8498561

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE

United States Patent and Trademark Office

June 17, 2024

THIS IS TO CERTIFY THAT ANNEXED IS A TRUE COPY FROM THE RECORDS OF THIS OFFICE OF THE FILE WRAPPER AND CONTENTS OF:

APPLICATION NUMBER: ***11/121,661***
FILING DATE: ***May 04, 2005***
PATENT NUMBER: ***7623439***
ISSUE DATE: ***November 24, 2009***

Certified by

Katherine Kelly Vidal

Performing the Functions and Duties of the
Under Secretary of Commerce
for Intellectual Property
and Director of the United States
Patent and Trademark Office

PTO/SB/05 (09-04)
Approved for use through 07/31/2006. OMB 0651-0032
U.S. Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE
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050405

UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	**050337-1020**
First Inventor	**Webster et al.**
Title	**CYCLIC DIVERSITY SYSTEMS AND METHODS**
Express Mail Label No.	**EV558411326US**

17772 U.S.PTO
11294 U.S.PTO
11/21661
050405

APPLICATION ELEMENTS

See MPEP Chapter 600 concerning utility patent application contents

ADDRESS TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450

1. ☒ Fee Transmittal Form *(e.g., PTO/SB/17)* *(Submit an original, and a duplicate for fee processing)*
2. ☐ Applicant claims small entity status. See CFR 1.27
3. ☒ Specification *[Total Pages* **23** *]* *(preferred arrangement set forth below)*
   Both the claims and abstract must start on a new page *(For Example on the preferred arrangement see MPEP 608.01(a))*
4. ☒ Drawing(s) *(35 USC 113)* *[Total Sheets* **11** *]*
5. Oath or Declaration *[Total Pages* **3** *]*
   a. ☒ Newly Executed (original or copy)
   b. ☐ Copy from a prior application (37 CFR §1.63(d)) *(for continuation/divisional with Box 18 completed)*
   DELETION OF INVENTOR(S)
   i. ☐ Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).
6. ☐ Application Data Sheet. See 37 CFR 1.76
7. ☐ CD-ROM or CD-R in duplicate, large table or Computer Program (Appendix)
8. Nucleotide and/or Amino Acid Sequence Submission *(if applicable, all necessary)*
   a. ☐ Computer Readable Copy (CRF)
   b. Specification Sequence Listing on:
      i. ☐ CD-ROM or CD-R (2 copies); or
      ii. ☐ Paper
   c. ☐ Statements verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

9. ☒ Assignment Papers (cover sheet & Documents(s))
   Name of Assignee Conexant Systems, Inc.
   4311 Jamboree Road, Newport Beach, CA 92660-3095
10. ☐ 37 CFR 3.73(b) Statement *(when there is an assignee)* ☐ Power of Attorney
11. ☐ English Translation Document *(if applicable)*
12. ☒ Information Disclosure Statement (IDS)/PTO-1449
    ☒ **Copies of citations attached**
13. ☐ Preliminary Amendment
14. ☒ Return Receipt Postcard (MPEP 503) *(Should be specifically itemized)*
15. ☐ Certified Copy of Priority Document(s) *(if foreign priority is claimed)*
16. ☐ Nonpublication Request under 35 U.S.C. 122(b)(2)(B)(i). Applicant must attach form PTO/SB/35 or its equivalent.
17. ☐ Other:

18. If a CONTINUING APPLICATION, *check appropriate box, and supply the requisite information below and in a preliminary amendment, or in an Application Data Sheet under 37 CFR 1.76:*

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No: / .

Prior application information: ***Examiner*** _____ ***Group / Art Unit:*** _____

19. CORRESPONDENCE ADDRESS

☒ *Customer Number:* **24504** *OR* ☐ *Correspondence address below:*

NAME	**Scott A. Horstemeyer** **Thomas, Kayden, Horstemeyer & Risley, L.L.P.**				
ADDRESS	**100 Galleria Parkway** **Suite 1750**				
CITY	**Atlanta**	*STATE*	**Georgia**	*ZIP CODE*	**30339-5948**
COUNTRY	**U.S.A.**	*TELEPHONE*	**770-933-9500**	*FAX*	**770-951-0933**

Name (Print/Type)	**David Rodack**	*Registration No. (Attorney/Agent)*	**47,034**
Signature		*Date*	5-4-05

This collection of information is required by 37 CFR 1.5. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 1.22 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, Patent and Trademark Office, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

If you need assistance in completing the form, call 1-800-PTO-9199 (1-800-786-9199) and select option 2.

PTO/SB/17 (12-04v2)
Approved for use through 07/31/2006 OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number

050405

Effective on 12/08/2004
Fees Pursuant to the Consolidated Appropriations Act. 2005 (H.R. 4818).

FEE TRANSMITTAL
For FY 2005

☐ Applicant claims small entity status. See 37 CFR 1.27

TOTAL AMOUNT OF PAYMENT | **($)1,190.00**

Complete if Known	
Application Number	To Be Assigned
Filing Date	May 4, 2005
First Named Inventor	Webster et al.
Examiner Name	To Be Assigned
Art Unit	To Be Assigned
Attorney Docket No.	050337-1020

METHOD OF PAYMENT (check all that apply)

☐ Check ☒ Credit Card ☐ Money Order ☐ None ☐ Other (please identify):

☐ Deposit Account Deposit Account Number: **20-0778** Deposit Account Name: **Thomas, Kayden, Horstemeyer Risley, L.L.P.**

For the above-identified deposit account, the Director is hereby authorized to: (check all that apply)

☐ Charge fee(s) indicated below ☐ Charge fee(s) indicated below, except for the filing fee

☒ Charge any additional fee(s) or underpayments of fee(s) under 37 CFR 1.16 and 1.17 ☒ Credit any overpayments

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

FEE CALCULATION

1. BASIC FILING, SEARCH, AND EXAMINATION FEES

	Filing Fees		Search Fees		Examination Fees		
Application Type	Fee ($)	Small Entity Fee($)	Fee ($)	Small Entity Fee($)	Fee ($)	Small Entity Fee($)	Fees Paid ($)
Utility	300	150	500	250	200	100	1,000.00
Design	200	100	100	50	130	65	
Plant	200	100	300	150	160	80	
Reissue	300	150	500	250	600	300	
Provisional	200	100	0	0	0	0	

2. EXCESSIVE CLAIM FEES

Fee Description	Fee ($)	Small Entity Fee($)
Each claim over 20 (including Reissues)	50	25
Each independent claim over 3 (including Reissues)	200	100
Multiple dependent claims	360	180

Total Claims		Extra Claims	Fee ($)	Fee Paid ($)	Multiple Dependent Claims Fee ($)	Multiple Dependent Claims Fee Paid ($)
23	-20 or HP =	3	150.00	150.00		

HP = highest number of total claims paid for, if great than 20

Indep. Claims		Extra Claims	Fee ($)	Fee Paid ($)
3	-3 or HP =	0	0.00	0.00

HP = highest number of total claims paid for, if great than 3

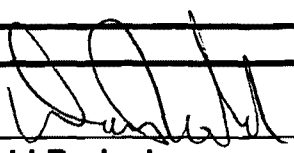
3. APPLICATION SIZE FEE

If the specification and drawings exceed 100 sheets of paper, the application size fee due is $250 ($125 for small entity) for each additional 50 sheets or fraction thereof. See 35 USC 41(a)(1)(G) and 37 CFR 1.16(s)

Total Sheets		Extra Sheets	Number of each additional 50 or fraction thereof		Fee ($)		Fee Paid ($)
23	-100 =	/50=	0	(round up to a whole number) x	0.00	=	0.00

4. OTHER FEE(S)

	Fee Paid ($)
Non-English Specification, $130 fee (no small entity discount)	
Other: **Assignment**	40.00

SUBMITTED BY			Complete (if applicable)
Signature		Registration No. **47,034**	Telephone Number 770-933-9500
Name: (Print/Type)	**David Rodack**		Date: 5-4-05

This collection of information is required by 37 CFR 1.136. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) and application. Confidentiality is governed by 35 USC 122 and 37 CFR 1.14. This collection is estimated to take 30 minutes to complete including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **Send to Commissioner For Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2

PATENTS

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re: **Webster et al.**

For: **Cyclic Diversity Systems and Methods**

CERTIFICATE OF EXPRESS MAIL

Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

Sir:
Enclosed for filing in the above case are the following documents:

Return Postcard
Utility Patent Application Transmittal Page
Fee Transmittal Page
Utility Patent Application Consisting of:
17 Pages of Specification
5 Pages of Claims (Claims 1-23)
1 Page of Abstract
11 Pages of Formal Drawings (Fig(s). 1, 2, 3A-3B, 4A-4B, 5-6, 7A-7B and 8-10)
Assignment of Utility Patent Application (4 pages)
Assignment Recordation Cover Sheet (1 page)
Declaration for Patent Application (3 pages)
Information Disclosure Statement
Form PTO 1449
Cited Prior Art (5 References)
PTO-2038 authorizing payment in the amount of $1,190.00 for utility application, 3 additional claims and assignment recordation fee

Further, the Commissioner is authorized to charge Deposit Account No. 20-0778 for any additional fees required. The Commissioner is requested to credit any excess fee paid to Deposit Account No. 20-0778.

Respectfully submitted,

David Rodack, Reg. No. 47,034

THOMAS, KAYDEN, HORSTEMEYER & RISLEY, L.L.P.
100 Galleria Parkway, N.W.
Suite 1750
Atlanta, Georgia 30339-5948

Our Docket No: **050337-1020**

I hereby certify that all correspondence listed above are being deposited for delivery to the above addressee, with the United States Postal Service **"EXPRESS MAIL POST OFFICE TO ADDRESSEE"** service under 37 CFR §1.10 on the date indicated below:

The envelope has been given U.S. Postal Service "Express Mail Post Office To Addressee" Package # **EV558411326US**.

