs. The entire short training field includes ten such periods, with a total duration of $T_{L-STF}$ = 8 μs, hence there are 10 L-STSs in the L-STF.

### 11.2.1.5.2 Legacy Long Training Field

The legacy long training OFDM symbol is identical to the 802.11a long training OFDM symbol. In the 20MHz mode, the long training OFDM symbol is given by

$$L_{-26,26} = \{1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,0,$$
$$1,-1,-1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,-1,-1,1,-1,1,-1,1,1,1,1\} \quad (21)$$

The legacy long training OFDM signal in the 40MHz mode is given by:

$$L_{-58,58} = \{1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,0,$$
$$1,-1,-1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,-1,-1,1,-1,1,-1,1,1,1,1,1,0,0,0,0,0,0$$
$$0,0,0,0,0,j,j,-j,-j,j,j,-j,j,-j,j,j,j,j,j,j,-j,-j,j,j,-j,j,-j,j,j,j,j,0,$$
$$j,-j,-j,j,j,-j,j,-j,j,-j,-j,-j,-j,-j,j,j,-j,-j,j,-j,j,-j,j,j,j,j\} \quad (22)$$

Tones in the upper subchannel (subcarriers +6 to +58) are obtained by phase rotating the 802.11a long OFDM training symbol tones by 90 degrees, whereas the tones within the lower subchannel (subcarriers -58 to -6) are identical to the 802.11a long OFDM training symbol tones.
It should be noted that neither the legacy fields (L-STF, L-LTF, LSIG) nor the HT-SIG undergo any phase rotation in the lower subchannel. The subcarriers at ±32 in 40MHz, which are the DC subcarriers for the legacy 20MHz transmission, are both nulled in the L-LTF. Such an arrangement allows proper synchronization of the 20MHz legacy device.

The L-LTF waveform is

$$r_{L-LTF}^{(i_{TX})}(t) = \frac{1}{\sqrt{N_{L-LTF}^{Tone}}} w_{L-LTF}(t) \sum_{k=-N_{SR}}^{N_{SR}} p_{i_{Tx}}^{L(k)} L_k \exp\left( j 2\pi k \Delta_F (t - T_{2GI}) \right) \quad (23)$$

where $T_{G12}$ = 1.6 μ sec. Observe that equation (23) is identical to the general expression (16) with $X_k^{(i_{Tx})} = p_{i_{Tx}}^{L(k)} L_k$.

Since $T_{L-LTF}$ = 8.0 μ sec and the symbol duration is $T_{FFT}$ = 3.2 μ sec, we see that the L-LTF consists of a double GI followed by two full symbols.

### 11.2.1.5.3 HT-Short Training Field

The HT-STF follows the HT-SIG (see Figure 31), whose purpose it to "fine tune" the AGC for HT MIMO reception. Note that the first AGC operation is performed on the L-STF.

The HT-STS for 20MHz is

$$HTS_{-26,26} = \frac{1}{\sqrt{2}} \begin{cases} \{0, 0, 1+j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, \\ 0, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 0\} & N_{STS} = 1 \\ \{0, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, \\ 0, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, 0\} & N_{STS} = 2 \\ \{0, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, \\ 0, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, 0\} & N_{STS} = 3 \\ \{0, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, \\ 0, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 0\} & N_{STS} = 4 \end{cases} \quad (24)$$

The HT-STS for 40 MHz consists of 48 tones, and is given by:

$$HTS_{-58,58} = \frac{1}{\sqrt{2}} \begin{cases} \{0, 0, 1+j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, \\ 0, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 0, 0, 0, 0, 0, 0, \\ 0, 0, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, 1+j, 0, & N_{STS} = 1 \\ 0, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 0\} \\ \{0, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, \\ 0, 0, 1+j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, 0, 0, 0, 0, 0, 0, \\ 0, 0, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, 1+j, 0, & N_{STS} = 2 \\ 0, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 0\} \\ \{0, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, \\ 0, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, 0, 0, 0, 0, 0, 0, \\ 0, 0, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, & N_{STS} = 3 \\ 0, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 0\} \\ \{0, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, \\ 0, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, \\ 0, 0, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, & N_{STS} = 4 \\ 0, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 0\} \end{cases} \quad (25)$$

In the duplicate 6Mbps mode in 40MHz, the HT-STF shown in (25) is used, except for a scaling factor change.

The HT-STF signal is then generated by the following rule.

$$r_{HT-STS}^{(i_{Tx})}(t) = \frac{1}{\sqrt{N_{HT-STF}^{Tone}}} w_{HT-STF}(t)\sqrt{N_{TX}} \sum_k q_{i_{Tx},m(k)\%N_{STS}}^{(k)} HTS_k \exp\left( j2\pi k\Delta_F (t - T_{GI}) \right) \quad (26)$$

where $T_{GI} = 0.8\mu s$ and $N_{HT-STF}^{Tone}$ is the number of active tones (= 24 for 20 MHz and 48 for 40 MHz).

The range of the summation index *k* is defined as follows:

$$k = \begin{cases} \text{-24, -22,...-2 2,4,...24} & \text{for 20 MHz} \\ \text{-56, -54,...-34 -30,-28, ...-8 8,10,...30 34,36,...56} & \text{for 40 MHz} \end{cases}$$

which are the indices of the non-zero tones of $HTS_k$, and

$$m(k) = \begin{cases} \begin{cases} \frac{k+24}{2} & k \le 0 \\ \frac{k+24}{2} - 1 & k > 0 \end{cases} & \text{for 20 MHz} \\ \begin{cases} \frac{k+56}{2} & k \le -34 \\ \frac{k+56}{2} - 1 & -30 \le k \le -8 \\ \frac{k+56}{2} - 8 & 8 \le k \le 30 \\ \frac{k+56}{2} - 9 & k \ge 34 \end{cases} & \text{for 40 MHz} \end{cases}$$

Tone interleaving across space-time streams works as follows. $HTS_k$ is non-zero for values of the tone index $k$. Define $m(k)$, which appears in the column subscript of the P-matrix. $m(k)$ runs through the integer values 0, …, $N_{HT-STF}^{Tone} - 1$ as a function of $k$. Thus, $m(k)\%N_{STS}$, which defines the space-time stream used on tone index k, selects the corresponding column from the P-matrix. The two tables below identify the set of tones for each space-time stream.

| $N_{STS}$ | Set 0 | Set 1 | Set 2 | Set 3 |
|---|---|---|---|---|
| 1 | [-24:2:-2] [2:2:+24] | | | |
| 2 | [-24:4:-4] [2:4:24] | [-22:4:-2] [4:4:24] | | |
| 3 | [-24:6:-6] [2:6:20] | [-22:6:-4] [4:6:22] | [-20:6:-2] [6:6:24] | |
| 4 | [-24:8:-8] [2:8:18] | [-22:8:-6] [4:8:20] | [-20:8:-4] [6:8:22] | [-18:8:-2] [8:8:24] |

**Table 21: Tone partitioning of HT-STF into sets for 20MHz (24 tones)**

| $N_{STS}$ | Set 0 | Set 1 | Set 2 | Set 3 |
|---|---|---|---|---|
| 1 | [-56:2:-34] [-30:2:-8] [8:2:30] [34:2:56] | | | |
| 2 | [-56:4:-36] [-30:4:-10] [8:4:28] [34:4:54] | [-54:4:-34] [-28:4:-8] [10:4:30] [36:4:56] | | |
| 3 | [-56:6:-38] [-30:6:-12] [8:6:26] [34:6:52] | [-54:6:-36] [-28:6:-10] [10:6:28] [36:6:54] | [-52:6:-34] [-26:6:-8] [12:6:30] [38:6:56] | |
| 4 | [-56:8:-40] [-30:8:-14] [8:8:24] [34:8:50] | [-54:8:-38] [-28:8:-12] [10:8:26] [36:8:52] | [-52:8:-36] [-26:8:-10] [12:8:28] [38:8:54] | [-50:8:-34] [-24:8:-8] [14:8:30] [40:8:56] |

**Table 22: Tone partitioning of HT-STF into sets for 40MHz (48 tones)**

The HT-STF signal has a period of 1.6μs, which is deemed sufficient for power measurement purposes. Since the HT-STF is tone-interleaved at the transmitter, the power periodicity of the HT-STF is also $1.6\mu s$ .

#### 11.2.1.5.4 HT-Long Training Field

The HT-LTFs are transmitted after the HT-STF. The number of HT-LTFs is equal to $N_{LTF}$ . For any PPDU, there must be at least as many HT-LTFs as space-time streams in the HT Data portion of the PPDU, i.e. $N_{LTF} = N_{STS}$ (the number of space-time streams). For a sounding PPDU it is permissible for $N_{LTF} \geq N_{STS}$ , because these PPDUs provide channel measurement capability for potentially more spatial dimensions than the number of space-time streams. In the case that $N_{LTF} > N_{STS}$, the HT-LTFs are partitioned as data HT-LTFs and extension HT-LTFs. The data HT-LTFs are the first $N_{STS}$ fields, which are indexed $i_{LTF} = 0, \ldots, N_{STS} - 1$. The last $N_{LTF} - N_{STS}$ HT-LTFs are the extension fields, which are indexed $i_{LTF} = N_{STS} - 1, \ldots, N_{LTF} - 1$. The result is referred to as a segmented HT-LTF. When a PPDU includes a segmented HT-LTF it is optional for a receiver to process the extension LTFs, however it is mandatory for a receiver to still process the data HT-LTFs and use these to decode HT-DATA in the normal manner.

As always, space-time streams are defined by columns of an orthogonal antenna map matrix $\mathbf{P}^{(k)}$, with the first $N_{STS}$ columns defining the space-time streams used for data transmission, and the last $N_{LTF} - N_{STS}$ columns defining the extension space-time streams. Thus, for the purpose of defining HT-LTFs, $\mathbf{P}^{(k)}$ is an $N_{Tx} \times N_{LTF}$ dimension matrix.

The first HT-LTF consists of two Long Training Symbols (LTS) as in 802.11a/g and a regular guard interval of 0.8 μs, giving a total length of 7.2μs. When present, the second and all subsequent HT-LTFs each consist of a single HT-LTS with a regular guard interval of 0.8 μs, giving a total length of 4μs.

To minimize the power fluctuation between the HT-LTF and the AGC setting (which is derived from the HT-STF), the HT-LTS is tone-interleaved across spatial streams, similar to the HT-STF definition. There are a total of 9 sequences. These sequences are defined to minimize PAPR for both direct MAP and spatial spreading, with tone-interleaving.

**Table 23: List of HT Long Training Fields**

| Sequence Number | $N_{STS}$ or $N_{LTF}$-$N_{STS}$ | BW | Comment |
|---|---|---|---|
| 1 | 1 | 20MHz | 56 tones |
| 2 | 2 | 20MHz | 56 tones |
| 3 | 3 | 20MHz | 56 tones |
| 4 | 4 | 20MHz | 56 tones |
| 5 | 1 | 40MHz | Duplicate format, 6Mbps in 40MHz (104 Tones) |
| 6 | 1 | 40MHz | 114 tones |
| 7 | 2 | 40MHz | 114 tones |
| 8 | 3 | 40MHz | 114 tones |
| 9 | 4 | 40MHz | 114 tones |

In 20MHz, sequence 1 is:

$$HTL_{-28:28}=[-1, -1, -1, 1, 1, 1, 1, -1, 1, -1, -1, -1, -1, 1, -1, 1, 1, -1, \ -1, 1, 1, 1, 1, -1, 1, 1, -1, 1, 0,$$
$$-1, -1, -1, 1, -1, -1, -1, -1, -1, -1, 1, -1, -1, -1, 1, -1, 1, -1, 1, -1, 1, -1, -1, 1, 1, -1, -1, -1] \quad (27)$$

In 20MHz, sequence 2 is:

$$HTL_{-28:28}=[-1, -1, 1, 1, 1, -1, 1, 1, -1, -1, 1, 1, 1, -1, 1, -1, -1, 1, 1, -1, 1, -1, -1, -1, -1, 1, -1, 1, 0,$$
$$-1, -1, -1, 1, -1, 1, -1, -1, 1, 1, -1, 1, -1, -1, 1, 1, -1, -1, -1, -1, 1, 1, 1, 1, 1, 1, 1] \quad (28)$$

In 20MHz, sequence 3 is:

$$HTL_{-28:28}=[1, -1, -1, -1, 1, 1, 1, 1, -1, 1, -1, -1, -1, 1, 1, 1, 1, -1, -1, 1, 1, 1, -1, \ -1, 1, -1, -1, -1, 0,$$
$$1, -1, 1, 1, 1, 1, -1, 1, -1, -1, 1, -1, -1, 1, -1, -1, 1, -1, -1, \ -1, -1, 1, -1, 1, 1, -1, -1, 1] \quad (29)$$

(30)

In 20MHz, sequence 4 is:

$$HTL_{-28:28}=[1, 1, 1, 1, -1, 1, -1, 1, -1, 1, 1, 1, 1, 1, -1, 1, -1, 1, 1, 1, 1, -1, 1, -1, \ -1, -1, -1, -1, 0,$$
$$-1, 1, 1, -1, -1, -1, 1, 1, 1, -1, -1, -1, 1, 1, -1, 1, 1, -1, -1, -1, 1, 1, -1, -1, 1, -1, -1, 1] \quad (31)$$

In the 40MHz mode, the subcarriers at $k = \pm 32$ are populated in the HT-STS. In 40MHz, sequence 5 is identical to sequence 6. Sequence 5 is used in the duplicate 6Mbps mode, whereby only 104 tones are needed, whereas sequence 6 corresponds to the 114 tones. Note that all 114 tones are transmitted in the 6Mbps duplicate mode.

$$HTL_{-58,+58} = \{-1\ 1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ 1\ -1\ 1\ 1\ -1\ -1$$
$$1\ 1\ -1\ -1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ 1\ -1\ 1\ 1\ -1\ -1\ -1\ 1\ -1\ -1\ 1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ 1 \quad (32)$$
$$0\ 0\ 0\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ 1\ -1\ 1\ 1\ -1\ -1\ 1\ -1\ -1\ 1\ -1\ 1$$
$$-1\ 1\ -1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ -1\ -1\ -1\ 1\ -1\ 1\ -1\ 1\ -1\ 1\ 1\ -1\ 1\ -1\ -1\ 1\ -1\ 1\ 1\ 1\}$$

In 40MHz, sequence 7 is:

$$HTL_{-58,+58} = \{-1\ 1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ -1\ 1\ 1\ -1\ 1\ -1\ 1\ 1\ -1$$
$$-1\ 1\ 1\ -1\ -1\ 1\ 1\ -1\ -1\ -1\ 1\ -1\ 1\ -1\ 1\ 1\ 1\ -1\ -1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ -1\ 1\ -1\ 1$$
$$0\ 0\ 0\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ 1\ -1\ 1\ 1\ -1\ -1\ 1\ -1\ 1\ 1\ -1\ 1\ -1 \quad (33)$$
$$1\ -1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ -1\ -1\ -1\ -1\ -1\ 1\ -1\ 1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ 1\ -1\ 1\ 1\ 1\}$$

In 40MHz, sequence 8 is:

$$HTL_{-58,+58} = \{-1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1$$
$$1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 0 \quad (34)$$
$$0\ 0\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1$$
$$-1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ \}$$

In 40MHz, sequence 9 is:

$$HTL_{-58,+58} = \{-1\ 1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ 1\ -1\ -1\ -1\ 1\ -1\ 1\ -1$$
$$1\ -1\ -1\ -1\ -1\ 1\ 1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ -1\ 1\ -1\ -1\ 1\ -1\ 1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ 1\ 0 \quad (35)$$
$$0\ 0\ -1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ -1\ 1\ -1\ 1\ -1\ -1\ -1\ 1\ -1\ 1\ -1$$
$$-1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ 1\ -1\ 1\ -1\ -1\ 1\ 1\}$$

The HT-LTF is generated similarly to the HT-STF. For the data HT-LTFs $i_{LTF} = 0, \ldots, N_{STS} - 1$, the signal is

$$r_{HT-LTF}^{(i_{Tx},i_{LTF})}(t) = \frac{1}{\sqrt{N_{HT-LTF}^{Tone}}} w_{HT-LTF}(t) \sum_{k=-N_{SR}}^{N_{SR}} P_{i_{Tx},(k+i_{LTF}+N_{SR}-u(k))\%N_{STS}}^{(k)} HTL_k \exp\left(j2\pi k\Delta_F(t-T_{GI})\right) \quad (36)$$

where $N_{SR}$ = 28 for 20 MHz and 58 for 40 MHz,

$$u(k) = \begin{cases} 1 & k > 0 \\ 0 & k < 0 \end{cases} \quad \text{for 20 MHz} \quad (37)$$

and

$$u(k) = \begin{cases} 3 & k > 0 \\ 0 & k < 0 \end{cases} \quad \text{for 40 MHz.} \tag{38}$$

A sequence from 1 – 4 is selected for 20 MHz depending on $N_{STS}$ for the data HT-LTFS. Similarly, a sequence from 5 – 9 is selected for 40MHz. For example with $N_{STS}$ = 3 and 20MHz, sequence 3 is selected for the data HT-LTFs.