Date: May 4, 2005

Marianne Boland

Marianne Boland

PTO/SB/05 (09-04)
Approved for use through 07/31/2006. OMB 0651-0032
U.S. Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE
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(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	**050337-1020**
First Inventor	**Webster et al.**
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Express Mail Label No.	**EV558411326US**

17772 U.S.PTO
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4. ☒ Drawing(s) *(35 USC 113)* *[Total Sheets* **11** *]*
5. Oath or Declaration *[Total Pages* **3** *]*
   a. ☒ Newly Executed (original or copy)
   b. ☐ Copy from a prior application (37 CFR §1.63(d)) *(for continuation/divisional with Box 18 completed)*
   DELETION OF INVENTOR(S)
   i. ☐ Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).
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   b. Specification Sequence Listing on:
      i. ☐ CD-ROM or CD-R (2 copies); or
      ii. ☐ Paper
   c. ☐ Statements verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

9. ☒ Assignment Papers (cover sheet & Documents(s))
   Name of Assignee Conexant Systems, Inc.
   4311 Jamboree Road, Newport Beach, CA 92660-3095
10. ☐ 37 CFR 3.73(b) Statement *(when there is an assignee)* ☐ Power of Attorney
11. ☐ English Translation Document *(if applicable)*
12. ☒ Information Disclosure Statement (IDS)/PTO-1449
    ☒ **Copies of citations attached**
13. ☐ Preliminary Amendment
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15. ☐ Certified Copy of Priority Document(s) *(if foreign priority is claimed)*
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17. ☐ Other:

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☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No: / .

Prior application information: **Examiner** _____ **Group / Art Unit:** _____

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COUNTRY	**U.S.A.**	*TELEPHONE*	**770-933-9500**	*FAX*	**770-951-0933**

Name (Print/Type)	**David Rodack**	*Registration No. (Attorney/Agent)*	**47,034**
Signature		*Date*	5-4-05

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PTO/SB/17 (12-04v2)
Approved for use through 07/31/2006 OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
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17172 U.S. PTO 050405

Effective on 12/08/2004
Fees Pursuant to the Consolidated Appropriations Act. 2005 (H.R. 4818).

FEE TRANSMITTAL
For FY 2005

☐ Applicant claims small entity status. See 37 CFR 1.27

TOTAL AMOUNT OF PAYMENT | **($)1,190.00**

Complete if Known	
Application Number	**To Be Assigned**
Filing Date	**May 4, 2005**
First Named Inventor	**Webster et al.**
Examiner Name	**To Be Assigned**
Art Unit	**To Be Assigned**
Attorney Docket No.	**050337-1020**

METHOD OF PAYMENT (check all that apply)

☐ Check ☒ Credit Card ☐ Money Order ☐ None ☐ Other (please identify):

☐ Deposit Account Deposit Account Number: **20-0778** Deposit Account Name: **Thomas, Kayden, Horstemeyer Risley, L.L.P.**

For the above-identified deposit account, the Director is hereby authorized to: (check all that apply)

☐ Charge fee(s) indicated below ☐ Charge fee(s) indicated below, except for the filing fee

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FEE CALCULATION

1. BASIC FILING, SEARCH, AND EXAMINATION FEES

	Filing Fees		Search Fees		Examination Fees		
Application Type	Fee ($)	Small Entity Fee($)	Fee ($)	Small Entity Fee($)	Fee ($)	Small Entity Fee($)	Fees Paid ($)
Utility	300	150	500	250	200	100	**1,000.00**
Design	200	100	100	50	130	65	
Plant	200	100	300	150	160	80	
Reissue	300	150	500	250	600	300	
Provisional	200	100	0	0	0	0	

2. EXCESSIVE CLAIM FEES

Fee Description	Fee ($)	Small Entity Fee($)
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Each independent claim over 3 (including Reissues)	200	100
Multiple dependent claims	360	180

Total Claims		Extra Claims	Fee ($)	Fee Paid ($)	Multiple Dependent Claims Fee ($)	Multiple Dependent Claims Fee Paid ($)
23	-20 or HP =	**3**	**150.00**	**150.00**		

HP = highest number of total claims paid for, if great than 20

Indep. Claims		Extra Claims	Fee ($)	Fee Paid ($)
3	-3 or HP =	**0**	**0.00**	**0.00**

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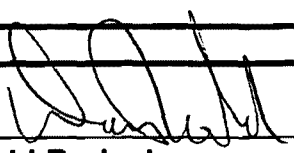
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Total Sheets		Extra Sheets	Number of each additional 50 or fraction thereof		Fee ($)	Fee Paid ($)
23	-100 =	**/50=**	**0**	(round up to a whole number) x	**0.00** =	**0.00**

4. OTHER FEE(S)

	Fee Paid ($)
Non-English Specification, $130 fee (no small entity discount)	
Other: **Assignment**	**40.00**

SUBMITTED BY			Complete (if applicable)
Signature		Registration No. **47,034**	Telephone Number 770-933-9500
Name: (Print/Type)	**David Rodack**		Date: 5-4-05

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If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2

PATENTS

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re: **Webster et al.**

For: **Cyclic Diversity Systems and Methods**

CERTIFICATE OF EXPRESS MAIL

Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

Sir:
Enclosed for filing in the above case are the following documents:

Return Postcard
Utility Patent Application Transmittal Page
Fee Transmittal Page
Utility Patent Application Consisting of:
17 Pages of Specification
5 Pages of Claims (Claims 1-23)
1 Page of Abstract
11 Pages of Formal Drawings (Fig(s). 1, 2, 3A-3B, 4A-4B, 5-6, 7A-7B and 8-10)
Assignment of Utility Patent Application (4 pages)
Assignment Recordation Cover Sheet (1 page)
Declaration for Patent Application (3 pages)
Information Disclosure Statement
Form PTO 1449
Cited Prior Art (5 References)
PTO-2038 authorizing payment in the amount of $1,190.00 for utility application, 3 additional claims and assignment recordation fee

Further, the Commissioner is authorized to charge Deposit Account No. 20-0778 for any additional fees required. The Commissioner is requested to credit any excess fee paid to Deposit Account No. 20-0778.

Respectfully submitted,

David Rodack, Reg. No. 47,034

THOMAS, KAYDEN, HORSTEMEYER & RISLEY, L.L.P.
100 Galleria Parkway, N.W.
Suite 1750
Atlanta, Georgia 30339-5948

Our Docket No: **050337-1020**

I hereby certify that all correspondence listed above are being deposited for delivery to the above addressee, with the United States Postal Service **"EXPRESS MAIL POST OFFICE TO ADDRESSEE"** service under 37 CFR §1.10 on the date indicated below:

The envelope has been given U.S. Postal Service "Express Mail Post Office To Addressee" Package # **EV558411326US**.

Date: May 4, 2005

Marianne Boland

Marianne Boland

CYCLIC DIVERSITY SYSTEMS AND METHODS

Inventors
MARK A. WEBSTER
MICHAEL J. SEALS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of copending U.S. provisional application having serial no. 60/572,481, filed May 20, 2004, which is entirely incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention.

[0002] The present disclosure is generally related to communication systems, and, more particularly, is related to wireless communication systems and methods.

2. Related Art.

[0003] Wireless communication systems are widely deployed to provide various types of communication, such as voice, data, and so on. These systems may be based on code division multiple access (CDMA), time division multiple access (TDMA), orthogonal frequency division multiplex (OFDM), or some other multiplexing techniques. Continual demand for increased data rates has resulted in the advancement of communications system technology, such as the use of multiple antennas in a single device having transmitter and/or receiver functionality. However, in systems utilizing multiple-antenna

devices, there is a need to consider legacy receivers (*e.g.*, single-input, single output (SISO), OFDM receivers) and the design challenges concomitant with implementing transmitters with multiple antennas in an environment that still uses legacy receivers.

[0004] FIG. 1 is a block diagram that illustrates such a mixed antenna transmitter device/legacy environment. As shown, an 802.11 compliant (*e.g.*, 802.11a, 802.11g) multi-antenna (MA) transmitter device 102 is shown in communication with a SISO 802.11 receiver device 112 (herein simply SISO receiver device 112). The MA transmitter device 102 comprises antennas 104 and 106. The SISO receiver device 112 comprises an antenna 110. The same signals transmitted from antennas 104 and 106 may follow direct paths and multi-paths to antenna 110. Normally, multiple-path signals (*e.g.*, resulting from reflections off of objects in the environment or from multiple antennas) can result in either partial or complete constructive interference or destructive interference of the same signals in a SISO receiver. One mechanism to avoid or mitigate completely destructive interference from multi-path signals is to equip one of the antennas 104 and 106 with a time delay element 108 (or provide a delay through a baseband processing section of the MA transmitter device 102). From the perspective of the SISO receiver device 112, the time delay element 108 appears to cause the signal sent from antenna 106 to reach antenna 110 later than the same signal sent from antenna 104. This technique is often referred to as linear delay diversity, and it's impact on performance of the SISO receiver device 112 is described below.