In the case that $N_{LTF} > N_{STS}$, the extension HT-LTFs are tone interleaved over the extension spatial dimensions. Thus, the extension HT-LTFs are

$$r_{HT-LTF}^{(i_{Tx},i_{LTF})}(t) = \frac{1}{\sqrt{N_{HT-LTF}^{Tone}}} w_{HT-LTF}(t) \sum_{k=-N_{SR}}^{N_{SR}} p_{i_{Tx},N_{STS}+(k+(i_{LTF}-N_{STS})+N_{SR}-u(k))\%(N_{LTF}-N_{STS})}^{(k)} HTL_k \exp\left(j2\pi k\Delta_F(t-T_{GI})\right) \tag{39}$$

for $i_{LTF} = N_{STS}, \ldots, N_{LTF}-1$.

A sequence from 1 – 4 is selected for 20 MHz depending on $N_{LTF}$ -$N_{STS}$ for the extension HT-LTFS. Similarly, a sequence from 5 – 9 is selected for 40MHz. For example with $N_{LTF} - N_{STS}$ = 2 and 20MHz, sequence 2 is selected for the extension HT-LTFs.

Since the HT-LTF is tone interleaved across streams, the 56 tones are partitioned across the streams during each OFDM symbol. Tone partitioning into sets for 20MHz is shown in Table 24. At each OFDM symbol interval, each set of tones maps to one space-time steam. And over time, all sets get mapped to a stream.

| $N_{STS}$ | Set 0 | Set 1 | Set 2 | Set 3 |
|---|---|---|---|---|
| 1 | [-28:1:-1] [1:1:+28] | | | |
| 2 | [-28:2:-2] [2:2:28] | [-27:2:-1] [1:2:27] | | |
| 3 | [-28:3:-1] [2:3:26] | [-27:3:-3] [3:3:27] | [-26:3:-2] [1:3:28] | |
| 4 | [-28:4:-4] [1:4:25] | [-27:4:-3] [2:4:26] | [-26:4:-2] [3:4:27] | [-25:4:-2] [4:4:28] |

**Table 24: Tone partitioning of HT-LTF into sets for 20MHz (56 tones)**

Tone partitioning into sets for 40MHz is shown in Table 25.

| $N_{STS}$ | Set 0 | Set 1 | Set 2 | Set 3 |
|---|---|---|---|---|
| 1 | [-58:1:-2] [2:1:+58] | | | |
| 2 | [-58:2:-2] [2:2:+58] | [-57:2:-3] [3:2:57] | | |

| | | | | |
|---|---|---|---|---|
| 3 | [-58:3:-4] [2:3:56] | [-57:3:-3] [3:3:57] | [-56:3:-2] [4:3:58] | |
| 4 | [-58:4:-2] [5:4:57] | [-57:4:-5] [2:4:58] | [-56:4:-4] [3:4:55] | [-55:4:-3] [4:4:56] |

**Table 25: Tone partitioning of HT-LTF into sets for 40MHz (114 tones)**

An example of tone interleaving 4 space-time streams across 4 transmit antennas is shown in Figure 35.

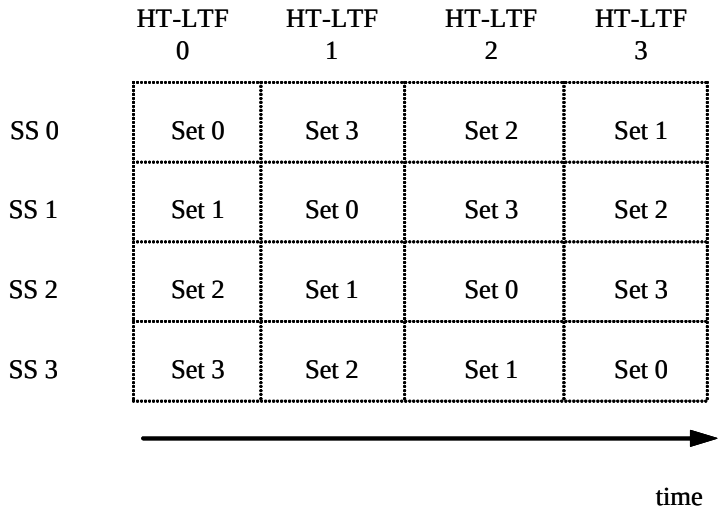



**Figure 35: HT-LTF tone interleaving across 4 spatial streams**

An example of tone interleaving with 2 space-time streams and 2 extension HT-LTFs is shown in Figure 36.

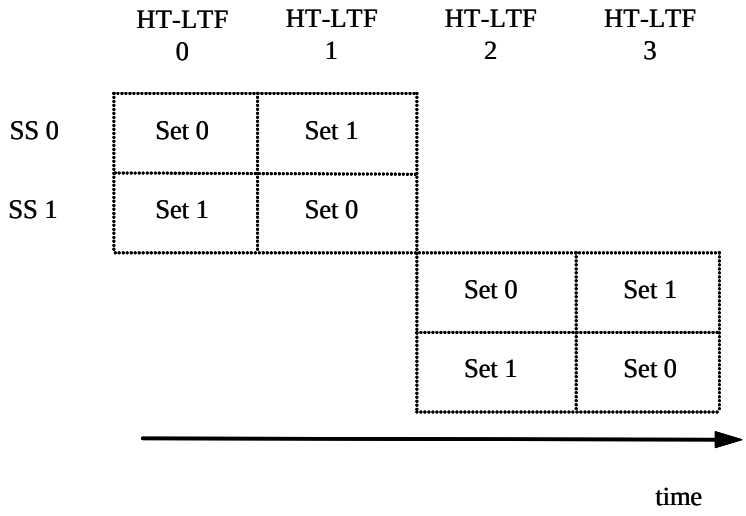



**Figure 36: HT-LTF tone interleaving of 2 spatial streams with 2 extension HT-LTFs across 4 transmit antennas**

### 11.2.1.6 Signal fields specification

The L-LTF shall be followed by the signal fields L-SIG and HT-SIG. The coding and modulation follow the steps of clause 17.3.4 in ref[2]: BPSK modulation is used for the L-SIG and HT-SIG, with code rate ½ resulting in 6 Mbit/s. Between the LSIG and the HT-SIG symbol, the BPSK modulation shall be rotated counter-clockwise by 90 degrees. This phase rotation can be used to "auto-detect" whether the frame being received is legacy or HT. The constellation bit encoding is depicted in Figure 37.

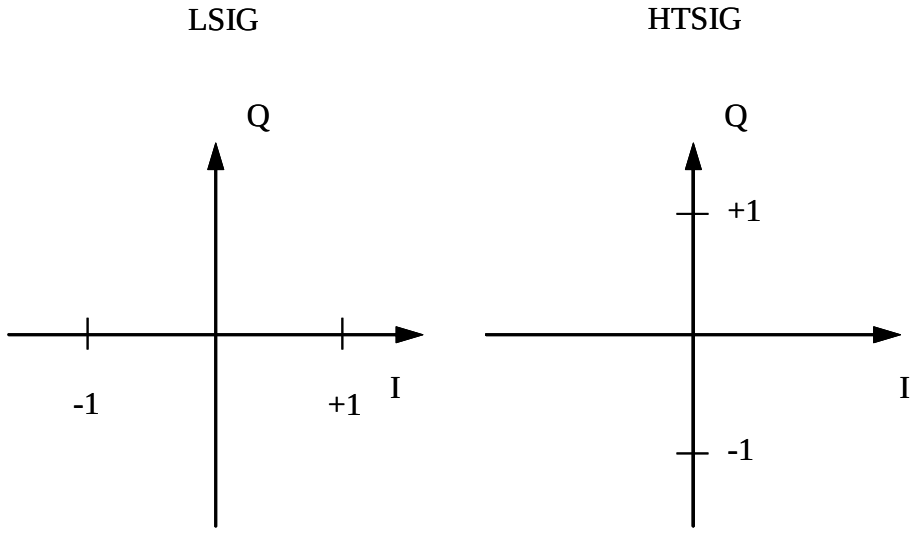



**Figure 37: Constellation specification for LSIG and HTSIG**

#### 11.2.1.6.1 L-SIG

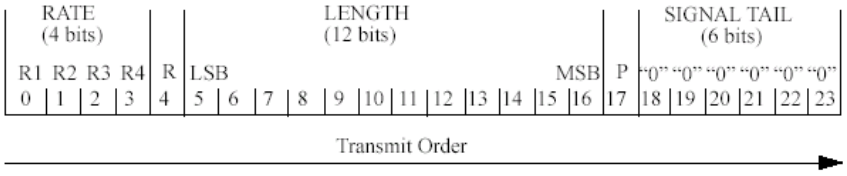



**Figure 38: SIGNAL field bit assignment**

In the 20MHz mode, the format of the LSIG field shall be the same as the SIGNAL field as defined in figure 111 in 17.3.4 in [1]. The combination of RATE and LENGTH is used to signal a station (OFDM mode only) the duration of a HT transmission. This duration does not have to be the actual duration of the HT frame. It can be used to reserve the medium beyond the actual transmission. The reservation of the medium through this kind of signalling is called Extended PHY protection.

To prevent a legacy station from accessing the medium during a HT frame transmission, the "duration" calculated from the RATE and LENGTH fields shall be at least as large as the actual duration of the HT frame, which is measured from the end of the L-SIG field to the end of the DATA field. During an HT transmission, the RATE field is set to 6Mbps, whereas the LENGTH field is set based on the "duration" value.

In the 40MHz mode, the legacy signal field is duplicated such that tones are filled from -58 to -6 (lower-subchannel), and from +6 to +58 (upper-subchannel). The upper subchannel shall be phase rotated by 90 degrees, in the same way as the LTS as described in 11.2.1.5.2

The LSIG shall be transmitted in the same fashion as the legacy short and the legacy long training fields. If L-STF and L-LTF are transmitted from a single antenna, we index that antenna as $i_{Tx} = 1$ to be consistent with 11.2.1.5.2. Denote $LSIG_{-26,26}$ and $LSIG_{-58,58}$ as the LSIG OFDM symbol generated for 20 MHz and 40 MHz respectively.

The L-SIG waveform is

$$r_{L-SIG}^{i_{Tx}}(t) = \frac{1}{\sqrt{N_{L-SIG}^{Tone}}} w_{L-SIG}(t) \sum_{k=-N_{SR}}^{N_{SR}} p_{i_{Tx}}^{L(k)} LSIG_k \exp\left(j2\pi k\Delta_F\left(t - T_{GI}\right)\right) \quad (40)$$

### 11.2.1.6.1.1 Data rate (RATE)

For a legacy station (11a or 11g), RATE has the original meaning as is defined in Table 80 of section 17.3.4.1 in [1]. For reference the table is repeated here:

| Rate (Mbits/s) | R1–R4 |
|---|---|
| 6 | 1101 |
| 9 | 1111 |
| 12 | 0101 |
| 18 | 0111 |
| 24 | 1001 |
| 36 | 1011 |
| 48 | 0001 |
| 54 | 0011 |

**Table 26: Content of the legacy SIGNAL field**

### 11.2.1.6.1.2 PLCP length field (LENGTH)

The PLCP length field in HT is used to indicate to both legacy and HT stations a protection duration. It contains a value, which when combined with the rate field defines a duration. The number of bytes in the LENGTH field is calculated based on the perceived RATE of a legacy station defined in R1-R4 and the actual number of bytes that the MAC is currently requesting the PHY to transmit, taking into account the number of transmit antennas (spatial streams), the bandwidth and the extra fields (symbols) in the preamble.

As indicated in 11.2.1.6.1, the calculated duration is allowed to be longer than the actual duration of the HT transmission. However the LENGTH value should be equal to or smaller than 2346 bytes to avoid mis-interpretation by existing legacy devices.

### 11.2.1.6.2 HT-SIG

The L-SIG field shall be followed by the HT-SIG, which serves as the signal field for the HT PHY. HT-SIG consists of two OFDM symbols: HT-SIG1 and HT-SIG2. HT-SIG1 shall be transmitted first in time.

The encoding of HT-SIG-1 and HT-SIG-2 shall be the same as L-SIG, with the exception that the BPSK modulation is rotated 90 degrees as described in clause 11.2.1.6.

In the 40MHz mode, the HT-SIG-1 and HT-SIG-2 are duplicated. The upper sub-channel shall be phase rotated by 90 degrees in the same way as the L-LTF, as described in 11.2.1.5.2 **Error! Reference source not found.** shows the bit assignment for the two symbols. They will be described in the next clauses.

HT-SIG-1 and HT-SIG-2 shall be transmitted in a similar fashion as the LSIG. Denote $HTSIG^{0}_{-26,26}$ and $HTSIG^{1}_{-58,58}$ as the first and second OFDM symbol of the following defined HT-SIG as a data field. Then

$$r^{(i_{Tx})}_{HT-SIG}(t) = \frac{1}{\sqrt{N^{Tone}_{HT-SIG}}} \sum_{n=0}^{1} w_{Symb}\left(t - nT_{Symb}\right) \sum_{k=-N_{SR}}^{N_{SR}} p^{L(k)}_{i_{Tx}} HTSIG^{n}_{k} \exp\left(j2\pi k\Delta_F\left(t - T_{GI} - nT_{Symb}\right)\right) \quad (41)$$

where $T_{Symb}$ = 4 μ sec is the OFDM symbol duration.

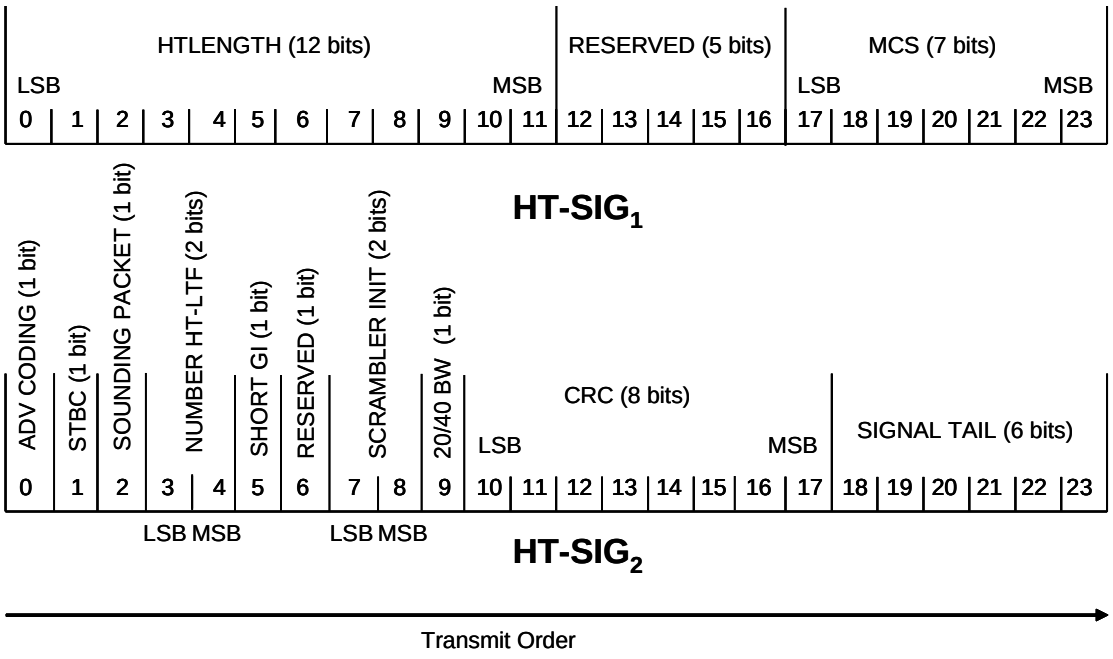



**Figure 39: HT-SIG field bit assignments**

### 11.2.1.6.2.1 HTLENGTH field

The HTLENGTH field shall be an unsigned 12-bit integer, which is interpreted using the following table:

| HTLENGTH<br>b'$H_{11}H_{10}$_$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$ | Contains A-MPDU? | Length interpretation |
|---|---|---|
| b'00_$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$ | No | b'00_$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$ octets |
| b'01_$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$ | No | b'01_$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$ octets |
| b'10_$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$ | No | b'10_$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$ octets |
| b'11_$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$ | Yes | b'$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$ OFDM symbols |

**Table 27: Interpretation of HT-LENGTH field in HT-SIG**

Bit 0 (i.e. $H_0$) is the LSB (least significant bit) and shall be transmitted first in time to the channel encoder.