[0005] FIG. 2 is block diagram that describes an exemplary OFDM packet structure 200 used in the transmission of information between the MA transmitter device 102 (FIG. 1) and the SISO receiver device 112 (FIG. 1). Additional information about the packet structure can be found in 802.11 standards. The packet structure 200 is generated in a

baseband processing section (*e.g.*, in or in cooperation with an inverse fast Fourier transform (IFFT) operation) of the MA transmitter device 102, and comprises several sections. Sections A and B are comprised of short training symbols (STS). Section A is used by a communication system to provide signal detection, automatic gain control (AGC), and diversity selection functionality. Section B is used by a communication system to provide coarse frequency offset estimation and timing synchronization. Section C, sometimes referred to as a long training symbol (LTS), is used by a communication system to provide channel and fine frequency offset estimation. Section D is referred to as the signal field or header, and contains data rate and packet length information. Sections E and F are OFDM symbols. Sections D, E, and F provide rate length, service and data, and data, respectively. Section F is used as an exemplary OFDM symbol for the discussion below, and will be referred to as an OFDM symbol 300.

[0006] FIG. 3A is a block diagram that illustrates exemplary OFDM symbols 300a, 300b, and 300c (herein, simply referenced as OFDM symbol 300) shown in a time-domain perspective. Each OFDM symbol 300 comprises a guard interval (GI) 302, which provides a buffer between symbols 300. That is, multipath is equivalent to echoes, and the guard intervals 302 comprise a zone built into an OFDM symbol 300 into which echoes from a preceding OFDM symbol are positioned. Such echoes cause inter-symbol interference. The guard intervals 302 are inserted in the OFDM symbol 300 in the baseband processor portion of the MA transmitter device 102 (FIG. 1), and are used to capture unwanted multipath-induced inter-symbol interference at the SISO receiver device 112 (FIG. 1). In an 802.11 implementation, each symbol 300 is approximately 4 microseconds (μsec) in duration. For instance, of the 80 samples in an OFDM symbol waveform, the guard interval 302 consumes 16 samples (the data portion comprising 64-

samples). Fast Fourier transforms (FFT) applied at the SISO receiver device 112 (*e.g.*, 64-point FFT) occur (or are placed) in the 3.2 (μsec) interval of each OFDM symbol 300. That is, the SISO receiver device 112 discards the 0.8 μsec duration guard interval 302 on each received 4 μsec OFDM symbol, leaving 3.2 μsec of signal (which comprises all of the information of the OFDM symbol) to FFT. No echoes are included in the 3.2 μsec interval (inter-symbol interference free). Thus, reference to "placing" or "to place" or "placement" of the FFT is understood to comprise a process or method of extracting the correct 3.2 μsec from each 4 μsec interval for implementing the FFT.

[0007] FIG. 3B is a sub-carrier level view of the OFDM symbol 300 of FIG. 3A shown in a frequency domain perspective, and is helpful to consider in understanding how the guard intervals 302 (FIG. 3A) are created. An OFDM symbol 300 comprises a plurality of frequency subcarriers or tones 304 (*e.g.*, 52 data subcarriers in an 802.11a or 802.11g OFDM symbol, although only a portion of the 52 are shown) distributed in both frequency directions from a center or direct current (DC) frequency. The subcarriers or tones 304 spin at progressively increasing rotations in an in-phase (I)/quadrature (Q) plane from center frequency. Assuming no guard interval insertion, the subcarrier located at frequency position 306 spins counter-clockwise (*e.g.*, in a direction of increasing positive angles off of the x-axis) in an I/Q plane one cycle over one-64 sample period of the symbol 300. The subcarrier located at frequency position 308 spins clockwise (*e.g.*, in a direction of negative angles off of the x-axis) in an I/Q plane one cycle over the 64 samples. The subcarrier located at frequency position 310 spins counter-clockwise two cycles over the 64 samples, and the subcarrier located at frequency position 312 spins clockwise two cycles over the 64 samples, and so on. Thus, with the guard intervals left out, what remains is a continuous waveform that repeats itself every 64-samples. The

guard intervals 302 are a time domain extension of the subcarriers 64 time samples, pre-spinning an additional 16 time domain samples. That is, subcarrier time samples are allowed to "pre-spin" out 16 samples, resulting in guard intervals being created as cyclic extensions of the spin of the subcarrier time samples. Thus, each subcarrier is allowed to spin approximately 25% more than the subcarrier spin without the guard intervals 302.

[0008] In light of the aforementioned background, and with continued reference to FIGS. 1-3B, consider how linear delay diversity impacts the symbol stream at the MA transmitter device 102 and the SISO receiver device 112. FIG. 4A is a block diagram that shows partial packet structures 200a and 200b, each having three symbols 300 (designated as symbol 1, symbol 2, and symbol 3) comprising guard intervals 302. Packet structure 200b is a delayed version of packet structure 200a. Packet structure 200b is delayed (*e.g.*, by delay element 108) a time delay duration designated as t_D.

[0009] With continued reference to FIGS. 1-4A, FIG. 4B is a block diagram that illustrates how the SISO receiver device 112 handles the received packet structures 200a and 200b shown in FIG. 4A. That is, FIG. 4B illustrates a single received signal (comprising the addition of the two transmit signals corresponding to packet structures 200a and 200b) output from the single receive antenna 110. The SISO receiver device 112 determines the guard interval and symbol location (and FFT placement) through an acquisition process that includes a correlation of the known pattern corresponding to the LTS (*e.g.*, section C of the OFDM packet 200 (FIG. 2)). Legacy receivers may perform a channel impulse response (CIR) estimate using the LTS. The LTS is designed to elicit an impulse response when correlated with multi-path, thus resulting in a multi-path profile. In the absence of a time delay (or in the absence of multi-path), the response to a received packet is an impulsive correlation (which would be

shown as a single impulse 402a in the guard interval 302), enabling proper timing or synchronization of the received signal and proper placement of the FFT. With the time delay (t_D) (or with multi-path), two impulsive responses (402a and 402b) are detected. The FFT is placed after the detection of the second impulse response 402b. Thus, FFT placement is accomplished by using the impulse response(s) to center the guard interval 302 on the transients so that inter-symbol interference ISI is minimized.

[0010] Linear delay diversity results in true delays that exhibits a behavior from a receiver perspective that is indistinguishable from true multi-path (*e.g.*, the situation where the signal bounces off an object and arrives at the SISO receiver device 112 with a time delay due to the greater path distance traveled). Further, with linear delay diversity, complete destructive interference is avoided, but at the expense of the consumption of the guard intervals 302.

[0011] Another technique used to make MA transmitters compatible with legacy receiver devices is referred to as cyclic delay diversity. With cyclic delay diversity, each tone or subcarrier is cyclically shifted (*e.g.*, in the baseband processing portion of the MA transmitter device 102, FIG 1) by a defined amount of samples, resulting in a circular shift of all of the samples involved (*e.g.*, 64 samples plus 16 samples of the data and guard interval, respectively). FIG. 5 is a schematic diagram that illustrates 1-sample cyclic delay diversity. The first tier 502 represents 80 total samples comprising 64 samples of symbol data 508 and 16 samples that are used for a guard interval 510. The second tier 504 is simply an extension of the first tier, showing the guard interval 510 corresponding to samples 510 adjacent to the next set of samples. This next set of samples comprises 64 samples of symbol data 512 and 16 samples corresponding to the guard interval 514a. The third tier 506 represents a 1-sample cyclic delay shift. As

shown, a delay of 1 sample results in the guard interval 514b preceding the 80 sample symbol in the third tier 506, starting with sample 4/7, as indicated by line 516. All of the other samples are likewise shifted as represented by the dotted arrow-head lines 518.

[0012] From a receiver standpoint, the guard intervals 510, 514b remain aligned, as represented by the dashed line 520. In other words, with cyclic delay diversity, guard intervals are not consumed as they are in linear delay diversity. The samples used for each guard interval are different after a cyclic shift, but the guard intervals still remain as 16 samples. However, one problem with cyclic delay diversity involves the acquisition process described earlier. When correlation occurs at the SISO receiver device 112 (FIG. 1), the sample shifting is detected, such shifting being indistinguishable from the sample shifting that occurs in linear delay diversity. In other words, the impulse response appears to shift directly with the cyclic shift. However, the true location of the guard interval does not change because the MA transmitter device 102 (FIG. 1) is using cyclic shifts. This can spoof the SISO receiver device 112 such that the FFT placement is erroneous. That is, the SISO receiver device 112 may shift the FFT over in a manner that spills over to the subsequent guard interval.

SUMMARY

[0013] Embodiments of cyclic diversity systems and methods are disclosed. One system embodiment, among others, comprises a logic configured to cyclically advance, or the periodic equivalent, one or more sections of an orthogonal frequency division multiplexing (OFDM) packet relative to the OFDM packet to be transmitted on a first transmit antenna, the packet having the one or more cyclically advanced sections to be

transmitted on a second transmit antenna, the duration of the cyclic advance having a duration less than a guard interval.

[0014] One method embodiment, among others, comprises providing an orthogonal frequency division multiplexing (OFDM) packet corresponding to a first transmit antenna, and cyclically advancing, or the periodic equivalent, one or more sections of the OFDM packet corresponding to a second transmit antenna, the duration of the cyclic advance having a duration less than a guard interval.

[0015] Other systems, methods, features, and advantages of the disclosed systems and methods will be or become apparent to one with skill in the art upon examination of the following drawings and detailed description. It is intended that all such additional systems, methods, features, and advantages be included within this description and be within the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Many aspects of the disclosure can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the disclosed systems and methods. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

[0017] FIG. 1 is a block diagram that illustrates a communication system comprising a multiple-antenna (MA) transmitter device and a single-input, single-output (SISO) receiver device.

[0018] FIG. 2 is block diagram that describes an exemplary OFDM packet structure used in the communication system shown in FIG. 1.

[0019] FIGS. 3A-3B are block diagrams that illustrates exemplary OFDM symbol structures.

[0020] FIGS. 4A-4B are block diagrams that illustrate the processing of packet structures in the context of linear delay diversity.

[0021] FIG. 5 is a schematic diagram that illustrates 1-sample cyclic delay diversity.

[0022] FIG. 6 is block diagram that illustrates a communication system comprising an embodiment of an enhanced, multiple-antenna (EMA) transmitter device and a SISO transmitter device.

[0023] FIGS. 7A-7B are schematic diagrams that illustrate two frequency selective spectrums that vary based on the amount of delay or advancement used.

[0024] FIG. 8 is a schematic diagram that illustrates cyclic advance diversity as implemented by the communication system shown in FIG. 6.

[0025] FIG. 9 is a plot that illustrates packet error performance of cyclic advance diversity compared to cyclic delay diversity.

[0026] FIG. 10 is a flow diagram of one embodiment of a cyclic diversity method.

DETAILED DESCRIPTION

[0027] Disclosed herein are various embodiments of cyclic diversity systems and methods, herein cyclic diversity systems. In one embodiment, a cyclic diversity system comprises a multiple-antenna, 802.11 compliant (*e.g.*, 802.11a, 802.11g, proposed 802.11n) transmitter device configured with cyclic extension logic that provides cyclic advance diversity, among other diversity (*e.g.*, cyclic delay, linear delay, *etc.*) to one or more sections of orthogonal frequency division multiplexing (OFDM) packet structures or OFDM continuous data streams (herein packet(s) or continuous data

stream(s) may each be referred to as a segment or segments). That is, cyclic diversity can be applied to one or more of the sections (*e.g.*, long training symbols, short training symbols, OFDM symbols, *etc.*) or periodic structures of a segment (*e.g.*, packet or continuous data stream) in the time domain (or the subcarrier structures in the frequency domain). By providing cyclic advances, cyclic shift diversity is employed which enables legacy receivers to experience improved packet error rate performance when compared to conventional diversity mechanisms, among other benefits.

[0028] FIG. 6 is block diagram that illustrates a communication system 600 comprising an embodiment of an enhanced, multiple-antenna (EMA) transmitter device and a single-input, single-output (SISO) receiver device. In particular, the communication system 600 comprises an EMA transmitter device 602 and a legacy receiver device 112, the legacy receiver device 112 described in association with FIG. 1. The EMA transmitter device 602 may be implemented using individual SISO transmissions (*e.g.*, one spatial stream per antenna) or using multiple-input, multiple-output (MIMO) technology that enables simultaneous or substantially simultaneous transmission over two or more spatial streams in the same spectrum. In other words, cyclic diversity may be applied to MIMO one spatial stream preambles, headers, and data symbols as well as to one or more sections of SISO transmission packets. The EMA transmitter device 602, or one or more components of the EMA transmitter device 602 may also be referred to as a cyclic diversity system. In some embodiments, a cyclic diversity system may comprise one or more components of a receiver device. In one embodiment, the EMA transmitter device 602 is compliant with 802.11 standards (*e.g.*, proposed 802.11n), and comprises modules 604 and 606. The EMA transmitter device 602 and/or the SISO receiver device 112 may each be embodied in any wireless (*e.g.*, radio frequency) communication

device, including computers (desktop, portable, laptop, *etc.*), consumer electronic devices (*e.g.*, multi-media players), compatible telecommunication devices, personal digital assistants (PDAs), or any other type of network devices, such as printers, fax machines, scanners, hubs, switches, routers, set-top boxes, televisions with communication capability, *etc.*

[0029] Module 604 comprises a transmit (TX) processor 608, which includes baseband processing modules (*i.e.*, logic, such as hardware and/or software) that comprise functionality for encoding, interleaving, mapping, and OFDM symbol generation and processing. In one embodiment, as part of the symbol generation and processing functionality, the transmit processor 608 comprises a cyclic extension module 622 that provides for cyclic extension (*e.g.*, guard intervals) insertion and cyclic advance diversity. In some embodiments, cyclic extension insertion may be implemented by a different module. Further, the cyclic extension module 622 may provide for delay diversity (cyclic and/or linear). The delay and/or cyclic advance may be a configurable and switchable function. For instance, the cyclic delay and/or advance functionality may be switched off or disabled (*e.g.*, through processing functionality in the transmit processor 608) when transmission delay is not implemented on the corresponding antenna 612. Further, the transmit processor 608 may deliver a cyclic advance in some transmissions, and switch the functionality to deliver a cyclic (or linear) delay. Module 604 further comprises radio circuitry 610 in communication with the transmit processor 608 and an antenna 612.

[0030] Module 606 comprises similar components and functionality to module 604, including a transmit processor 614, radio circuitry 618, and antenna 620. Transmit processor 614 further comprises a cyclic extension module 616, that operates in similar

manner to cyclic extension module 622, and thus the discussion of the same and other like components of module 606 is omitted for brevity.

[0031] Note that in some embodiments, the communication system 600 may comprise multiple-antenna receiver devices mixed with SISO receiver devices. Also, in some embodiments, transmitter functionality may be included in one or more receiver devices of the communication system 600 and/or receiver functionality may be included in one or more transmitter devices of the communication system 600.

[0032] In operation, transmit processors 608 and 614 encode and interleave the incoming data (designated TX data1 at TX data rate1at module 604, which is also provided to module 606 as represented by connection 630). Transmit processors 608 and 614 map the interleaved data into respective sub-carrier channels as frequency domain symbols. Inverse fast Fourier transform (IFFT) logic in baseband processing circuitry of the transmit processors 608 and 614 performs an inverse fast Fourier transformation on the frequency domain symbols to create OFDM symbols.

[0033] Cyclic extension modules 616 or 622 provide for cyclic extension insertion and/or advance diversity (and delay diversity in some embodiments). In one embodiment, the cyclic advance is approximately 100 nano-seconds (nsec). The choice of duration for the advance depends on several considerations. FIGS. 7A-7B are schematic diagrams that illustrate two frequency selective spectrums 700a and 700b, respectively, that vary based on the amount of delay or advancement used. When providing advance or delay diversity, intentional multi-path is created, which in turn creates frequency selective fading. With reference to FIG. 7A, introducing one sample delay or advance introduces a "notch" 702 in the waveform, with a location of that notch 702 depending at least in part on phase of

the second (delayed) signal. If the notch falls in the center, a significant portion of the signal waveform is eliminated.

[0034] With reference to FIG. 7B, introducing a two-sample delay or advance introduces notches 704 and 706 in two locations. By using a two-sample delay or advance, although more notches are introduced, the center portion of the signal waveform (50% of the signal waveform) is "flattened" out, thus preserving a significant portion of the waveform.

[0035] In some embodiments, additional cyclic extension modules corresponding to additional antennas may be used, and a variation of delays and advances may be implemented. For instance, and with continued reference to FIG. 6, antenna 612 may transmit with no delay or advance, antenna 620 may transmit with an advance, a third antenna may transmit with a delay, and a fourth antenna may transmit with an advance. Additional functionality, such as digital-to-analog (D/A) functionality, may also be included in the transmit processors 608 and 614, as would be understood by one having ordinary skill in the art.

[0036] With reference to FIG. 6, the transmit processors 608 and 614 provide the processed data to radio circuitry 610 and 618, which provides such well-know functions as filtering, modulation, amplification, and conversion (*e.g.*, upconversion) functionality. The radio circuitry 610 and 618 provide the processed signals (*e.g.*, no advance and no delay, and advanced, respectively) to antennas 612 and 620, from which the transmitted signals are delivered to SISO receiver device 112.

[0037] The signals transmitted from antennas 612 and 620 are received at antenna 110 of SISO receiver device 112, demodulated and converted to baseband, and processed to recover the transmitted data.

[0038] FIG. 8 is a schematic diagram that illustrates 4-sample cyclic advance diversity as implemented by the communication system 600 shown in FIG. 6. The first tier 802 represents 80 total samples comprising 64 samples of symbol data 808 and 16 samples that are used for a guard interval 810. The second tier 804 is simply an extension of the first tier 802, showing the guard interval corresponding to samples 810 adjacent to the next set of samples. This next set of samples comprises 64 samples of symbol data 812 and 16 samples corresponding to the guard interval 814a. The third tier 806 represents a 4-sample cyclic advance shift. As shown, an advance shift of 4 samples results in the guard interval 814b preceding the 80 sample symbol in the third tier 806 starting with sample 5/2, as represented by line 816. All of the other samples are likewise shifted as represented by the dotted arrow-head lines 818.

[0039] From a receiver standpoint, the guard intervals 810, 814b remain aligned, as represented by the dashed line 820. In other words, with cyclic advance diversity, and similar to cyclic delay diversity, guard intervals are not consumed as they are in linear delay diversity. However, unlike cyclic delay diversity, cyclic advance diversity does not result in net shifting of the FFT. That is, the FFT placement remains substantially centered and unshifted. One reason for this phenomenon is that the cyclic shifts created by the cyclic extension modules 616 and 622 (FIG. 6) provide a shift that is in a direction opposite to any FFT shift that occurs in response to multi-path created by the multiple antennas and reflections.