#### 11.2.1.6.2.2 MCS field

The MCS field is a 7-bit field (bit 17-23 of HT-SIG1) that defines the modulation and coding scheme, as indicated in Table 17. MCS indices from 0 to 15 are mandatory, and the rest are optional.

#### 11.2.1.6.2.3 ADVCODING

ADVCODING is a 1-bit field that indicates if advanced coding has been applied to the PPDU.

#### 11.2.1.6.2.4 STBC

This bit is set to 1 is the PPDU has been encoded using STBC, else it is set to NULL.

#### 11.2.1.6.2.5 SOUNDING PACKET

This bit indicates that a sounding PPDU is being sent. The reception of a PPDU with the sounding bit set to '1' indicates to an STA that it should buffer the CSI estimate if it has the capability and desire to do so, as the contents of the MPDU will request a function requiring further processing of the CSI. A sounding packet may contain any valid number of HT-LTFs ( $N_{STS} \leq N_{LTF} \leq N_{TX}$ ).

#### 11.2.1.6.2.6 NUMBER (of) HT-LTF

These bits indicate the number of HT-LTFs in the current PPDU. The number of HT-LTFs may be greater than the number of space-time-streams. Note that the number of HT-LTFs is less than or equal to the number of transmit antennas. The N_LTF bits are encoded as show in Table 28:

| HT-SIG encoding of N_LTF | Enumeration of N_LTF |
|---|---|
| b'00 | 1 |
| b'01 | 2 |
| b'10 | 3 |
| b'11 | 4 |

**Table 28: Encoding of N_LTF in HT-SIG**

#### 11.2.1.6.2.7 SHORT GI (Optional)

SHORT GI is a 1-bit field. If SHORT GI is 1, the Short Guard Interval is used in the data portion of the frame.

#### 11.2.1.6.2.8 SCRAMBLERINIT

SCRAMBLERINIT is a 2-bit field that contains the initialization value of the scrambler. This value is used to initialize the scrambler at the receiver. The mapping of the 2-bit field to initialization sequences is described in Table 11.

#### 11.2.1.6.2.9 20/40 BW

This bit indicates whether the current PPDU is signaled in 20MHz or 40MHz bandwidth. A value of 0 indicates 20MHz, whereas a value of 1 indicates 40MHz.

#### 11.2.1.6.2.10 CRC

The CRC field is an 8-bit CRC value. It is used as a Frame Check Sequence (FCS) to protect the information-bearing fields of LSIG, HT-SIG1 and HT-SIG2.

The CRC field shall be the one's complement of the remainder generated by the modulo 2 division of the protected bits by the polynomial

$$x^8 + x^2 + x^1 + 1 \qquad (42)$$

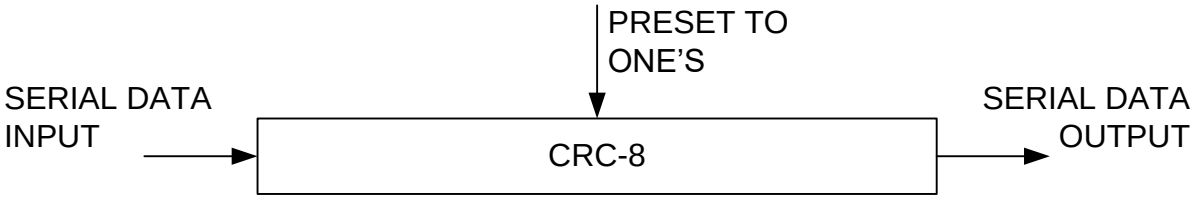
where the shift-register state shall be preset to all-ones. The protected bits shall be bit0-bit16 of LSIG, bit0-bit23 of HTSIG1, and bit0-bit9 of HTSIG2. The protected bits shall be processed by the CRC encoder in transmit order. A schematic of the processing is shown in Figure 40.

As an example, given the following LSIG, HT-SIG1 and HT-SIG2 fields
1101 0001 1101 1101 0000 0000 [LSIG]
0111 1011 0100 1011 1010 0000 [HT-SIG1]
0010 1101 10CC CCCC CC00 0000 [HT-SIG2]
b0.....b23 [leftmost bit (b0) transmitted first in time]

then the protected bits input to the CRC encoder are
1101 0001 1101 1101 0, 0111 1011 0100 1011 1010 0000, 0010 1101 10

and the calculated CRC8 equals
00001101

so that HT-SIG2 equals
0010 1101 1000 0011 0100 0000




1. Present shift register to all one's
2. Shift bit0-bit16 of LSIG, HTSIG1, and bit0-bit9 of HTSIG2 through the shift register
3. Take one's complement of the remainder
4. Transmit out serial $x^7$ first

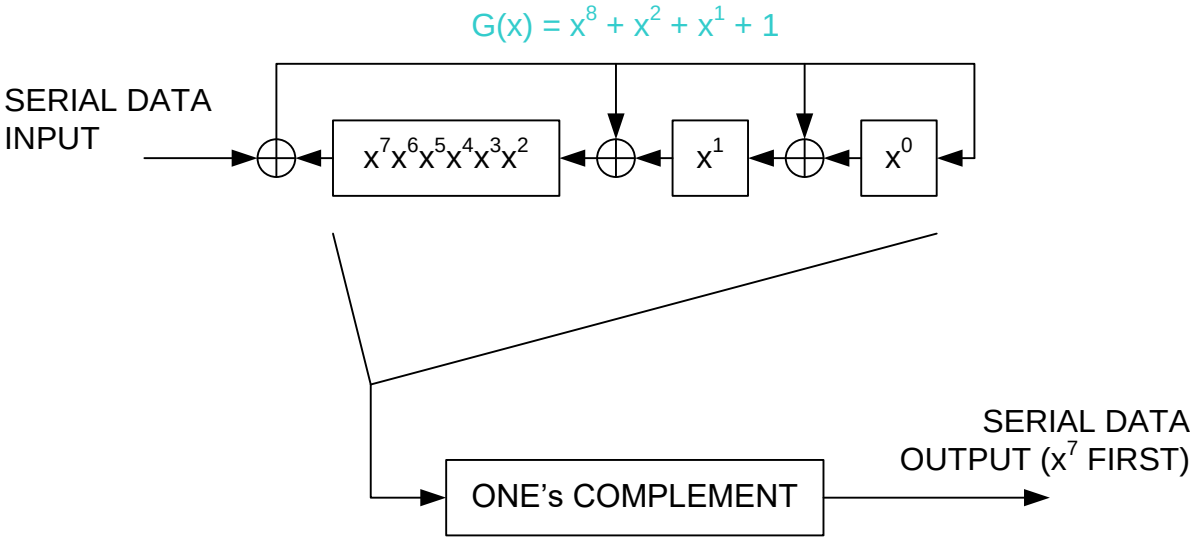



**Figure 40: CRC8 implementation**

### 11.2.1.6.2.11 SIGNALTAIL

The bits 18-23 constitute the SIGNALTAIL field, and all 6 bits shall be set to zero.

## 11.2.1.7 Datafield

Contrary to 801.11a, the data field in our proposal does not contain a SERVICE field.

The data field contains the PSDU, the Tail bits and the PAD bits. All bits in the DATA field are scrambled, as described in 11.2.1.7.3. The PPDU is de-multiplexed across several spatial streams, which are created after the parser.

### 11.2.1.7.1 PSDU tail bit field (TAIL)

The PSDU tail bit field shall be six bits of "0," which are required to return the convolutional encoder to the "zero state." This procedure improves the error probability of the convolutional decoder, which relies on future bits when decoding and which may be not be available past the

end of the message. The PLCP tail bit field shall be produced by replacing six scrambled "zero" bits following the message end or padding bit(s) with six non-scrambled "zero" bits.
When A-MPDU is not applied, tail bits should be located just after PSDU, as same as in 802.11a.
When A-MPDU is applied, tail bits should be located after padding bit(s) such that the tail bits always appear as the last 6 bits in the last OFDM symbol.

#### 11.2.1.7.2 Pad bits (PAD)

The length of the message is extended so that it becomes a multiple of the number of data bits per OFDM symbol for each data (spatial) stream. The number of pad bits is dependent on how the bits are divided over the spatial streams.
When A-MPDU is not applied, pad bit(s) should be located after tail bits as same as in 802.11a, if padding is required. In this case, receiver PHY should remove pad bit(s) and tail bits before delivering decoded bits to MAC layer.
When A-MPDU is applied, pad bit(s) should be located between PSDU and tail bits such that the tail bits always appear as the last 6 bits in the last OFDM symbol. In this case, receiver PHY should deliver all decoded bits, except for tail bits, to MAC layer.

#### 11.2.1.7.3 PLCP Data Scrambler and Descrambler

The 11a Scrambler and Descrambler will be used as described in 17.3.5.4 in ref [1].
The DATA field, composed of PSDU, tail, and pad parts, shall be scrambled with the length-127 frame-synchronous scrambler.
The scrambler shall be initialized according to the SCRAMBLERINIT fields in HT-SIG2.
As described in 11.2.1.7.1 the PLCP tail bit field shall be produced by replacing six scrambled "zero" bits following the message end with six nonscrambled "zero" bits.

#### 11.2.1.7.4 Antenna streams / Transmitter architecture

In the basic MIMO mode, space-time streams may be mapped to transmit antennas using direct mapping (Figure 21), or spatial spreading (Figure 22). In the case of direct mapping, the number of space-time streams equals the number of active transmit antennas. By active, we imply those antennas that transmit data fields. In the case of spatial spreading, the number of space-time streams must be less than or equal to the number of transmit antennas.

The information bits first go through a convolutional encoder. The convolutional encoder is of rate ½ , from which other rates are derived by puncturing (see 11.2.1.7.6). The output of the puncturer feeds into the spatial parser, which creates several spatial streams, using round robin cycling. The frequency interleaver places the bits in the frequency domain and the constellation position according to the rules of the 802.11a interleaver. The interleaved bits are then mapped to constellation points. The resulting QAM symbols are fed to the antenna map transformation (Figure 20), and the output of this for each transmit antenna is fed as a block of data to the iFFT to create the time-domain signal. The pilot tones are also inserted in the frequency domain. The cyclical prefix is inserted in the time domain, and windowing of the OFDM symbols is also performed in the time domain. The resulting signal is then converted into analog format via a Digital-to-Analog (D/A) converter.

#### 11.2.1.7.5 Encoder

The DATA field shall be coded with the convolutional encoder of coding rate R=1/2. The encoder is defined in clause 17.3.5.5 in [1] (i.e. the 11a encoder).

.

#### 11.2.1.7.6 Puncturing of Coded Data

Coded bits at the output of the convolutional encoder are at rate 1/2. For lower rates, the puncturer can selectively puncture the coded bits to achieve the desired "effective" coding rate of 2/3, 3/4 or 5/6. For code rates of 2/3 and 3/4 the puncturing patterns are as defined in clause 17.3.5.5 in [1]. For a code rate of 5/6, the puncturing pattern is illustrated in Figure 41.

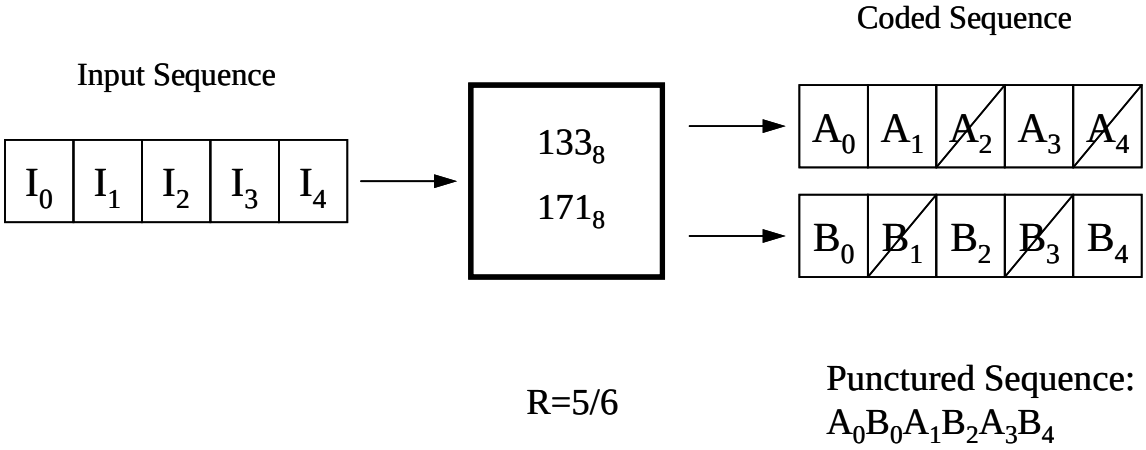



**Figure 41: Puncturing pattern for code rate = 5/6**

In the basic MIMO mode, all spatial streams are identically punctured.

#### 11.2.1.7.7 Data interleaving

Coded and punctured bits are interleaved across spatial streams and frequency tones. There are two steps to the space-frequency interleaving: spatial stream parsing and frequency interleaving.

##### 11.2.1.7.7.1 Spatial Parsing

Encoded and punctured bits are parsed to multiple spatial streams by a round-robin parser. Define:

$$s = \max\left\{N_{BPSC}/2, 1\right\} \quad (43)$$

which is the number of QAM bit order values. The parser sends consecutive blocks of $s$ bits to each spatial streams in a round-robin fashion starting with the first spatial stream. The reason for parsing in blocks of $s$ bits is to prevent clustering of QAM orders.

##### 11.2.1.7.7.2 Frequency interleaver

All encoded bits shall be interleaved by a separate block interleaver for each spatial stream, with a block size corresponding to the number of coded bits in a single OFDM symbol, $N_{CBPS}$. The block interleavers are based on the 802.11a interleaver, with certain modifications to allow for multiple spatial streams and 40MHz transmissions as shown in Figure 42.

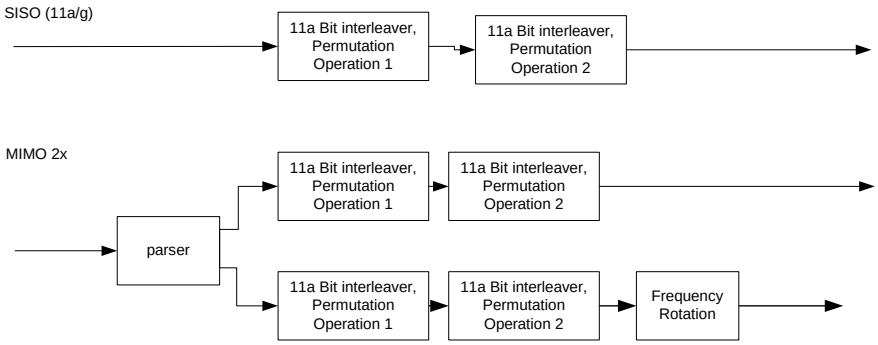



**Figure 42: Structure of interleaver**

The interleaver is defined by a three-step permutation. The first permutation ensures that adjacent coded bits are mapped onto nonadjacent subcarriers. The second permutation ensures that coded bits are mapped alternately onto less and more significant bits of the constellation and thereby long runs of low reliability (LSB) bits are avoided. The third permutation ensures that coded bits are mapped to achieve better frequency-spatial diversity among all spatial streams via frequency rotation. The operations of the first two permutations are the same as in 802.11a.