[0040] As is shown below, small cyclic advances are preferred over small cyclic delays, since the SISO receiver 112 (FIG. 1) handles small amounts of delays or advances because they are designed in the context of expected multipath. That is, the SISO receiver device 112 is designed to handle a multi-path spread (*e.g.*, defined as the time spread

from a first multipath ray arrival and a last multipath arrival at the SISO receiver device 112) of up to approximately 200 nsec. For instance, an 802.11 compliant WLAN transmitter device may transmit a packet with a guard interval having a duration of approximately 800 nsec. The guard interval, as described above, is designed to catch multipath. Shifts should look like multipath to a legacy receiver device, and thus are preferably less in duration that the duration of the guard interval. Due to the periodic nature of OFDM subcarriers, mathematically, a small cyclic advance of 100 nsec is identical or equivalent to a large delay of 3100 nsecs (the OFDM symbol waveform repeats with a period of 3.2 μsec or 3200 nsec). In other words, 3100 nsec is a periodic equivalent to 100 nsec. Likewise, a small delay of 100 nsec is identical to an advance of 3100 nsec, again due to the periodic nature of the OFDM symbol 300 (*e.g.*, FIG. 3). Thus, a signal received by the SISO receiver device 112 (FIG. 6) having a cyclic advance of 100 nsec or a signal having a cyclic delay of 3100 nsec is processed as an identical signal from the perspective of the SISO receiver device 112, since the EMA transmitter device 602 (FIG. 6) transmits the identical signal in each case. Since a circular shift is indeed circular, the FFT placement is at the same position shifting in either direction (100nsec advance, 3100 nsec delay). What has been determined experimentally is that small cyclic advances are superior to small cyclic delays.

[0041] Experimental testing has shown that legacy radios show significant performance gains in packet error rate with small advancements (*e.g.*,100 nsec) as opposed to large delays (*e.g.*, that span an almost an entire FFT). FIG. 9 is a plot that illustrates packet error performance of cyclic advance diversity compared to cyclic delay diversity. In particular, FIG. 9 shows a plot 900 of the packet error performance (PER) on the y-axis 902 (0.1 corresponds to 10% PER), and the x-axis 904 is the Eb/No ratio in

decibels (dB), where E_b is the energy per information bit and N_0 is the (one-sided) noise power spectral density. The legend 906 shows numbers –2 through 0 and 2 through 4. The numbers 2-4 correspond to cyclic advance diversity of 2-4 samples, respectively. Two (2) sample shifts is equal to 100 nsec, three (3) sample shifts are equal to 150 nsec, and four (4) samples shifts is equal to 200 nsec. The –1 and –2 are cyclic delays of 1-sample (50 nsec) and 2-samples (100 nsec), respectively. The 0 corresponds to a situation in which the second antenna had no delay relative to the first antenna, so signals were not separable by a SISO receiver device. The sample rate corresponding to the curves in this plot 900 was 20 MHz for an 802.11 OFDM. As shown in the plot 900 of FIG. 9, the lower the curve, the better the PER performance for a particular SNR. The cyclic advance diversity, such as shown in curves 2-4 works well and indeed is generally superior in PER performance to cyclic delay diversity. Additional performance curves may be found in the provisional application referenced in the cross-reference to related applications section of this disclosure.

[0042] Embodiments of a cyclic extension system, comprised of one or more components of the EMA transmitter device 602 (FIG. 6) (*e.g.*, such as cyclic extension modules 616 and/or 622), can be implemented in hardware, software, firmware, or a combination thereof. If implemented in hardware, such embodiments can be implemented with any or a combination of the following technologies, which are all well known in the art: a discrete logic circuit(s) having logic gates for implementing logic functions upon data signals, an application specific integrated circuit (ASIC) having appropriate combinational logic gates, a programmable gate array(s) (PGA), a field programmable gate array (FPGA), *etc.*

[0043] Functionality of one or more components that comprise embodiments of a cyclic extension system may also be implemented in software or firmware that is stored in a memory and that is executed by a suitable instruction execution system.

[0044] In light of the above description, it will be appreciated that a cyclic diversity method embodiment 600a may be described by the flow diagram illustrated in FIG. 10. In particular, the method 600a comprises providing an orthogonal frequency division multiplexing (OFDM) packet corresponding to a first transmit antenna (1002) and cyclically advancing, or performing the periodic equivalent of the same, one or more sections of the OFDM packet corresponding to a second transmit antenna, the duration of the cyclic advance having a duration less than a guard interval.

[0045] Any process descriptions or blocks in flow charts should be understood as representing modules, segments, or portions of code which include one or more executable instructions for implementing specific logical functions in the process, and alternate implementations are included within the scope of the embodiments in which functions may be executed out of order from that shown or discussed, including substantially concurrently or in reverse order, depending on the functionality involved, as would be understood by those reasonably skilled in the art.

[0046] It should be emphasized that the above-described embodiments of the disclosure, particularly, any "preferred" embodiments, are merely possible examples of implementations, merely set forth for a clear understanding of the principles of the disclosed systems and methods. Many variations and modifications may be made to the above-described embodiment(s) without departing substantially from the scope of the disclosure. All such modifications and variations are intended to be included herein within the scope of this disclosure s.

CLAIMS

What is claimed:

1. A cyclic diversity method, comprising:

providing an orthogonal frequency division multiplexing (OFDM) packet corresponding to a first transmit antenna; and

cyclically advancing, or performing the periodic equivalent of the same, one or more sections of the OFDM packet corresponding to a second transmit antenna, the duration of the cyclic advance having a duration less than a guard interval.

2. The method of claim 1, wherein cyclically advancing comprises cyclically advancing a duration of less than approximately 800 nanoseconds.

3. The method of claim 1, further comprising transmitting the OFDM packet corresponding to the first transmit antenna from the first transmit antenna and transmitting the OFDM packet having the one or more cyclically advanced sections from the second transmit antenna.

4. The method of claim 1, further comprising transmitting the OFDM packet corresponding to the first transmit antenna with cyclic delay, cyclic advance, or linear time delay for the one or more sections of the OFDM packet from additional transmit antennas.

5. The method of claim 1, further comprising determining whether to transmit the OFDM packet corresponding to the first transmit antenna with a cyclic delay, cyclic advance, or a linear time delay applied to the one or more sections of the OFDM packet when transmission is to be from additional transmit antennas.

6. The method of claim 1, further comprising transmitting the OFDM packet corresponding to the first transmit antenna and the OFDM packet having the one or more cyclically advanced sections corresponding to the second transmit antenna from a multiple-antenna transmitter device.

7. The method of claim 1, further comprising receiving the OFDM packet corresponding to the first transmit antenna and the OFDM packet having the one or more cyclically advanced sections corresponding to the second transmit antenna and placing a fast Fourier Transform (FFT) in an interval corresponding to the duration of a recovered OFDM symbol corresponding to one of the OFDM packets without shifting the FFT into an adjacent OFDM symbol.

8. The method of claim 7, wherein receiving and placing comprises receiving at a single-input, single-output (SISO) receiver device.

9. A cyclic diversity system, comprising:

a logic configured to cyclically advance, or perform the periodic equivalent of the same, one or more sections of an orthogonal frequency division multiplexing (OFDM) packet relative to the OFDM packet to be transmitted on a first transmit antenna, the packet having the one or more cyclically advanced sections to be transmitted on a second transmit antenna, the duration of the cyclic advance having a duration less than a guard interval.

10. The system of claim 9, further comprising transmit logic configured to transmit the OFDM packet and the OFDM packet having the one or more cyclically advanced sections on the first transmit antenna and the second transmit antenna, respectively.

11. The system of claim 10, wherein the transmit logic is configured to transmit the OFDM packet with a cyclic delay, cyclic advance, or linear time delay for the one or more sections of the OFDM packet from additional transmit antennas.

12. The system of claim 9, wherein the logic is configured to cyclically advance the one or more sections of the OFDM packet to be transmitted from the second transmit antenna a duration of less than approximately 800 nanoseconds.

13. The system of claim 9, wherein the logic is configured to determine whether to transmit the OFDM packet with a cyclic delay, cyclic advance, or a linear time delay applied to the one or more sections of the OFDM packet.

14. The system of claim 9, wherein the system is embodied as a multiple-antenna transmitter device.

15. The system of claim 9, further comprising receive logic configured to receive the OFDM packet corresponding to the first transmit antenna and the OFDM packet having the one or more cyclically advanced sections corresponding to the second transmit antenna.

16. The system of claim 15, further comprising processing logic configured to place a fast Fourier Transform (FFT) in an interval corresponding to the duration of an OFDM symbol of one of the received OFDM packets without shifting the FFT into an adjacent OFDM symbol.

17. The system of claim 16, wherein the receive logic and the processing logic is located in a single-input, single-output (SISO) receiver device.

18. The system of claim 9, wherein the system comprises an 802.11 compliant device.

19. The system of claim 9, wherein the logic is configured in hardware, software, or a combination of hardware and software.

20. The system of claim 9, wherein the logic is configured in digital circuitry, analog circuitry, or a combination of digital and analog circuitry.

21. A cyclic diversity system, comprising:

means for providing an orthogonal frequency division multiplexing (OFDM) segment corresponding to a first transmit antenna; and

means for cyclically advancing, or performing the periodic equivalent of the same, one or more sections of the OFDM segment corresponding to a second transmit antenna, the duration of the cyclic advance having a duration less than a guard interval.

22. The system of claim 21, wherein the segment comprises a continuous data stream.

23. The system of claim 21, wherein the segment comprises a packet.

ABSTRACT

[0047] Embodiments of cyclic diversity systems and methods are disclosed. One system embodiment, among others, comprises a logic configured to cyclically advance, or perform the periodic equivalent of the same, one or more sections of an orthogonal frequency division multiplexing (OFDM) packet relative to the OFDM packet to be transmitted on a first transmit antenna, the packet having the one or more cyclically advanced sections to be transmitted on a second transmit antenna, the duration of the cyclic advance having a duration less than a guard interval.