The basic interleaver array has $N_{row}$ rows and $N_{column}$ columns and the base of frequency rotation is defined by $N_{rot}$. These parameters are specified in Table 29 where $N_{BPSC}$ is the number of coded bits per subcarrier (e.g., $N_{BPSC}$ = 1 for BPSK, 2 for QPSK, 4 for 16 QAM, etc).

**Table 29: Interleaver Parameters**

| | $N_{column}$ | $N_{row}$ | $N_{rot}$ |
|---|---|---|---|
| 20 MHz channels | 13 | $4N_{BPSC}$ | 11 |
| 40 MHz channels | 18 | $6\ N_{BPSC}$ | 29 |

The amount of frequency rotation for each spatial streams is illustrated in Table 30.

**Table 30: Frequency Rotation across spatial streams**

| Frequency Rotation | Total Number of Streams | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 1st stream | 0 | 0 | 0 | 0 |
| 2nd stream | | $2N_{rot}$ | $2N_{rot}$ | $2N_{rot}$ |
| 3rd stream | | | $N_{rot}$ | $N_{rot}$ |
| 4th stream | | | | $3N_{rot}$ |

The index of the coded bit before the first permutation shall be denoted by *k*; *i* shall be the index after the first and before the second permutation; *j* shall be the index after the second permutation and before the third permutation; *r* shall be the index after the third permutation and just prior to modulation mapping.

The first permutation is defined by the rule

$$i = N_{row} \times \left(k \bmod N_{column}\right) + \text{floor}\left(k / N_{column}\right) \quad k = 0,1,\ldots, N_{CBPS} - 1 \tag{44}$$

The second permutation is defined by the rule

$$j = s \times \text{floor}\left(i / s\right) + \left(i + N_{CBPS} - \text{floor}\left(N_{column} \times i / N_{CBPS}\right)\right) \bmod s \quad i = 0,1,\ldots, N_{CBPS} - 1 \tag{45}$$

where *s* is determined according to

$$s = \max\left(N_{BPSC} / 2, 1\right) \tag{46}$$

The third permutation is defined by the rule

$$r = \left(j - \left(\left(2 \times i_{ss}\right) \bmod 3 + 3 \times \text{floor}(i_{ss} / 3)\right) \times N_{rot} \times N_{BPSC}\right) \bmod N_{CBPS} \qquad j = 0,1,\ldots, N_{CBPS} - 1 \tag{47}$$

where $i_{SS} = 0,1,\ldots, N_{SS} - 1$ is the index of the spatial stream on which this interleaver is operating.

The deinterleaver, which performs the inverse relation, is also defined by three permutations. Here the index of the original received bit before the first permutation shall be denoted by *r*; *j* shall be the index after the first and before the second permutation; *i* shall be the index after the second and before the third permutation; and *k* shall be the index after the third permutation.

The first permutation is defined by the rule

$$j = \left(r + \left(\left(2 \times i_{ss}\right) \bmod 3 + 3 \times \text{floor}(i_{ss} / 3)\right) \times N_{rot} \times N_{BPSC}\right) \bmod N_{CBPS}, \qquad r = 0,1,\ldots, N_{CBPS} - 1 \tag{48}$$

This permutation is the inverse of the permutation described in Equation (44).

The second permutation is defined by the rule

$$i = s \times \text{floor}\left( j / s \right) + \left( j + \text{floor}\left( N_{column} \times j / N_{CBPS} \right) \right) \bmod s, \quad j = 0,1,\ldots, N_{CBPS} - 1 \qquad (49)$$

where *s* is as defined in Equation (46). This permutation is the inverse of the permutation described in Equation (45).

The third permutation is defined by the rule

$$k = N_{column} \times i - \left( N_{CBPS} - 1 \right) \text{floor}\left( i / N_{row} \right), \quad i = 0,1,\ldots, N_{CBPS} - 1 \qquad (50)$$

This permutation is the inverse of the permutation described in Equation (47).

#### 11.2.1.7.8 Subcarrier Modulation Mapping

The subcarrier modulation mapping for BPSK, QPSK, 16-QAM, and 64-QAM will be identical to clause 17.3.5.7 in [1]

There is one exception as described in clause 11.2.1.6. The mapping of the HT-SIG field shall be rotated by 90 degrees.

##### 11.2.1.7.8.1 Subcarrier Modulation Mapping for 256-QAM (optional)

256QAM is introduced in the optional MCS sets in MCS capability classes of "1000", "1101", "1110", and "1111".. The normalization factor $K_{MOD}$ for 256QAM is $1/\sqrt{170}$ . For 256-QAM, $b_0b_1b_2b_3$ determines the I value and $b_4b_5b_6b_7$ determines the Q value. The constellation mapping for 256QAM is as follows.

**Table 31: Constellation Mapping for 256-QAM**

| Input bits $b_0b_1b_2b_3$ | I-out |
|---|---|
| 0000 | -15 |
| 0001 | -13 |
| 0011 | -11 |
| 0010 | -9 |
| 0110 | -7 |
| 0111 | -5 |
| 0101 | -3 |
| 0100 | -1 |
| 1100 | 1 |
| 1101 | 3 |
| 1111 | 5 |
| 1110 | 7 |
| 1010 | 9 |
| 1011 | 11 |
| 1001 | 13 |
| 1000 | 15 |

| Input bits $b_4b_5b_6b_7$ | Q-out |
|---|---|
| 0000 | -15 |
| 0001 | -13 |
| 0011 | -11 |
| 0010 | -9 |
| 0110 | -7 |
| 0111 | -5 |
| 0101 | -3 |
| 0100 | -1 |
| 1100 | 1 |
| 1101 | 3 |
| 1111 | 5 |
| 1110 | 7 |
| 1010 | 9 |
| 1011 | 11 |
| 1001 | 13 |
| 1000 | 15 |

### 11.2.1.7.9 MIMO-OFDM symbol iFFT mapping

For the MIMO-OFDM operation in 20 MHz bandwidth, each OFDM symbol is constructed from 56 tones, of which 52 are data tones and 4 are pilot tones. The tone mapping is identical to that in IEEE 802.11a (subclause 17.3.5.9 in reference) except the 2 extra tones on either side.

Construction of the OFDM data symbol in 40MHz begins with bonding two adjacent 20MHz OFDM symbols, as shown in Figure 43. There are a total of 11 guard tones between the two 20MHz channels, ranging from -5 to +5. Note that the legacy channels occupy tones from -58 to -6 in the lower sub-channel, and from +6 to +58 in the upper sub-channel. Of the 11 guard tones, 3 are nulled out: -1, 0, +1. This provides 8 additional data tones. Two DC tones are also inherited from the legacy sub-channels. These occur at -32 and +32 in the lower and upper sub-channels respectively. There are 4 pilot tones in each legacy sub-channel, and when mapped to the 40MHz iFFT indices, they occur at ±53, ±39, ±25, ±11. Of these 8 tones, the two tones at -39 and +39 are swapped with data, leading to a total of 6 pilot tones in the 40MHz channel. Tone assigned during 40MHz for DATA symbols can be summarized as:

$$
\begin{aligned}
&\textit{Nulled Tones} = \{-64\ldots-59,-1,0,+1,+59\ldots+63\}\\
&\textit{Populated Tones} = \{-58\ldots-2,+2\ldots+58\}\\
&\textit{Pilot Tones} = \{-53,-25,-11,+11,+25,+53\}\\
&\textit{Data Tones} = \{\textit{Populated Tones}\}-\{\textit{Pilot Tones}\}
\end{aligned}
\qquad (51)
$$

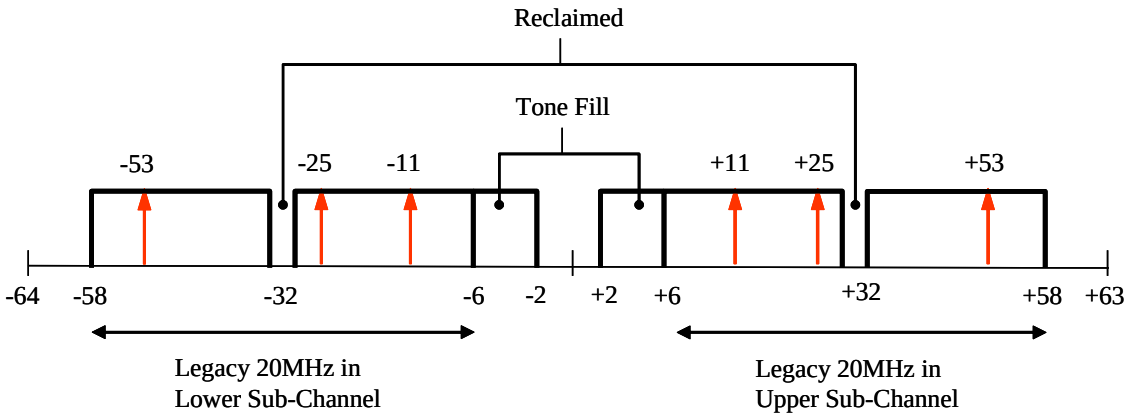



**Figure 43: Tone Format for 40MHz channelization**

The mapping of the input of the 40MHz channel to a 128-point IFFT is illustrated in Figure 44.

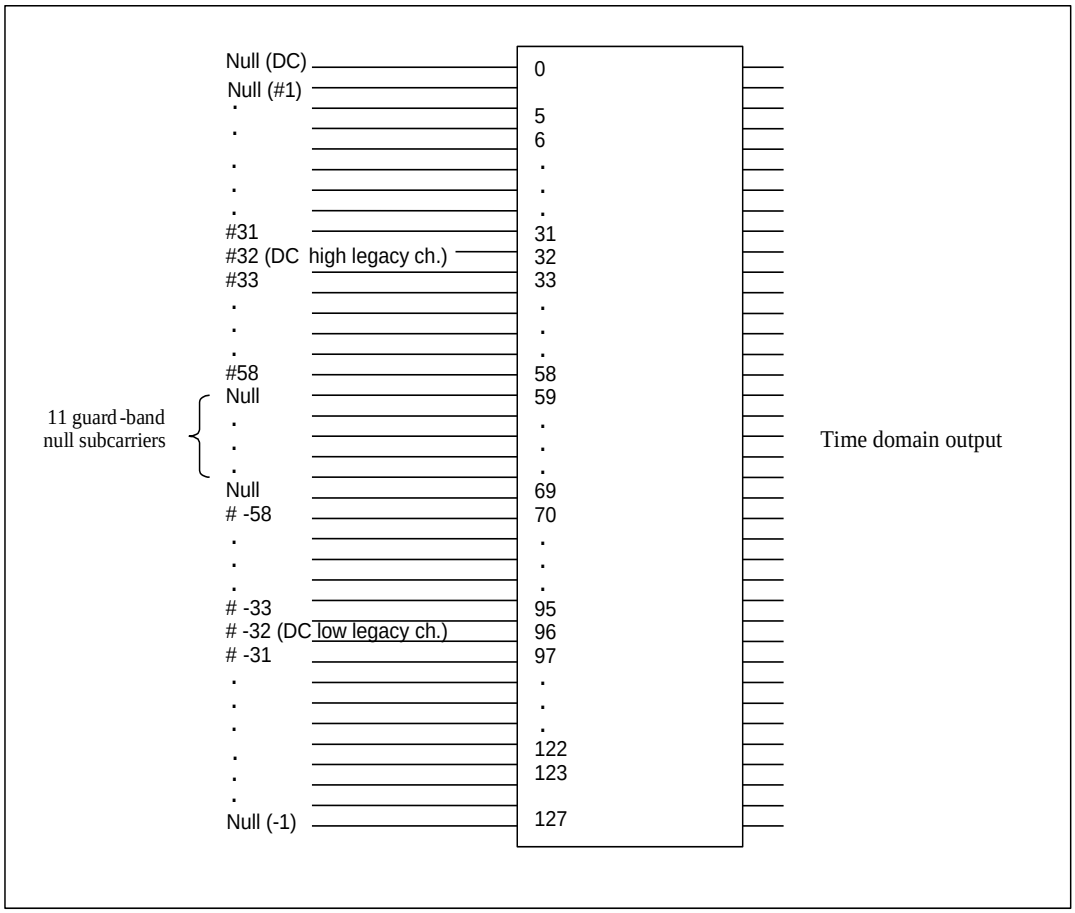



**Figure 44 Inputs and Outputs of IFFT for a 40 MHz channel**

The complex numbers after the mapping are divided into groups of $N_{SD}$, where $N_{SD}$ = 52 in the 20MHz mode and $N_{SD}$ = 108 in the 40MHz mode (excluding 6 Mbps duplicate format).

Following the convention in clause 17.3.5.9 in [1], the complex number is denoted as $d_{k,n}^{(i_{SS})}$, which corresponds to the $k$ th modulation symbol in the $n$ th OFDM symbol that is transmitted on space-time stream $i_{STS}$ (= 0, …, $N_{STS}$ −1).

The complete data field is

$$r_{HT-Data}^{(i_{Tx})}(t) = \sum_{n=0}^{N_{Data}-1} r_{HT-Data,n}^{(i_{Tx})}\left(t - nT_{Symb}\right). \quad (52)$$

The n$^{th}$ OFDM data symbol is

$$r_{HT-Data,n}^{i_{TX}}(t) = w_{Symb}(t)\left\{ \sum_{k=0}^{N_{SD}-1}\left( \sum_{i_{STS}=0}^{N_{STS}-1} p_{i_{Tx},i_{STS}}^{(k)} d_{i_{STS}}^{(k,n)} \right)\exp\left( j2\pi M(k)\Delta_F (t-T_{GI}) \right) \right.$$

$$\left. + pt_{n+3} \sum_{k=-N_{SR}}^{N_{SR}} \left( \sum_{i_{STS}=0}^{N_{STS}-1} p_{i_{Tx},i_{STS}}^{(k)} PT_{i_{STS}}^{(k,n)} \right) \exp\left( j2\pi k\Delta_F (t-T_{GI}) \right) \right\} \quad (53)$$

where function $M(k)$, defines the mapping from the logical subcarrier number $k$ to a value between $-N_{SR}$ and $+N_{SR}$, while skipping the pilot subcarriers and DC and its adjacent subcarriers. $M(k)$ in the 20MHz mode is same as the one defined in clause 17.3.5.9 in [1]. $M(k)$ in the 40MHz mode is defined as

$$M(k) = \begin{cases} k-58 & 0 \le k \le 4 \\ k-57 & 5 \le k \le 31 \\ k-56 & 32 \le k \le 44 \\ k-55 & 45 \le k \le 53 \\ k-52 & 54 \le k \le 62 \\ k-51 & 63 \le k \le 75 \\ k-50 & 76 \le k \le 102 \\ k-49 & 103 \le k \le 107 \end{cases} \quad (54)$$

The contribution of pilot subcarriers in the 20MHz mode is given by (24) in clause 17.3.5.9 in ref [1]. The subcarrier frequency locations in the 20MHz mode is shown in Figure 117 in clause 17.3.5.9 in ref [1]. The subcarrier frequency locations in the 40MHz mode is shown in Figure 43.

The iFFT mapping for the 6Mbps duplicate mode in 40MHz differs from the mapping shown in (53):

$$r_{HT-Data,n}^{i_{TX}}(t)$$

$$= w_{Symb}(t)\left\{ \sum_{k=0}^{N_{SD}-1}\left( \sum_{i_{STS}=0}^{N_{STS}-1} p_{i_{Tx},i_{STS}}^{(k)} d_{i_{STS}}^{(k,n)} \right) \right. \left( \exp\left( j2\pi\left(M(k)-32\right)\Delta_F (t-T_{GI}) \right) \right.$$

$$\left. + j\exp\left( j2\pi\left(M(k)+32\right)\Delta_F (t-T_{GI}) \right) \right) \quad (55)$$

$$+ pt_{n+3} \sum_{k=-N_{SR}}^{N_{SR}} \left( \sum_{i_{STS}=0}^{N_{STS}-1} p_{i_{Tx},i_{STS}}^{(k)} PT_{i_{STS}}^{(k,n)} \right) \left( \exp\left( j2\pi\left(k-32\right)\Delta_F (t-T_{GI}) \right) \right.$$

$$\left. \left. + j\exp\left( j2\pi\left(k+32\right)\Delta_F (t-T_{GI}) \right) \right) \right\}$$

where, $N_{SD}$ = 52 and $N_{SR} = 28$ are values that correspond to a 20 MHz transmission. $M(k)$, $PT_{i_{STS}}^{(k)}$ and $pt_n$ follow the definitions in (23) to (25) in clause 17.3.5.9 in [ref 2]. $PT_{i_{STS}}^{(k)}$ for the HT 40MHz mode is defined in 11.2.1.7.10.2.

### 11.2.1.7.10 Pilot subcarrier

In each OFDM symbol, four of the subcarriers in 20 MHz mode and six of the subcarriers in 40 MHz mode are dedicated to pilot signals in order to make the coherent detection robust against frequency offsets and phase noise. These pilot signals shall be put in subcarriers –21, -7, 7, and 21 in 20MHz mode, and in subcarriers -53, -25, -11, 11, 25 and 53 in 40MHz mode.

#### 11.2.1.7.10.1 Legacy pilot subcarriers

Legacy pilots are defined as in 802.11a; refer to clause 17.3.5.8 in [1].

#### 11.2.1.7.10.2 Pilot subcarriers in HT mode

The contribution of pilot subcarriers at the $i_{Tx}$th transmission stream in 20MHz mode is produced by inverse Fourier transform of sequence $PT_{k,n}^{(i_{Tx})}$ given by

$$\begin{aligned} PT_{i_{STS}}^{(-28..28,n)} = \{ & 0,0,0,0,0,0,0,PT_{i_{STS}}^{(-21,n)},0,0,0,0,0,0,0,0,0,0,0,0,0,PT_{i_{STS}}^{(-7,n)},0,0,0,0,0,0,0, \\ & 0,0,0,0,0,0,PT_{i_{STS}}^{(-7,n)},0,0,0,0,0,0,0,0,0,0,0,0,0,-PT_{i_{STS}}^{(21,n)},0,0,0,0,0,0,0 \} \end{aligned} \quad (56)$$

where non-zero element of $PT_{i_{Tx}}^{(k,n)}$ is generated by the following rule

$$PT_{i_{STS}}^{(k,n)} = \exp\left\{ \frac{j\pi}{2}(i_{SS}-1)m \right\}, \quad m = \left( \frac{1}{2}\left( \frac{k}{7}+3 \right)+n \right) \bmod 4 \quad (57)$$

In the 40MHz mode, $PT_{k,n}^{(i_{Tx})}$ is given by

$$\begin{aligned} PT_{i_{STS}}^{(-58..58,n)} = \{ & 0,0,0,0,0,PT_{i_{STS}}^{(-53,n)},0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,PT_{i_{STS}}^{(-25,n)},0,0, \\ & 0,0,0,0,0,0,0,0,0,0,0,-PT_{i_{STS}}^{(-11,n)},0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,PT_{i_{STS}}^{(11,n)},0,0,0,0, \\ & 0,0,0,0,0,0,0,0,0,0,-PT_{i_{STS}}^{(25,n)},0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0, \\ & 0,0,PT_{i_{STS}}^{(53,n)},0,0,0,0,0 \} \end{aligned} \quad (58)$$

where non-zero element of $PT_{k,n}^{(i_{Tx})}$ is generated by the following rule

$$PT_{i_{STS}}^{(k,n)} = \exp\left\{ \frac{j\pi}{2}(i_{STS}-1)m \right\}, \quad m = \begin{cases} \left( \frac{(k+11)}{14}+3+n \right) \bmod 4, & k=-53,-25,-11 \\ \left( \frac{(k+3)}{14}+3+n \right) \bmod 4, & k= 11,\ 25,\ 53 \end{cases} \quad (59)$$

The polarity of the pilot subcarriers is controlled by sequence $pt_n$, which is a cyclic extension of the 127 elements sequence as defined in clause 17.3.5.9 in ref[2].

#### 11.2.1.7.11 GI / windowing

The windowing function in both 20MHz and 40MHz modes is the same as the one described in clause 17.3.2.4 and 17.3.2.5 in [1]. The example in clause 17.3.2.5 in [1] still holds for the 20MHz modes. In the 40MHz modes, the changes in this example is the sampling rate becomes 40MHz and $T_{TR} = 50ns$, then the discrete implementation of the windowing function is

$$w_T[n] = w_T(nT_s) = \begin{Bmatrix} 1 & 1 \le n \le 159 \\ 0.5 & 0,160 \\ 0 & otherwise \end{Bmatrix} \quad (60)$$

### 11.2.1.8 Clear channel assessment

When operating in the 5 GHz band the HT PHY shall follow the CCA requirements of 11a, clause 17.3.10.5 in [1]. When operating in the 2.4 GHz band the HT PHY shall follow the 11g spec according to 19.3.5 and 19.4.6 in ref [3].

### 11.2.1.9 PMD operating spec

In the 20 MHz bandwidth mode the HT PHY shall follow the 11a spec (clause 17.3.8 in ref [1]) and subsequent specifications when operating in the 5 GHz band.
In the 20 MHz bandwidth mode the HT PHY shall follow the 11g spec (clause 19.4) when operating in the 2.4 MHz band.

#### 11.2.1.9.1 Transmit spectral mask

##### 11.2.1.9.1.1 20MHz channel spacing

In the 20 MHz bandwidth mode the HT PHY shall follow 17.3.9.2 in ref [1]. The transmitted spectrum shall have a 0dBr (dB relative to the maximum spectral density of the signal) bandwidth not exceeding 18MHz, -20dBr at 11 MHz frequency offset, -28dBr at 20MHz frequency offset and -45dBr at 30MHz frequency offset and above. The transmitted spectral density of the transmitted signal shall fall within the spectral mask, as shown in Figure 1. The measurements shall be made using a 100kHz resolution bandwidth and a 30kHz video bandwidth.

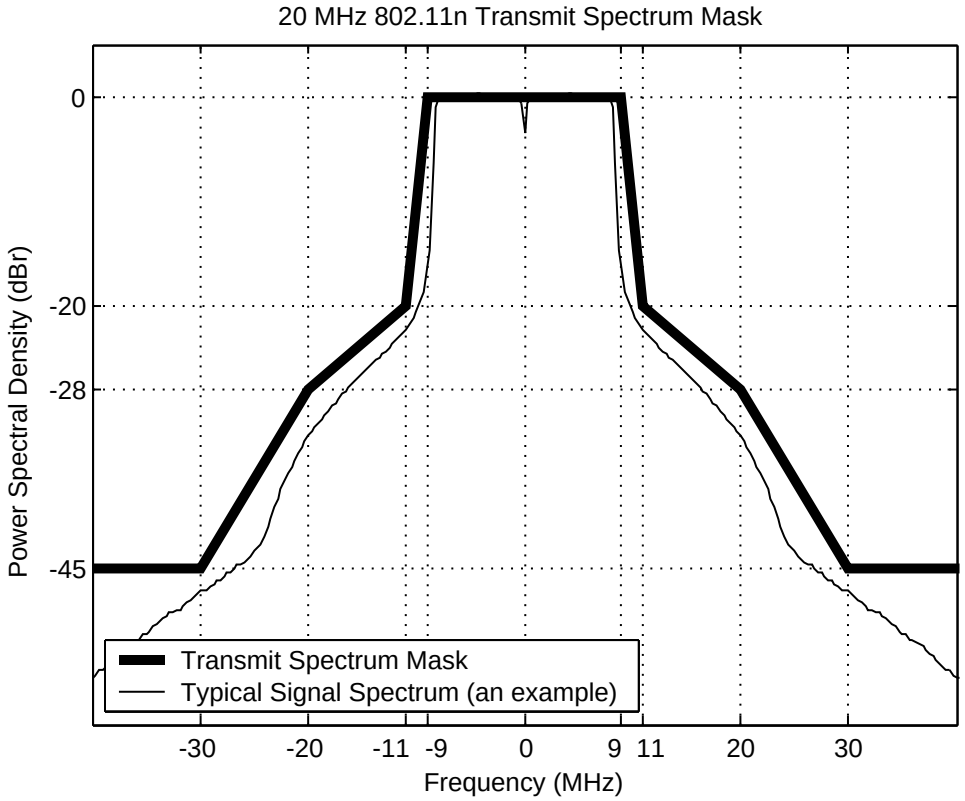



**Figure 45: Transmit Spectrum Mask for 20MHz channelization**

### 11.2.1.9.1.2 40MHz channel spacing

The transmitted spectrum shall have a 0dBr (dB relative to the maximum spectral density of the signal) bandwidth not exceeding 38MHz, -20dBr at 21 MHz frequency offset, and -45dBr at 60MHz frequency offset and above. The transmitted spectral density of the transmitted signal shall fall within the spectral mask, as shown in Figure 2. The measurements shall be made using a 100kHz resolution bandwidth and a 30kHz video bandwidth.

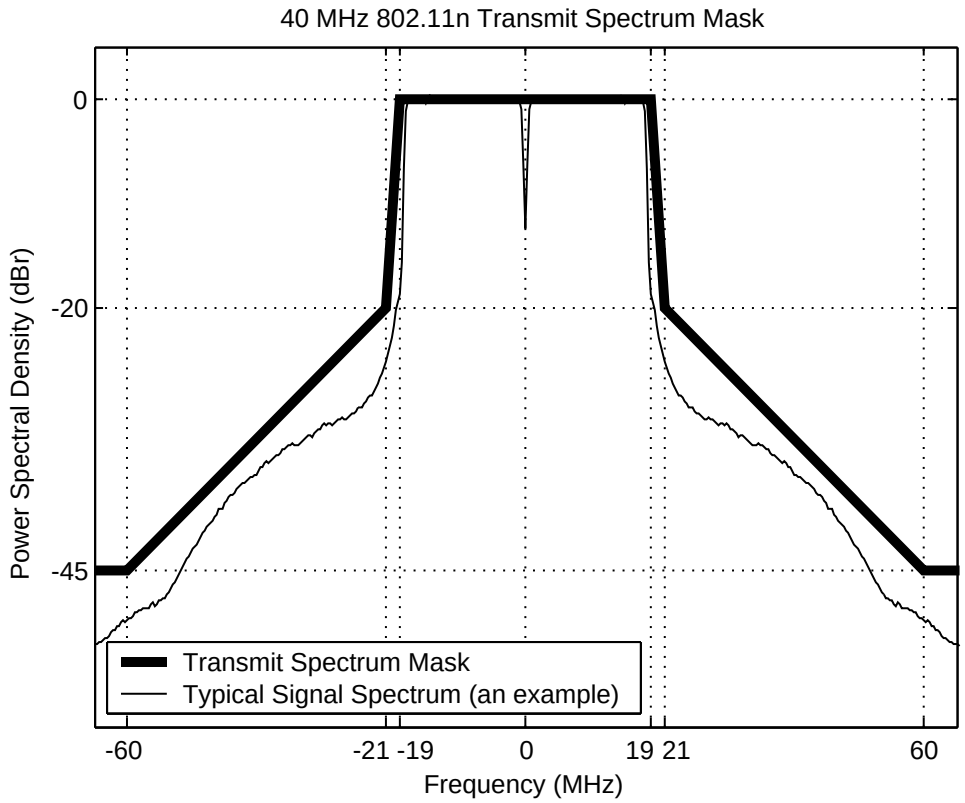



**Figure 46: Transmit spectrum mask for 40MHz channelization**

A HT device transmitting a 20MHz signal in a 40MHz BSS shall conform to the spectral mask shown in Figure 46.

### 11.2.2 Space Time Block Coding (Optional Mode)

#### 11.2.2.1 STBC PPDU format

The STBC PPDU format is identical to the Basic MIMO PPDU format (see section 11.2.1.1), with the added requirement that the DATA fields contain an even number of OFDM symbols.

#### 11.2.2.2 Space Time Block Coding of Modulation Symbols

When STBC encodes a single input stream of modulation symbols, the input modulation symbol in subcarrier $\ell$ in OFDM symbol $n$ is $s_\ell(n)$. For each sequential pair of input symbols in the input modulation symbol stream, the STBC processing generates two output symbol vectors as follows. Given two sequential input symbols $s_\ell(2k)$ and $s_\ell(2k+1)$, the STBC processing generates two sequential output symbol vectors $\mathbf{x}_\ell(2k)$ and $\mathbf{x}_\ell(2k+1)$ given by

$$\mathbf{x}_\ell(2k) = \begin{bmatrix} s_\ell(2k) \\ -s_\ell^*(2k+1) \end{bmatrix} \quad \text{and} \quad \mathbf{x}_\ell(2k+1) = \begin{bmatrix} s_\ell(2k+1) \\ s_\ell^*(2k) \end{bmatrix}.$$

The proposal also supports STBC encoding of two input streams of modulation symbols in parallel. In this case the two input streams can be expressed as a vector of modulation symbols,

$$\mathbf{s}_\ell(n) = \begin{bmatrix} s_\ell^0(n) \\ s_\ell^1(n) \end{bmatrix},$$

and the output of the STBC processing is

$$\mathbf{x}_\ell(2k) = \begin{bmatrix} s_\ell^0(2k) \\ -s_\ell^{0*}(2k+1) \\ s_\ell^1(2k) \\ -s_\ell^{1*}(2k+1) \end{bmatrix} \text{ and } \mathbf{x}_\ell(2k+1) = \begin{bmatrix} s_\ell^0(2k+1) \\ s_\ell^{0*}(2k) \\ s_\ell^1(2k+1) \\ s_\ell^{1*}(2k) \end{bmatrix}.$$

This processing takes place in all 52 data subcarriers of the 20 MHz OFDM symbol and all 108 data subcarriers of the 40 MHz OFDM symbol.

### 11.2.2.3 Antenna mapping of STBC encoded spatial streams

The STBC processing is applied only to the OFDM symbols in the HT-Data portion of the PPDU. The pilot subcarriers in the HT-Data portion are transmitted as they normally would be for either direct-mapped or spatial spreaded operation. This is illustrated below in Figure 47, which shows preamble and pilot insertion subsequent to the STBC encoding. A normal packet using STBC will include $N_{STS}$ HT-LTF symbols.