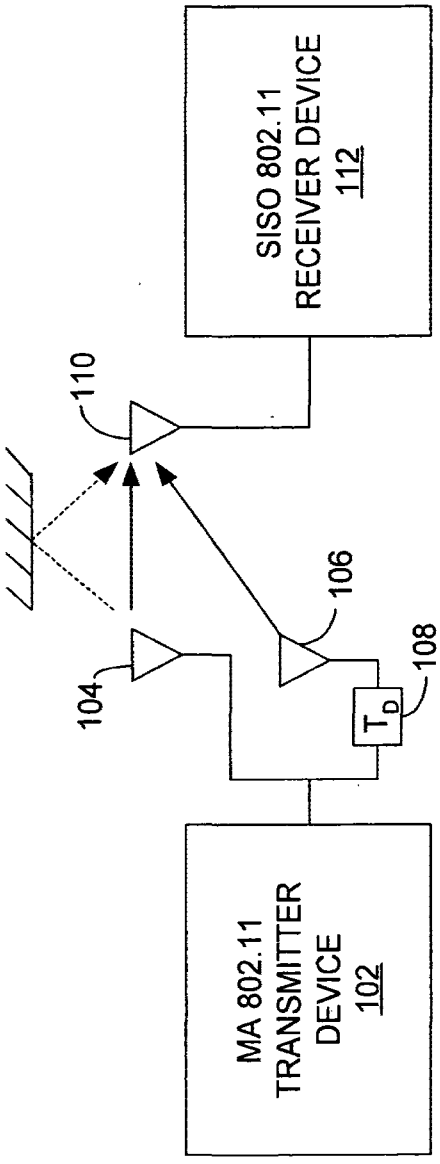


FIG. 1
(PRIOR ART)

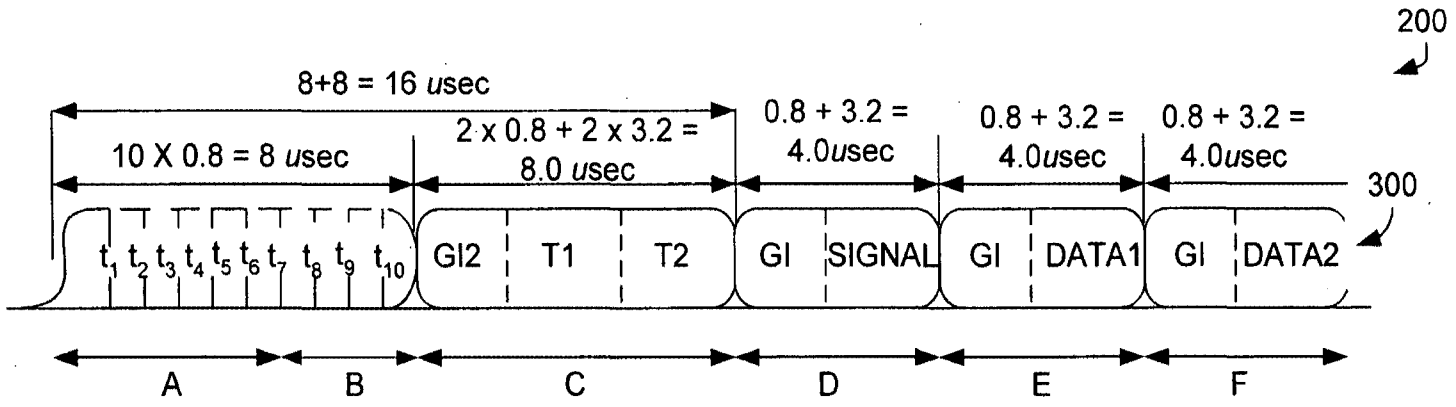


FIG. 2 (PRIOR ART)

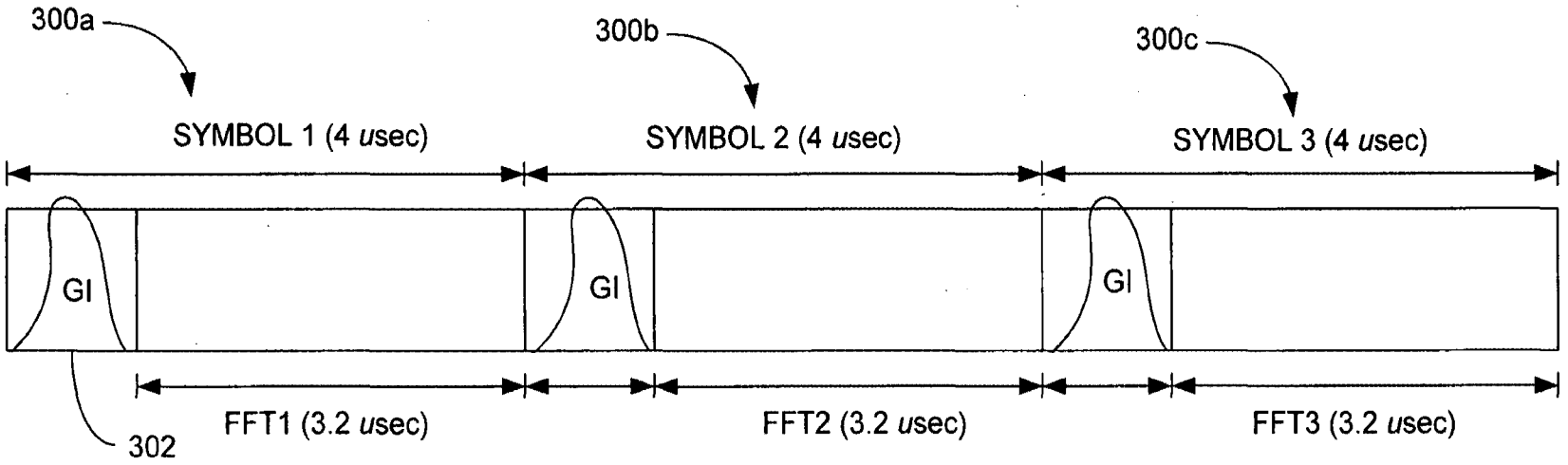


FIG. 3A (PRIOR ART)

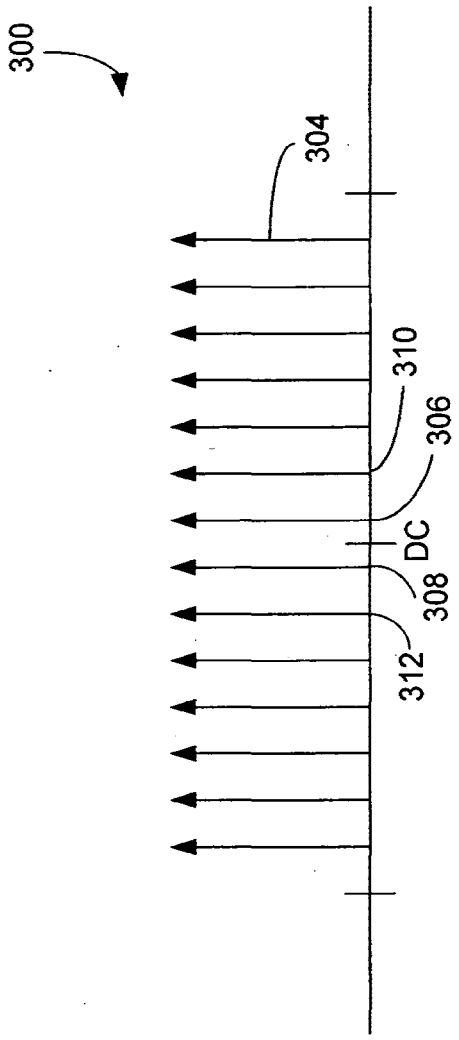


FIG. 3B (PRIOR ART)

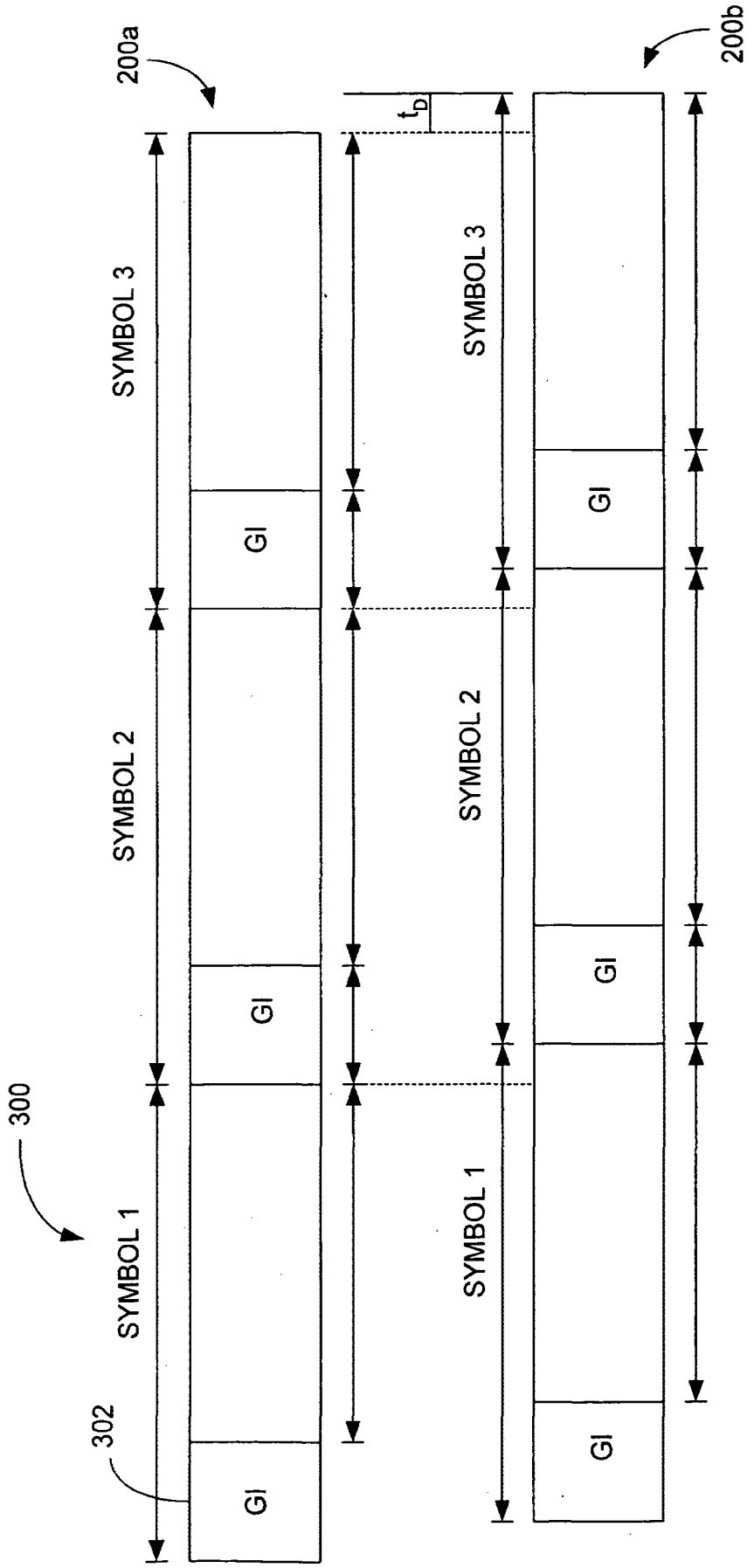


FIG. 4A (PRIOR ART)