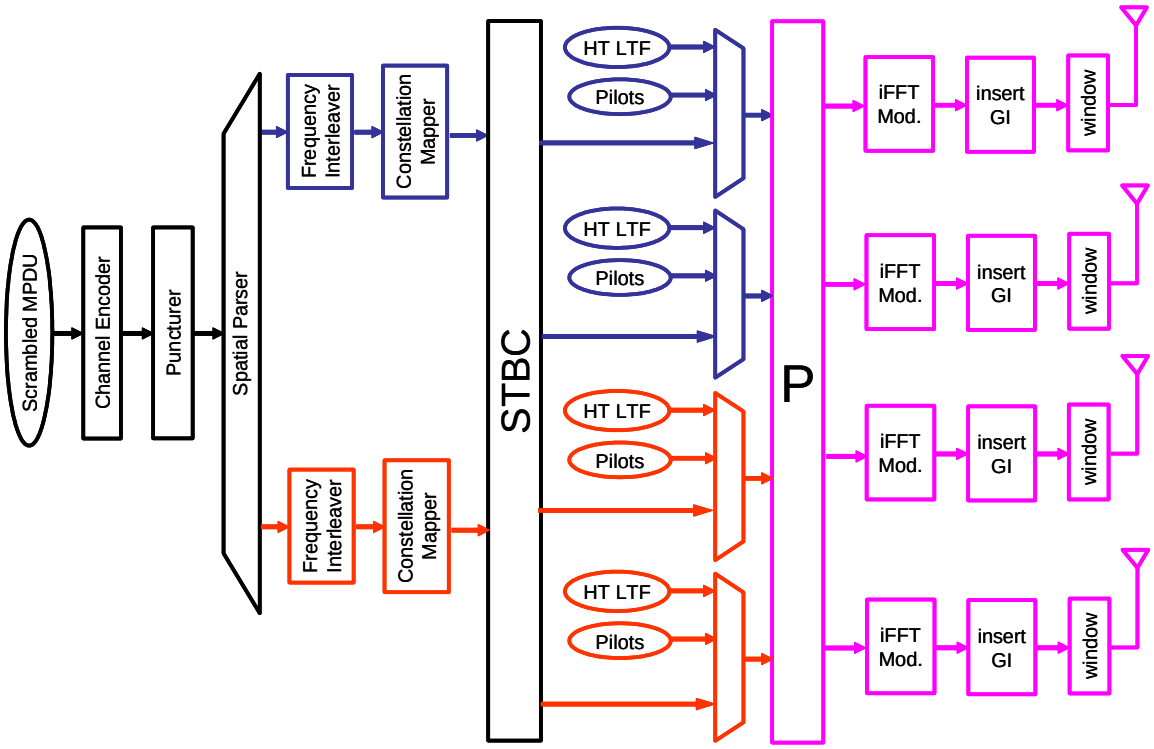



**Figure 47: Example of antenna mapping of STBC encoded spatial streams**

#### 11.2.2.4 HT-Short Training Field in STBC mode

HT-STF is identical to basic MIMO case (refer to section 11.2.1.5.3). The HT-STF is transmitted as it would be for normal direct mapped operation, when the STBC output is direct mapped to the transmit antennas, or as it would be for normal spatial spreading operation when the STBC output is applied to the transmit antennas through a spatial spreading **P** matrix.

#### 11.2.2.5 HT-Long Training Field in STBC mode

HT-LTFs are identical to the basic MIMO case (refer to section 11.2.1.5.4). The HT-LTF is transmitted as it would be for normal direct mapped operation, when the STBC output is direct mapped to the transmit antennas, or as it would be for normal spatial spreading operation when the STBC output is applied to the transmit antennas through a spatial spreading **P** matrix. A normal packet using STBC will include $N_{STS}$ HT-LTF symbols.

##### 11.2.2.5.1 MIMO Channel sounding

MIMO channel sounding in STBC mode is identical to that of basic MIMO. Sounding packets can be sent in STBC mode, in which case the number of HT-LTF symbols may be greater than $N_{STS}$.

#### 11.2.2.6 MCS field in STBC mode

MCS set for STBC is identical to that of basic MIMO, as described in section 11.2.1.6.2.2.

##### 11.2.2.6.1 Pad bits (PAD)

The length of the message is extended so that it becomes a multiple of the number of data bits per OFDM symbol for each data (spatial) stream. When operating in STBC mode, the length of the message is further extended so that the number of OFDM symbols is even. The number of Pad bits is dependent on how the bits are divided over the spatial streams.

#### 11.2.2.7 Puncturing of Coded Data in STBC mode

STBC uses the same puncturing pattern as the basic MIMO mode, described in 11.2.1.7.6.

#### 11.2.2.8 MCS set in STBC mode

MCS 0 through MCS 15, MCS 32, and MCS 33 through MCS 43 (see Table 17) may be used with STBC.

### 11.2.3 Transmit Beamforming (Optional Mode)

#### 11.2.3.1 Introduction

One method of improving the SNR at the receiver, for a given distance between stations, is to apply transmit beamforming. A basic requirement for transmit beamforming is the availability of channel state information (CSI). In our proposal, CSI is obtained by assuming channel reciprocity. The initiator sends a TRQ, which is a request for a sounding PPDU, to the intended recipient. The recipient may send a sounding packet back to the initiator, however this is optional. The initiator extracts the CSI from this packet, and uses the CSI to compute transmit steering vectors for the forward channel.

While support for the transmission and reception of extension LTFs is optional, the additional CSI that they allow a TxBF capable STA to obtain can significantly improve performance. It is recommended that the recipient of a TRQ should respond with a sounding PPDU, and that this PPDU should contain extension LTFs if $N\_STS \leq N\_TX$.

This successful application of this process depends on the presumption that the forward channel is reciprocal to the reverse channel. This presumption relies on calibrated RFs to compensate for imbalances between the gain and phase responses of the transmit and receive RF chains in a STA. Our proposal also includes a packet exchange sequence to enable calibration of RF chains at a STA.

While support for the calibration protocol is not mandatory, any STA that supports transmit beamforming should also implement support for calibration in order to ensure reliable reception of beamformed PPDUs that it transmits. A STA that does not support transmit beamforming does not need to implement calibration in order to ensure reliable reception of beamformed PPDUs that are directed to it.

#### 11.2.3.2 Motivation of MIMO-Beamforming (Informative)

Beamforming-MIMO can achieve higher throughput than basic MIMO at the same SNR, or conversely, higher range at the same data rate. The benefit of TX beamforming is most pronounced when the number of TX antennas is larger than the RX antennas, when multiple spatial streams are being transmitted. For e.g., a typical configuration involving TX beamforming could be either 3 or 4 antennas at the AP, and 2 antennas at the client. Hence, the client is kept low-cost, while the AP shoulders a higher cost burden.

#### 11.2.3.3 Description of BF-MIMO

##### 11.2.3.3.1 Beamformed PPDU

The transmitter may choose to use antenna beamforming in order to increase the antenna gain in the direction of an intended receiver. The beamforming process is represented mathematically as a linear transformation, mapping the streams of data to the transmit antennas.

Let *x* be the $N_{SS}$ dimensional vector of data, where each element of *x* is from one of the spatial streams of data. The beamforming transformation is represented by a $N_{TX}$ x $N_{SS}$ matrix, V. The beamforming operation, on a per subcarrier basis, is represented by,

$$y_{N_{TX} \times 1} = V_{N_{TX} \times N_{SS}} \cdot x_{N_{ss} \times 1} \quad (61)$$

The *y* vector is an $N_{TX}$ dimensional vector whose elements get mapped to the $N_{TX}$ antennas. The beamforming matrix V is applied to the HT-STF and HT-LTF training fields as well as the data. There are several methods for calculating V. One of them involves singular value decomposition (SVD) of the channel transfer matrix H.

It is optional for a device to be able to perform TX beamforming.

### 11.2.3.3.2 MIMO Channel sounding

#### 11.2.3.3.2.1 MIMO Channel sounding principles

MIMO channel measurement takes place in every PPDU as a result of transmitting the HT-LTFs as part of the PLCP preamble. At a minimum, the number of HT-LTFs transmitted must be equal to the number of spatial streams transmitted, and these must be transmitted using the same spatial steering transformation that is used for the HT-Data. This enables the computation of the spatial equalization at the receiver.

When the number of spatial streams, $N_{SS}$, is less than the number of transmit antennas, sending only $N_{SS}$ HT-LTFs does not allow the receiver to recover a full characterization of the MIMO channel, even though the resulting MIMO channel measurement is sufficient for receiving the HT-Data. However, there are several cases where it is desirable to obtain as full a characterization of the channel as possible, thus requiring the transmission of as many HT-LTFs as an STA is willing to send, subject to $N_{LTF} \le N_{TX}$. We refer to these cases of MIMO channel measurement as MIMO channel sounding, and the PPDUs carrying extension HT-LTFs should be sounding PPDUs, identified by the appropriate bit being set in HT-SIG.

##### *11.2.3.3.2.1.1 Sounding PPDU for calibration*

In the case of a bidirectional calibration exchange, two STAs exchange sounding PPDUs enabling the receiving STA to compute an estimate of the MIMO channel matrix, $\mathbf{H}^{(k)}$, for each subcarrier. In general, in an exchange of calibration messages, the number of spatial streams will be less than the number of transmit antennas, necessitating the use of segmented-LTFs. Particularly when a small number of spatial streams is used for transmiting HT-Data, it is therefore recommended that spatial spreading be used for the HT-Data portion of the PPDU, so that the spatial spreading transmit steering will also be used for the HT-LTFs.

##### *11.2.3.3.2.1.2 Sounding PPDU for channel quality assessment*

A MIMO channel with $N_{Tx}$ transmit antennas and $N_{Rx}$ receive antennas can support a maximum of $N_{SS,\max} = \min\left(N_{Tx}, N_{Rx}\right)$ spatial streams. In order for a receiving STA to obtain a channel quality assessment for all $N_{SS,\max}$ available spatial streams when using a transmit steering matrix $\mathbf{P}^{(k)}$, it needs an estimate of the effective channel $\mathbf{H}^{(k)}\mathbf{P}^{(k)}$, where $\mathbf{P}^{(k)}$ is in this case a $N_{Tx} \times N_{SS,\max}$ orthonormal steering matrix. This requires the transmitting STA to send $N_{SS,\max}$ HT-LTFs, using the tone interleaved columns of $\mathbf{P}^{(k)}$. If an STA supports the transmission of segmented-LTFs it can send a sounding PPDU containing $N_{SS,\max}$ HT-LTFs, comprising $N_{SS}$ data HT-LTFs and $N_{SS,\max} - N_{SS}$ extension HT-LTFs. If an STA does not support segmented-LTFs then a channel quality assessment can still be conducted, however the quality of the assessment will be reduced.

#### *11.2.3.3.2.1.3 Sounding PPDU for transmit steering computation*

In order to compute transmit steering vectors through either eigenvalue decomposition or singular value decomposition, a transmitting STA must in general have a good estimate of the channel matrix, $\mathbf{H}^{(k)}$, for each subcarrier of the channel over which it is transmitting. The STA computing transmit steering vectors can obtain this estimate if the STA to which it intends to transmit sends it a sounding PPDU that allows it to estimate $\mathbf{H}_R{}^{(k)} = \left(\mathbf{H}_F{}^{(k)}\right)^T$ (assuming channel reciprocity is in effect), where $\mathbf{H}_R{}^{(k)}$ is the reverse channel, which is the channel over which the HT-LTFs were transmitted, and $\mathbf{H}_F{}^{(k)}$ is the forward channel, which is the channel for which the transmit steering vectors are being computed. The format of the sounding PPDU may be either direct-mapped, spatially spread, or beamformed.

The description below assumes that the STAs support segmented-LTFs. If this is not the case, then an STA will not be able to send PPDUs containing $N_{Tx}$ HT-LTFs unless $N_{STS} = N_{TX}$. In this situation the calculated transmit steering vectors will be sub-optimal.

If the HT-LTF is transmitted in direct-mapped format, then it should contain $N_{Tx}$ HT-LTFs, and the receiver may then obtain a direct estimate of the channel matrices $\mathbf{H}_R{}^{(k)}$ from which it may compute an SVD or the eigenvalue decomposition of $\mathbf{R}_F{}^{(k)} = \left(\mathbf{H}_F{}^{(k)}\right)^H \mathbf{H}_F{}^{(k)} = \left(\mathbf{H}_R{}^{(k)}\right)^* \left(\mathbf{H}_R{}^{(k)}\right)^T$.

If the HT-LTF is transmitted in spatially spread mode, then it should also contain $N_{Tx}$ HT-LTFs. The receiver may obtain a direct estimate of $\mathbf{H}_F{}^{(k)}$ by right multiplying its estimate of the effective channel, $\mathbf{H}_R{}^{(k)}\mathbf{P}^{(k)}$, by $\left(\mathbf{P}^{(k)}\right)^H$. Alternately, the receiver can compute an estimate of $\mathbf{R}_F{}^{(k)}$ directly, since $\left(\mathbf{H}_R{}^{(k)}\mathbf{P}^{(k)}\right)^* \bullet \left(\mathbf{H}_R{}^{(k)}\mathbf{P}^{(k)}\right)^T = \left(\mathbf{H}_R{}^{(k)}\right)^* \bullet \left(\mathbf{H}_R{}^{(k)}\right)^T = \mathbf{R}_F{}^{(k)}$, since $\mathbf{P}^{(k)}$ is in this case an $N_{Tx,R} \times N_{Tx,R}$ unitary matrix, where the notation $N_{Tx,R}$ refers to the number of transmit antennas on the reverse link.

Finally, if the HT-LTF is transmitted in beamforming mode, so that $\mathbf{P}_R{}^{(k)} = \mathbf{V}_R{}^{(k)}$ is the $N_{Tx,R} \times N_{SS,\max}$ matrix of right singular vectors of the reverse channel matrix $\mathbf{H}_R{}^{(k)}$, then the PPDU only needs to contain $N_{SS,\max} = \min(N_{Tx}, N_{Rx})$ HT-LTFs. The receiver obtains from this an estimate of the $N_{Rx,R} \times N_{SS,\max}$ equivalent channel matrix $\mathbf{H}_R{}^{(k)}\mathbf{V}_R{}^{(k)}$. The receiver can compute from this an estimate of the sample covariance matrix as $\mathbf{R}_F{}^{(k)} = \left(\mathbf{H}_R{}^{(k)}\mathbf{V}_R{}^{(k)}\right)^* \bullet \left(\mathbf{H}_R{}^{(k)}\mathbf{V}_R{}^{(k)}\right)^T = \left(\mathbf{H}_R{}^{(k)}\right)^* \bullet \left(\mathbf{H}_R{}^{(k)}\right)^T$. Even though $\mathbf{V}_R{}^{(k)}$ is not in general unitary (i.e. it is not, in general, square, since the channel is not symmetrical), this equality holds since $\mathbf{H}_R{}^{(k)}\mathbf{V}_R{}^{(k)} = \mathbf{U}_R{}^{(k)}\mathbf{\Sigma}_R{}^{(k)}$ and $\left(\mathbf{U}_R{}^{(k)}\mathbf{\Sigma}_R{}^{(k)}\right)^* \bullet \left(\mathbf{U}_R{}^{(k)}\mathbf{\Sigma}_R{}^{(k)}\right)^T = \mathbf{R}_F{}^{(k)}$.

#### 11.2.3.3.3 Calculation of beamforming matrix using SVD (Informative)

Once a STA has a proper estimate of the channel, then it can use that channel estimate to select a recommended beamforming matrix. There are a variety of techniques that can be used to select the beamforming matrix. One method of selecting the beamforming matrix is by calculating the singular value decomposition of the channel from this STA to the intended receiving STA. Let H be the channel matrix from the transmitter to the receiver. The SVD of the channel matrix is given by,

$$H = UDV^H \quad (62)$$

Both U and V are unitary matrices and D is a diagonal matrix of singular values. The transmitter selects the dominant $N_{SS}$ singular values and then sends only $N_{SS}$ spatial streams. The first $N_{SS}$ rows of the V matrix are used as the beamforming matrix, mapping the spatial streams of data to the TX antennas. This same beamforming matrix is applied to the HT-LTFs, except for one difference. The number of HT-LTFs is equal to Nss, and each transmission of HT-LTF is shaped by one singular vector.

##### 11.2.3.3.3.1 Channel Reciprocity

To determine the beamforming matrix, the transmitter needs to know the channel from the transmitter to the intended receiver. That channel is estimated using implicit feedback and channel reciprocity. The transmitter uses the previous sounding PPDU sent from the intended receiver to estimate the channel from the intended receiver to the transmitter. In order to estimate the channel from the receiver to the transmitter, it uses the principle of reciprocity. The principle of reciprocity is that the downlink channel (the channel from the AP to the STA) is the transpose of the uplink channel (the channel from the STA to the AP). Letting $H_D$ be the downlink channel and $H_U$ be the uplink channel, reciprocity is,

$$H_U = H_D^T \quad (63)$$

#### 11.2.3.3.4 Calibration Methodology (Informative)

##### 11.2.3.3.4.1 Calibration Overview

In order for a transmitting 802.11n STA to transmit to another 802.11n STA using beamforming, it must have a good characterization of the channel that it is transmitting over so that it can choose the correct transmit steering vectors. The STA obtains this characterization by observing the HT-LTF transmitted by the STA to which it is transmitting. This approach is based on the reciprocal property of the over-the-air (antenna-to-antenna) TDD channel, and reciprocity must be in effect for the approach to provide the best rate and range performance available.