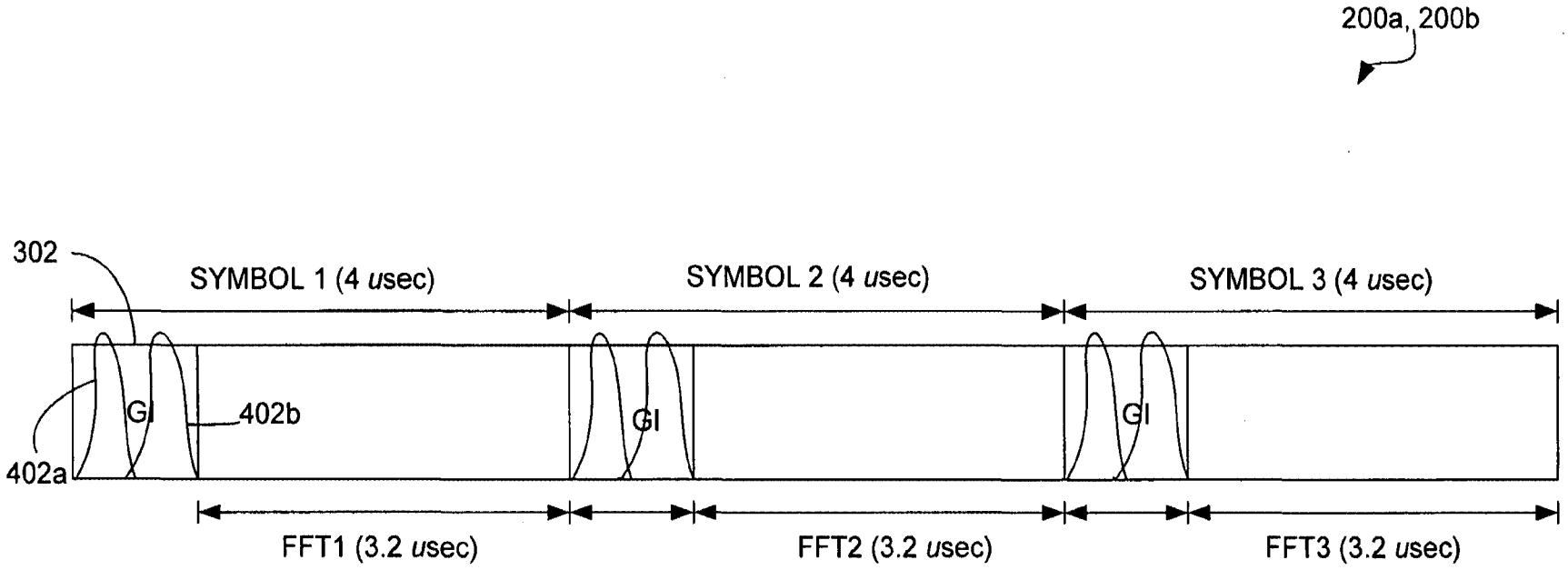


FIG. 4B (PRIOR ART)

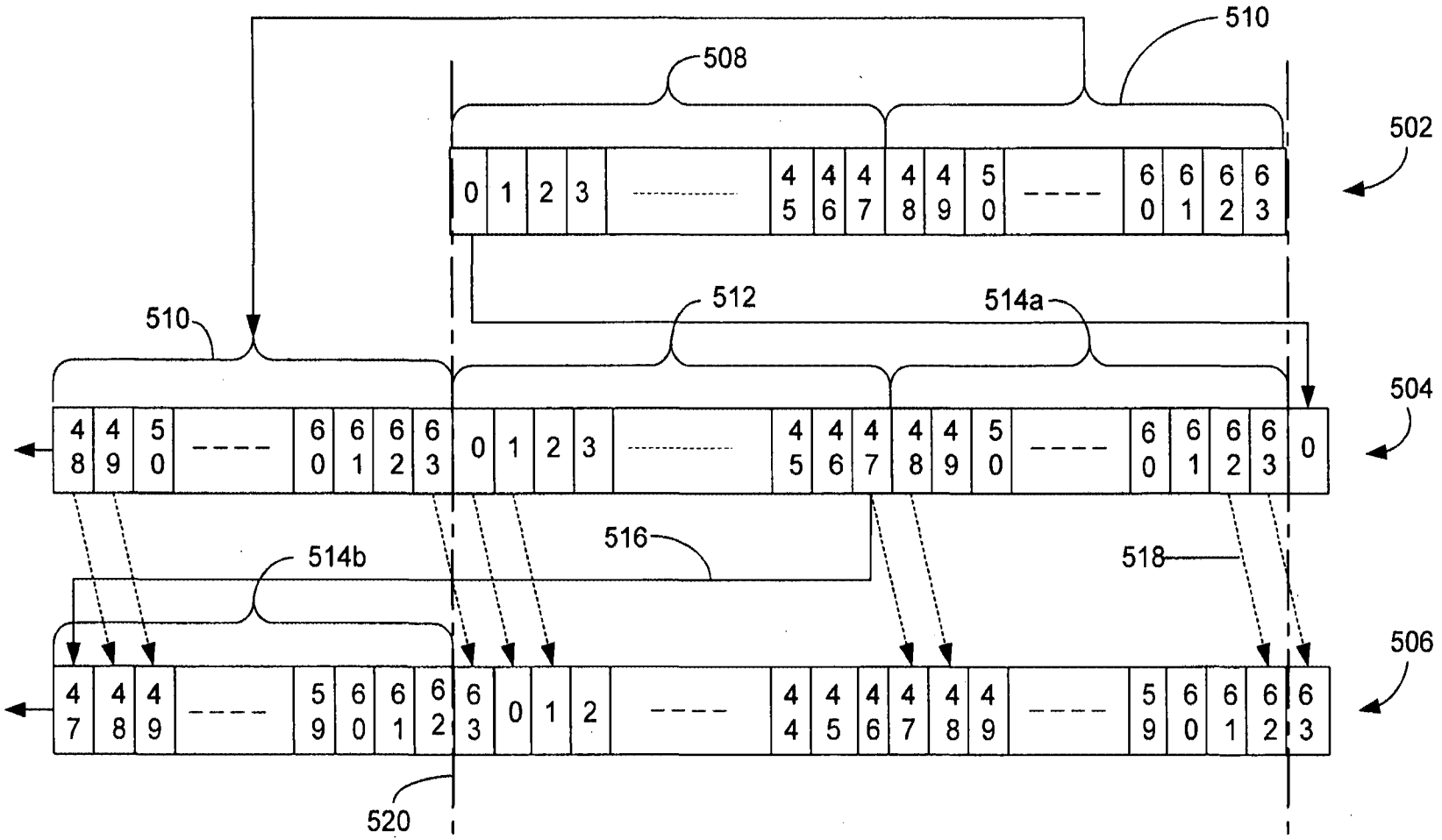


FIG. 5 (PRIOR ART)