Although the Basic MIMO and Walsh-CDD modes do not require it, calibration neither improves nor degrades performance with those modes. Thus, STAs may calibrate upon entering a BSS in which the AP is transmit beamforming capable, or at any other time, and if they are capable of transmitting in beamforming mode, the resulting calibration correction vectors may be employed for all transmission modes and on all frames. STAs that are not capable of transmitting in beamforming mode may also perform the calibration procedure with any transmit beamforming capable AP with which they associate, in order to enable that AP to transmit to them in beamforming mode.

Throughout the discussion of beamforming transmission in this document, it is assumed that communication in beamforming mode takes place between devices that have been calibrated.

The following section describes the calibration procedure for a communication link, where the two communicating STAs are referred to as STA A and STA B. Note: calibration as described here is only applicable to STAs with two or more antennas, where both transmission and reception are possible on each antenna.

#### 11.2.3.3.4.2 Calibration procedure for Tx Corrections

In order to consider the operation of a TDD MIMO OFDM system in conjunction with beamforming techniques through transmit and receive steering, it is necessary to first consider the need to ensure that the over-the-air reciprocity of the TDD channel is preserved in the observed, baseband-to-baseband TDD channel. Reciprocity is critical in the functioning of these systems because it provides efficient means for a STA to learn the transfer function of the channel over which it will transmit.

In order to ensure that the baseband-to-baseband channel seen by the spatial processing engines is reciprocal, it is necessary to calibrate the STA radio to correct the differences in phase and amplitude response in the transmit and receive chains.

The reciprocity of the over-the-air TDD MIMO channel can be expressed as a transpose relationship between the channel response matrices associated with forward and reverse channels between two STAs. Consider, for example, STA A and STA B, where we will refer to the channel over which STA A transmits as the forward link, and the channel over which STA B transmits as the reverse link. Thus we will define the following two gain matrices for the over-the-air channels (the over-the-air channel is the complex baseband channel that would be realized if the transmitter and receiver responses have ideal constant gain and zero phase across the channel bandwidth):

- $\mathbf{H}_{A\to B}(\ell)$: forward link gain matrix for subcarrier $\ell$
- $\mathbf{H}_{B\to A}(\ell)$: reverse link gain matrix for subcarrier $\ell$,

The reciprocal relationship between these two channels is expressed as:

$$\mathbf{H}_{B\to A}(\ell) = \mathbf{H}^{t}_{A\to B}(\ell).$$

The observed channels, however, are effected by the amplitude and phase responses of the transmit and receive chains. Assuming good isolation, these can be expressed as diagonal matrices with complex valued diagonal entries, of the form $\mathbf{C}_{A,Tx}(\ell)$. The relationship between the observed channels, $\tilde{\mathbf{H}}_{A\to B}(\ell)$ and $\tilde{\mathbf{H}}_{B\to A}(\ell)$, and the over-the-air channel is

$$\tilde{\mathbf{H}}_{A\to B}(\ell) = \mathbf{C}_{B,Rx}(\ell)\mathbf{H}_{A\to B}(\ell)\mathbf{C}_{A,Tx}(\ell), \text{ and}$$

$$\tilde{\mathbf{H}}_{B\to A}(\ell) = \mathbf{C}_{A,Rx}(\ell)\mathbf{H}_{B\to A}(\ell)\mathbf{C}_{B,Tx}(\ell).$$

The resulting observed channels are not, in general, reciprocal. However, through a simple channel sounding procedure that involves an exchange of training sequences, correction vectors

can be calculated that are applied on transmit to restore reciprocity. The resulting calibration is quite stable and needs to be updated infrequently, typically on association.

The object of the procedure is to compute correction vectors $\mathbf{K}_A(\ell)$ and $\mathbf{K}_B(\ell)$ that restore reciprocity such that

$$\tilde{\mathbf{H}}_{A\to B}(\ell)\mathbf{K}_A(\ell) = \left[\tilde{\mathbf{H}}_{B\to A}(\ell)\mathbf{K}_B(\ell)\right]^t.$$

The correction vectors are applied on transmit in such a way that each element in the correction vector scales the transmit vector element associated with a specific antenna. Given a modulation symbol vector, $\mathbf{s}_A(\ell)$, in subcarrier $\ell$ at STA A, and beamforming matrix $\mathbf{V}(\ell)$, then the transmitted vector in subcarrier $\ell$ is given by $\mathbf{x}(\ell) = \mathbf{K}_A(\ell)\mathbf{V}_A(\ell)\mathbf{s}_A(\ell)$.

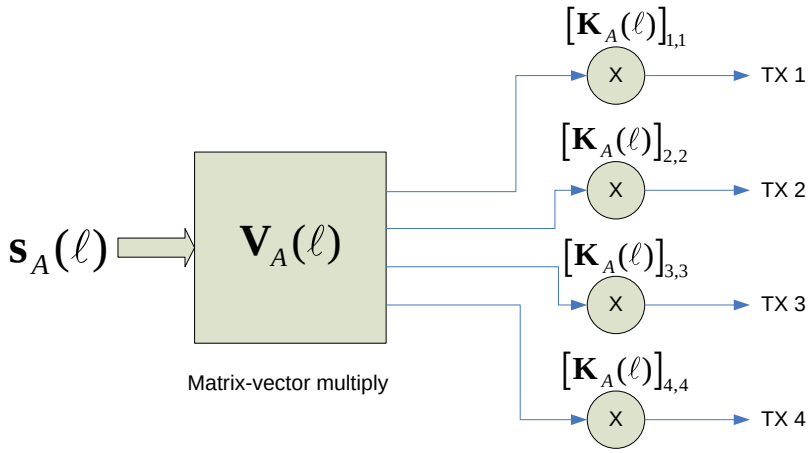



**Figure 48: Application of calibration correction vector on Tx**

Correction vectors that will satisfy this relationship are given by:

$$\mathbf{K}_A(\ell) = \left(\mathbf{C}_{A,Tx}(\ell)\right)^{-1}\mathbf{C}^t_{A,Rx}(\ell), \text{ and}$$

$$\mathbf{K}_B(\ell) = \left(\mathbf{C}_{B,Tx}(\ell)\right)^{-1}\mathbf{C}^t_{B,Rx}(\ell).$$

Calibration can also be applied on receive in a similar manner. Tx calibration only is addressed here.

For STAs that support only 20 MHz operation, calibration must be performed for subcarriers with indices between -26 and 26, except for the subcarrier with index 0. For STAs supporting both 20 MHz and 40 MHz operation, calibration must be performed for subcarriers with indices between -58 and 58, except for the subcarriers with indices -1, 0, and 1.

The calibration procedure is as follows:

1. STA A transmits a Calibration Training message, initiating the calibration procedure.

2. STA B transmits a Calibration Training message, which includes the HT-LTF that allows a receiving STA A to estimate the channel matrices $\mathbf{H}_{B\to A}(\ell)$.

3. STA A transmits a Calibration Training message, which includes the HT-LTF that allows STA B to estimate the channel matrices $\mathbf{H}_{A\to B}(\ell)$.

    a. The previous two steps must occur over a sufficiently short time interval that the channel does not change over the interval.

4. STA A computes an estimate of $\mathbf{H}_{B\to A}(\ell)$ based on the received HT-LTF.

5. STA B computes an estimate of $\mathbf{H}_{A\to B}(\ell)$ based on the received HT-LTF.

6. STA B sends the quantized estimates of $\mathbf{H}_{A\to B}(\ell)$ to STA A using the Calibration Measurement Message that contains the Channel Measurement Report.

7. STA A uses the estimates of $\mathbf{H}_{B\to A}(\ell)$ and $\mathbf{H}_{A\to B}(\ell)$ to compute the correction vectors $\mathbf{K}_A(\ell)$ and $\mathbf{K}_B(\ell)$.

8. STA A sends the quantized correction vectors $\mathbf{K}_B(\ell)$ to STA B using the Calibration Correction Vector Message that contains the Correction Vector element.

9. STA A and STA B now have correction vectors and are considered to be calibrated.

Once a STA has completed the calibration procedure, the correction vectors, $\mathbf{K}(\ell)$, are assumed to be available at the STA's transmitter, and are incorporated into the transmit spatial processing procedure for all subsequent communications.

This procedure needs to be performed only once for any STA that will participate in a beamforming exchange with another STA. For example, once an AP performs this procedure with one STA, it is calibrated and may participate in a beamforming exchange with any other calibrated STA. However, in many networks, the AP will be the primary agent for calibrating client STAs. Thus a typical AP will participate in many of these calibration procedures.

#### 11.2.3.3.4.3 Calibration for Beamforming Rx-only STAs

STAs that have no transmit beamforming capabilities, but that still are capable of receiving beamforming transmissions, are referred to as Rx-only STAs. Such STAs may participate in a calibration procedure similar to that described above. However, it is not necessary for such a STA to have calibrated RFs in order to reliably receive PPDUs that are transmitted to it using Tx beamforming.

#### 11.2.3.3.4.4 Calibration Processing

The MIMO calibration training sequence consists of $N_{\mathrm{CAL}} = N_{Tx}$ HT-LTFs. The HT-LTF for the first stream consists of an 800 ns guard interval followed by two periods of a 3.2 μs training symbol sequence, for a total duration of 7.2 μs. The HT-LTF for the second, third, and fourth stream, if exist, consists of an 800 ns guard interval followed by one periods of a 3.2 μs training

symbol sequence, for a total duration of 4.0 µs. For details on the format of the HT-LTF, see section 11.2.1.5.4.

#### 11.2.3.3.5 HT-Short Training Field in BF-MIMO mode

HT-STF is identical to basic MIMO case (refer to section 11.2.1.5.3). The HT-STF undergoes the same spatial steering as the DATA.

#### 11.2.3.3.6 HT-Long Training Field in BF-MIMO mode

HT-LTFs are identical to the basic MIMO case (refer to section 11.2.1.5.4). The HT-LTF undergoes the same spatial steering as the DATA.

#### 11.2.3.3.7 MCS field in BF-MIMO mode

MCS set for BF-MIMO is identical to that of basic MIMO, as described in section 11.2.1.6.2.2.

#### 11.2.3.3.8 Antenna streams / Transmitter architecture in BF-MIMO mode

The only difference in the transmitter architecture with respect to the basic MIMO mode is the introduction of the spatial steering matrix, as shown in Figure 49:

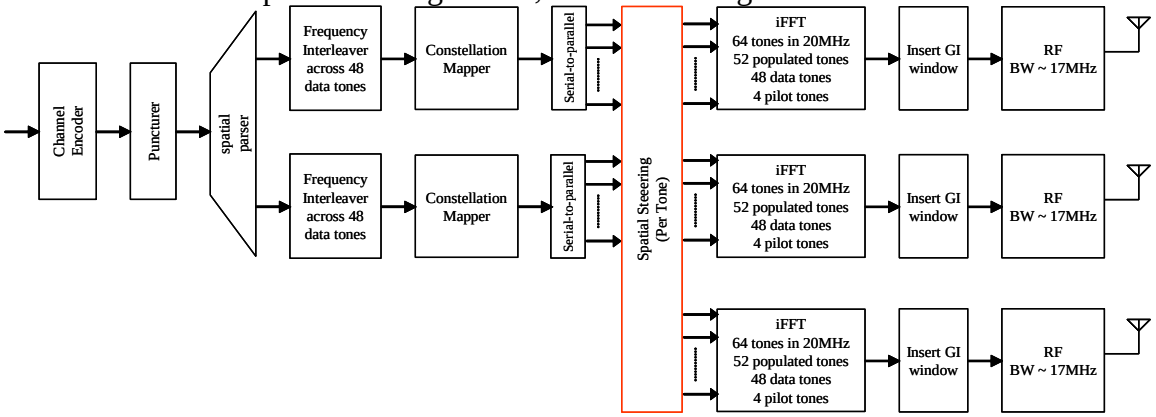



**Figure 49: Transmitter architecture for TX Beamforming for $N_{ss}$=2,and $N_{TX}$ = 3**

#### 11.2.3.3.9 Puncturing of Coded Data in BF-MIMO mode

TX Beamforming uses the same puncturing pattern as the basic MIMO mode, described in 11.2.1.7.6.

#### 11.2.3.3.10 MCS set in BF-MIMO mode

Any MCS (see Table 17) in the mandatory MCS set or the optional MCS set may be used in BF-MIMO. A station intending to transmit using any optional MCS (those with indices above 15) must establish support of the optional MCS at the receiving STA.

#### 11.2.3.3.11 Power Loading of spatial streams in BF-MIMO

All spatial streams in the BF-MIMO mode are transmitted at the same power level.

### 11.2.4 Low-Density Parity-Check Coding (Optional Mode)

Optional Low-Density Parity-Check (LDPC) coding may be used with all MCS 0-126 from Table 17. When encoding specified in this clause is applied, convolutional encoder and its associated puncturing and padding shall not be used.

#### 11.2.4.1 Code Rates and Codeword Lengths

Code rate (R) of the LDPC code may be selected from the set of code rates defined for mandatory convolutional codes (1/2, 2/3, 3/4 and 5/6). One of three codeword sizes is used to encode packets. Codeword size in bits, N, may be 576, 1152, or 1728.

#### 11.2.4.2 PPDU Encoding using LDPC Codes

This subclause, which specifies the LDPC encoding, replaces corresponding procedure defined for mandatory convolutional codes.

LDPC codes are block codes that are specified by the parity check matrix of size MxN , which defines an LDPC block code (N,K), where K is the information block size in bits, N is the length of the codeword, and M is the number of parity check bits, M=N-K. Code rate is defined as R=K/N. The general characteristic of an LDPC parity check matrix is a low density of non-zero elements (1's in this case), which allows utilization of efficient decoding algorithms. LDPC parity check matrix is designed in a way that enables simple encoding as well. It can be represented in the following form:

$$\mathbf{H} = [\mathbf{H}^d \mid \mathbf{H}^p]$$

$\mathbf{H}^d$ is an MxK matrix and corresponds to the "data" bits of the codeword. The design of this matrix ensures high coding gain. $\mathbf{H}^p$ is an MxM modified "dual diagonal" matrix, which corresponds to the "parity" bits of the codeword. LDPC codes applied here are systematic and canonic block codes. Codewords have the following structure:

$$\mathbf{c} = \begin{bmatrix} \mathbf{d} \\ \mathbf{p} \end{bmatrix}$$

where $\mathbf{d} = [d_0, d_1, ..., d_{K-1}]^T$ is the block of (uncoded) data bits and $\mathbf{p} = [p_0, p_1, ..., p_{M-1}]^T$ are the parity bits. A codeword is any binary N-vector **c** that satisfies:

$$\mathbf{Hc} = \mathbf{H}^d\mathbf{d} + \mathbf{H}^p\mathbf{p} = \mathbf{0}.$$

Since the information packet size may not in general be a multiple of number of information bits per codeword, procedure for encoding is defined in this subclause.
Based on the MCS, following two parameters are derived first:

$N_{CBPS} = N_{SD} \times \sum_{i_{ss}=1}^{N_{ss}} N_{BPSC\_i_{ss}}$ , number of coded bits per OFDM symbol

$N_{DBPS} = N_{CBPS} \times R$, number of information bits per OFDM symbol

where: $N_{BPSC\_i_{ss}}$ is the number of coded bits per sub-carrier in $i_{ss}$ spatial stream, $N_{SD}$ is the number of data sub-carriers, and $N_{SS}$ is the number of spatial streams.

Both shortening (padding the payload with zeros before encoding and removing those extra zero bits from transmission), and puncturing (reduction of number of bits of the codeword prior to transmission) may be applied in order to ensure minimum overhead without degrading performance.

HTLENGTH parameter in HT_SIGNAL field is calculated based on the value of two TXVECTOR array parameters: A-MPDU and HT_LENGTH, as follows:

```
if A-MPDU == 0
        HTLENGTH = HT_LENGTH
else
        if(NDBPS <= 234)
                NOFDM = ceiling (HT_LENGTH × 8/ NDBPS) +1
        else
                NCWORDS_MIN = ceiling (HT_LENGTH × 8/(1728 × R))
                NSHORTENING = NCWORDS_MIN × 1728 × R – HT_LENGTH × 8
                NOFDM = ceiling ((NCWORDS_MIN × 1728 – NSHORTENING)/ NCBPS)
        end
        HTLENGTH = 110000000000b + NOFDM
end
```

This means that in the non-A-MPDU mode the HTLENGTH field specifies the number of octets in the PSDU, whereas in the A-MPDU mode, the HTLENGTH field (bits 0 through 9) specifies the number of transmitted OFDM symbols in the data mode.

The encoding procedure uses the following parameters as input:

HTLENGTH – containing the information as described in the previous paragraph
MCS – modulation type and code rate set

The procedure for encoding consists of the following steps:

a) Based on the contents of HTLENGTH, compute the following parameters:

```
if (the two MSBs of  HTLENGTH are NOT 11b)     // non-A-MPDU mode

        NINFO_BITS = HTLENGTH×8
        NOFDM_MIN = ceiling (NINFO_BITS / NDBPS)
        NCWORDS = ceiling (NINFO_BITS / (1728 × R))
        n1 = ceiling (((NINFO_BITS /R)/ NCWORDS)/576)
        n2 = floor ((NCBPS × NOFDM_MIN – NINFO_BITS) / (576 × (1-R) × NCWORDS))
        N = max(n1, min(3,n2)) × 576
        K = N × R, M = N - K
else                                            // A-MPDU mode
```

```
        if (NDBPS <= 234)
                NOFDM = HTLENGTH (bits 0 through 9)
                NINFO_BITS = (NOFDM – 1) × NDBPS
                NCWORDS = ceiling (NINFO_BITS / (1728 × R))
                n1 = ceiling (((NINFO_BITS /R)/ NCWORDS)/576)
                n2 = floor ((NCBPS × NOFDM – NINFO_BITS)/(576 × (1-R) × NCWORDS))
                N = max(n1, min(3,n2)) × 576
                K = N × R, M = N - K
        else
                N = 1728, K = N × R, M = N - K
                if (rem (NOFDM × NCBPS, N) > M)
                        NCWORDS = ceiling (NOFDM × NCBPS / N)
                else
                        NCWORDS = floor (NOFDM × NCBPS / N)
                end
                NINFO_BITS = min (NOFDM × NDBPS, NOFDM × NCBPS – NCWORDS×M,
                        NCWORDS × K)
        end
end
```

b) In non-A-MPDU mode, extra OFDM symbols may be added to guarantee performance of punctured LDPC code. The algorithm below determines the optimum number of OFDM symbols, $N_{OFDM}$ based on following performance parameters:

- Shortening to puncturing ratio, defined as $SP_{RATIO} = (1\text{-}R)/R \times Ns/Np$, where Ns is number of shortened bits, and Np is number of punctured bits for a transmission of current PSDU. Minimum shortening to puncturing ratio is set to $SP_{RATIO\_MIN} = 1.2$
- Maximum number of extra OFDM symbols allowed is set to $N_{OFDM\_EXTRA\_MAX} = 2$

```
        NPARITY_BITS = ceiling (NCWORDS × M - (1/ SPRATIO_MIN) × ((1-R)/R) ×
                (NCWORDS × K – NINFO_BITS))
        NOFDM = min (ceiling (NINFO_BITS / NDBPS) + NOFDM_EXTRA_MAX,
                ceiling ((NPARITY_BITS + NINFO_BITS)/ NCBPS));
```

c) For each of the codewords of length N determine amount of the information bits to encode, $K_1 \leq K$, as well as the number of parity check bits to be transmitted, $M_1 \leq M$. This, in turn, determines by how many bits to shorten the information portion of the codeword $N_{SHORTEN\_CW}$, as well as by how many bits to puncture a codeword, $N_{PUNCTURE\_CW}$. In some cases it may be required that the last codeword has different number of data and parity bits, $K_{1\_LAST}$ and $M_{1\_LAST}$, respectively, (and consequently $N_{SHORTEN\_CW\_LAST}$ and $N_{PUNCTURE\_CW\_LAST}$) than the other codewords.
The calculations below also ensure that the last codeword may only be shortened more than others, and punctured less than others.

```
        K1 = ceiling (NINFO_BITS /NCWORDS)
        NPARITY_BITS = min (NCWORDS × M, NOFDM × NCBPS - NINFO_BITS)
        M1 = min (M, floor (NPARITY_BITS / NCWORDS)
```

$K_{1\_LAST} = N_{INFO\_BITS} - K_1 \times (N_{CWORDS} - 1)$

$M_{1\_LAST} = \min(M, N_{PARITY\_BITS} - M_1 \times (N_{CWORDS} - 1))$

$N_{SHORTEN\_CW} = K - K_1$

$N_{SHORTEN\_CW\_LAST} = K - K_{1\_LAST}$

$N_{PUNCTURE\_CW} = M - M_1$

$N_{PUNCTURE\_CW\_LAST} = M - M_{1\_LAST}$

d) For A-MPDU mode only, calculate information bits padding, $N_{PADDING\_INFO}$.

The number of zero bits, $N_{PADDING\_INFO}$, concatenated to the information bits and passed through the scrambler is calculated the following way:

$N_{PADDING\_INFO} = N_{INFO\_BITS} - HT\_LENGTH \times 8$

e) Last OFDM symbol padding field parameter computation

If the total number of coded bits doesn't fit integer number of OFDM symbols, then additional padding (scrambled zeros) bits are added to the last OFDM symbol. Number of those bits, $N_{PAD\_OFDM\_LAST}$, is computed as follows:

$N_{PAD\_OFDM\_LAST} = N_{OFDM} \times N_{CBPS} - (N_{INFO\_BITS} + M_1 \times (N_{CWORDS} - 1) + M_{1\_LAST})$

f) LDPC encoding

Generate all $N_{CWORDS}$ codewords by applying any of the encoding methods, such that $\mathbf{Hc}_i = \mathbf{0}$, where i=0, 1, …, $N_{CWORDS}$-1 with shortening and puncturing as necessary. **H** is the parity check matrix for the selected codeword size and code rate. Only one **H** matrix is used for the entire packet. The information vector for the i-th codeword to be encoded is formed by concatenating $K_1$ scrambled bits, which include information bits and optional $N_{PADDING\_INFO}$ zeros - (denoted as z's below, last codeword, A-MPDU mode only), and $N_{SHORTEN\_CW} = K - K_1$ zeros:

$$\mathbf{d}^i = [\underbrace{d^i_0, d^i_1, ..., d^i_{K_1-1}}_{K}, \overbrace{0,0,...,0}^{N_{SHORTEN\_CW}}]^T \qquad \text{// non- A-MPDU mode}$$

$$\mathbf{d}^i = [\underbrace{d^i_0, d^i_1, ..., d^i_n, \overbrace{z^i_{n+1}, z^i_{n+2}, ..., z^i_{K_{1\_LAST}-1}}^{N_{PADDING\_INFO}}, \overbrace{0,0,...,0}^{N_{SHORTEN\_CW}}}_{K}]^T \qquad \text{// A-MPDU mode, last codeword}$$

After the encoding, obtained codeword is punctured (if necessary) by removing the last $N_{PUNCTURE\_CW}$ bits:

*// non- A-MPDU mode*

$$\mathbf{c}^i = [\underbrace{d^i_0, d^i_1, ..., d^i_{K_1-1}, \overbrace{0,0,...,0}^{N_{SHORTEN\_CW}}}_{K}, \underbrace{p^i_0, p^i_1, ..., p^i_{M_1-1}, \overbrace{p^i_{M_1}, p^i_{M_1+1}, ..., p^i_{M-1}}^{N_{PUNCTURE\_CW}}}_{M}]^T$$

*// A-MPDU mode, last codeword*

$$\mathbf{c}^i = [\underbrace{d^i_0, d^i_1, ..., d^i_n, \overbrace{z^i_{n+1}, z^i_{n+2}, ..., z^i_{K_{1\_LAST}-1}}^{N_{PADDING\_INFO}}, \overbrace{0,0,...,0}^{N_{SHORTEN\_CW}}}_{K}, \underbrace{p^i_0, p^i_1, ..., p^i_{M_1-1}, \overbrace{p^i_{M_1}, p^i_{M_1+1}, ..., p^i_{M-1}}^{N_{PUNCTURE\_CW}}}_{M}]^T$$

Shortened and punctured bits are not transmitted over the air. Rather, a concatenation of $K_1$ data bits and $M_1$ parity bits is transmitted only:

*// non- A-MPDU mode*

$$\mathbf{c}^i_{transmit} = [\underbrace{d^i_0, d^i_1, ..., d^i_{K_1-1}}_{K_1}, \underbrace{p^i_0, p^i_1, ..., p^i_{M_1-1}}_{M_1}]^T$$

*// A-MPDU mode, last codeword*

$$\mathbf{c}^i_{transmit} = [\underbrace{d^i_0, d^i_1, ..., d^i_n, z^i_{n+1}, z^i_{n+2}, ..., z^i_{K_{1\_LAST}-1}}_{K_{1\_LAST}}, \underbrace{p^i_0, p^i_1, ..., p^i_{M_1-1}}_{M_{1\_LAST}}]^T$$

g) Codeword and the last OFDM symbol padding field concatenation

Concatenate $N_{CWORDS}$ codewords and $N_{PAD\_OFDM\_LAST}$ padding bits (denoted as q's below) to form a vector of bits to be transmitted:

*// non- A-MPDU mode*

$$\mathbf{c}_{transmit} = [d^0_0, ..., d^0_{K_1-1}, p^0_0, ..., p^0_{M_1-1}, ....., d^{N_{CWORDS}-1}_0, ..., d^{N_{CWORDS}-1}_{K_{1\_LAST}-1}, p^{N_{CWORDS}-1}_0, ..., p^{N_{CWORDS}-1}_{M_{1\_LAST}-1}, q_0, ..., q_{N_{PAD\_OFDM\_LAST}-1}]^T$$

*// A-MPDU mode*

$$\mathbf{c}_{transmit} = [d^0_0, ..., d^0_{K_1-1}, p^0_0, ..., p^0_{M_1-1}, ....., d^{N_{CWORDS}-1}_0, ..., z^{N_{CWORDS}-1}_{K_{1\_LAST}-1}, p^{N_{CWORDS}-1}_0, ..., p^{N_{CWORDS}-1}_{M_{1\_LAST}-1}, q_0, ..., q_{N_{PAD\_OFDM\_LAST}-1}]^T$$

Bit $d^0_0$ is transmitted first.

### 11.2.4.3 Parity Check Matrices

Parity check matrices **H** used in Step c) of the encoding procedure, described in sub-clause 11.2.4.2, are derived from one of the "base" parity check matrices, $\mathbf{H_b}$, specified below. One base matrix is defined per code rate. Size of a base parity check matrix is denoted as $M_b \times N_b$. $N_b$, the number of columns in the base matrix, is fixed for all code rates, $N_b$=24. $M_b$, the number of rows in the base matrix, depends on the code rate as follows: $M_b = N_b(1-R)$. Parity check matrix **H** of size M×N is generated by expanding the base matrix for the selected rate, $\mathbf{H_b}$, z-times: $z=N/N_b=M/M_b$. The expansion operation is defined by element values of the base matrix. Each non-negative base matrix element, s, is replaced by a z×z identity matrix, $\mathbf{I}_z$, cyclically shifted to the right $s'=s_{mod(z)}$ times. Each negative number (-1) in the base matrix is replaced by a z×z zero matrix, $\mathbf{0}_{zxz}$. For the codeword of size 576 bits, z = 24, for codeword of size 1152 bits, z = 48, and for the codeword of size 1728 bits, z = 72.

Base matrices specification

Rate 1/2: $M_b \times N_b = 12 \times 24$

```
 0  0 -1  0 -1  0 -1 -1 -1  0 -1 -1  1  0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
29 -1  0 26 -1 -1  0 -1  0 -1 -1 -1 -1  0  0 -1 -1 -1 -1 -1 -1 -1 -1 -1
```

```
-1 -1 -1 21  0 -1 17 -1 -1 38 -1  0 -1 -1  0  0 -1 -1 -1 -1 -1 -1 -1 -1
43 -1 -1 30 -1 -1 -1  0 -1 41  0 -1 -1 -1 -1  0  0 -1 -1 -1 -1 -1 -1 -1
 5 -1  1 -1 -1 20 35 -1 -1  2 -1 -1 -1 -1 -1 -1  0  0 -1 -1 -1 -1 -1 -1
-1 46 -1 -1 -1 -1 22 -1 40  8 -1 -1  0 -1 -1 -1 -1  0  0 -1 -1 -1 -1 -1
-1 -1 -1  9 -1 -1 18 13 -1 35 -1 27 -1 -1 -1 -1 -1 -1  0  0 -1 -1 -1 -1
 2 -1 44 -1 -1 -1 27 -1 -1 25 18 -1 -1 -1 -1 -1 -1 -1 -1  0  0 -1 -1 -1
33 35 -1 29 -1 -1 16 -1 -1 -1 -1 30 -1 -1 -1 -1 -1 -1 -1 -1  0  0 -1 -1
-1 -1 -1  4  4 -1 -1 -1 15 17 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1  0  0 -1
 5 -1 -1 19 -1 14 -1 -1 -1 -1 11 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1  0  0
10 -1 -1 -1 21 -1 18  8 -1 -1 -1 -1  1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1  0
```

Rate 2/3: $M_b \times N_b = 8 \times 24$

```
71 40 -1 -1 11 40 -1 -1 -1 69 -1 59 10 -1 -1 21 46  0 -1 -1 -1 -1 -1 -1
18 -1 35 51 27 -1 -1 49 17 -1 -1 37  4 -1 -1 -1 -1  0  0 -1 -1 -1 -1 -1
42 52 -1 -1 12 -1 54 -1 43 -1 62 62 52 -1 -1 -1 -1 -1  0  0 -1 -1 -1 -1
13 -1 27 -1 -1 -1  5 -1 28 33 -1 -1 58 47 18 -1  0 -1 -1  0  0 -1 -1 -1
-1 -1 -1 38 50 -1  7  9 34 -1 -1 -1 65 -1 17 70 -1 -1 -1 -1  0  0 -1 -1
71 -1 -1 39 62 14 -1 -1 53 -1 39 -1  2 67 -1 -1 -1 -1 -1 -1 -1  0  0 -1
54 56 -1 -1 53 -1 -1  2 66 57 -1 -1 -1 24 -1 52 -1 -1 -1 -1 -1 -1  0  0
17 -1 44 -1 44 29 -1 -1 48 -1 26 -1 39 -1 14 -1 46 -1 -1 -1 -1 -1 -1  0
```

Rate 3/4: $M_b \times N_b = 6 \times 24$

```
 0 23 -1 -1  0 47 53  1 -1  5 -1 13 66 34 -1 62 65 -1  1  0 -1 -1 -1 -1
14 57  7 11 -1 -1 69 -1 25 34 -1 25 13 -1 19 70 -1 35 -1  0  0 -1 -1 -1
59  3 -1 18 -1 43 48 58 -1 29 -1 54 49 -1 25  0 66 -1 -1 -1  0  0 -1 -1
15  1  2 -1 -1 39 19 -1 37 64 52 -1 28  4 -1 21 20 -1  0 -1 -1  0  0 -1
22 64 -1 48 60 -1 36 -1 15 62 68 -1 46 55 -1 41 -1  7 -1 -1 -1 -1  0  0
63 36 57 -1 55 -1 41 34 -1 45 46 -1  8 -1 37 44 -1 15  1 -1 -1 -1 -1  0
```

Rate 5/6: $M_b \times N_b = 4 \times 24$

```
11 26 59 44 36 45 51 32 13 60  3 70 47 21 -1 67 52 49 15 -1  1  0 -1 -1
39 58 28 60 43 55 30 51 49 13 50  4 -1 26 10 -1 30 58 28 22 -1  0  0 -1
36 11 35 38  1  5  9 36 15 47 -1 39 39 -1 71 53 66 -1 20 45  0 -1  0  0
54 67 51  0 15 65 24 17 38 58 53 -1 11  2  2 26 -1 15 -1  6  1 -1 -1  0
```

**(END)**