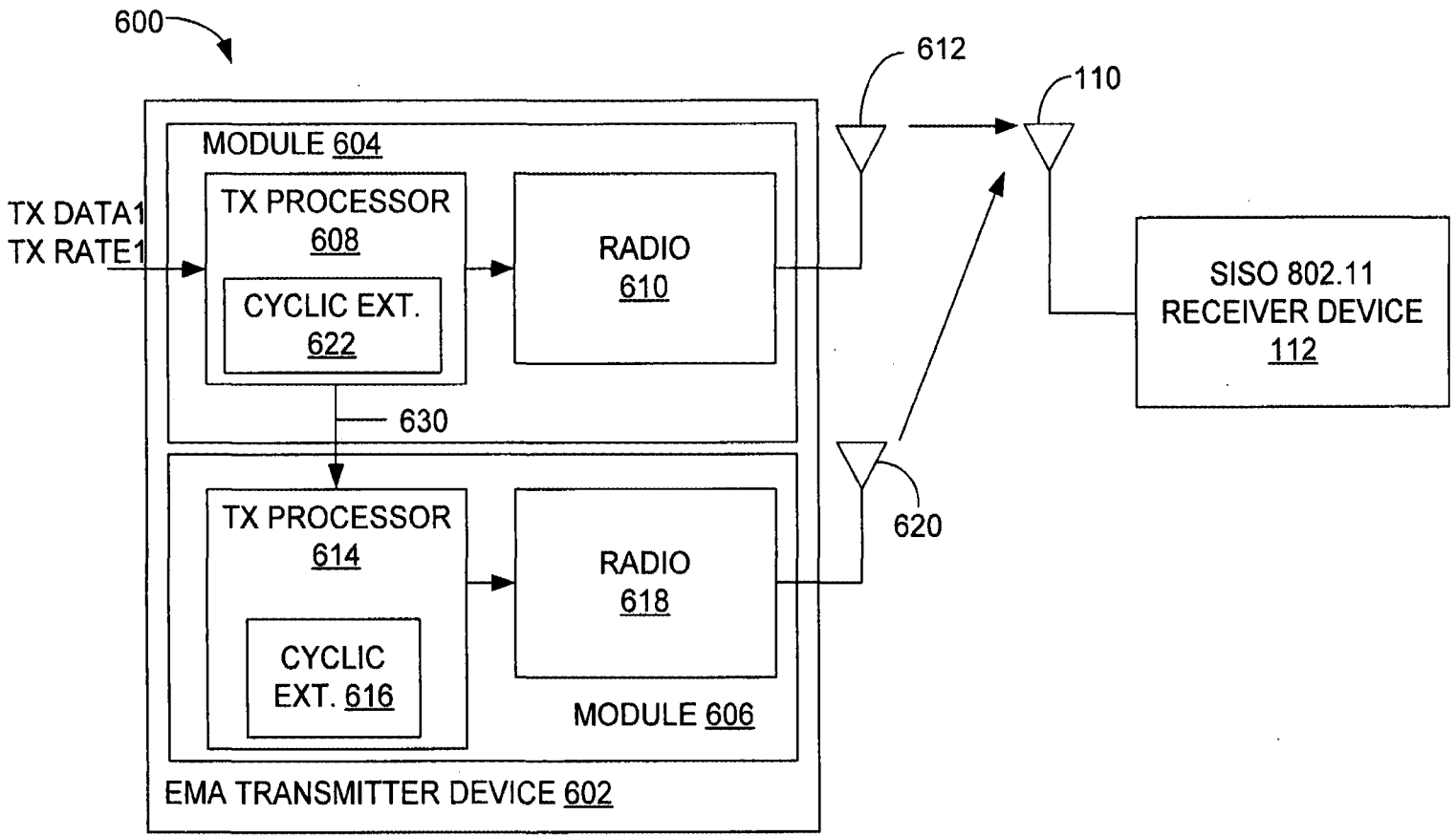

600
612
110
MODULE 604
TX DATA1
TX RATE1
TX PROCESSOR
608
CYCLIC EXT.
622
RADIO
610
SISO 802.11
RECEIVER DEVICE
112
630
TX PROCESSOR
614
CYCLIC
EXT. 616
RADIO
618
620
MODULE 606
EMA TRANSMITTER DEVICE 602

FIG. 6

FIG. 7A

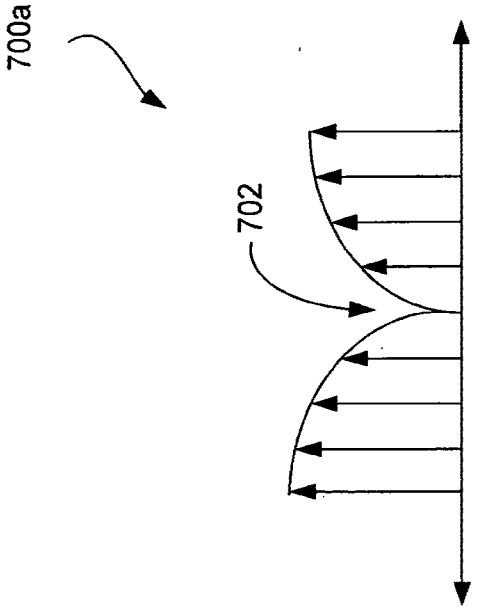
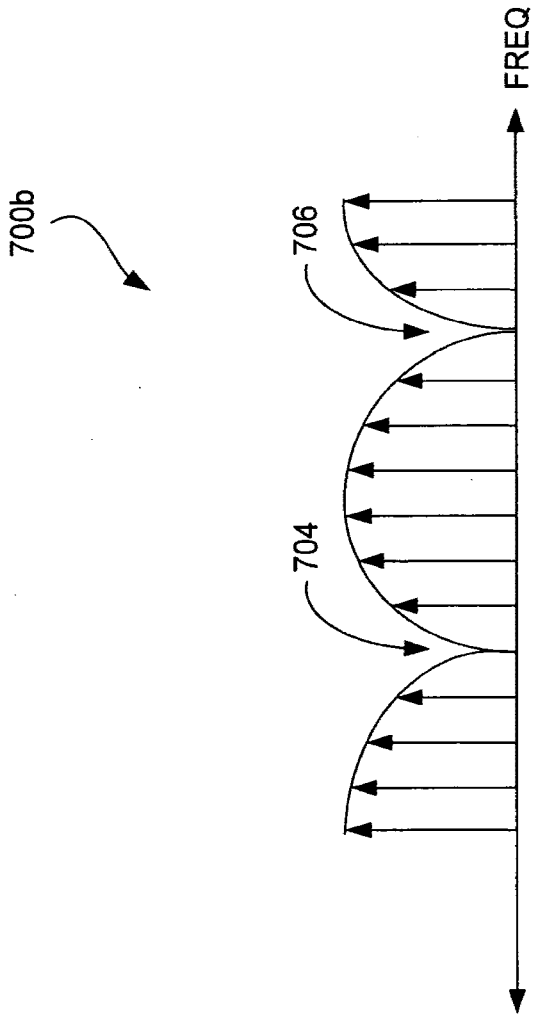


FIG. 7B



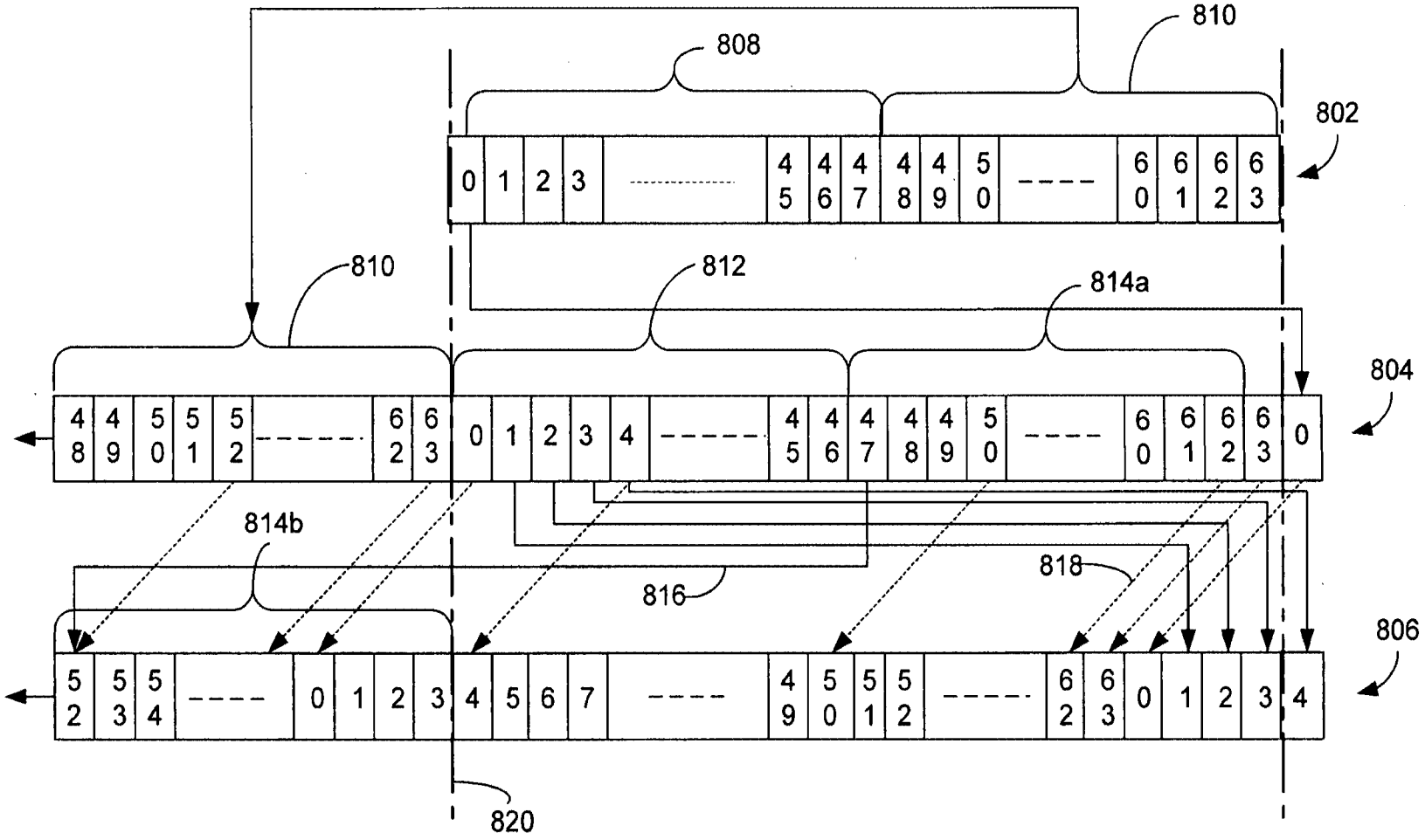

808
810
802
0 1 2 3 ---- 45 46 47 48 49 50 ---- 60 61 62 63
810
812
814a
804
48 49 50 51 52 ---- 62 63 0 1 2 3 4 ---- 45 46 47 48 49 50 ---- 60 61 62 63 0
814b
816
818
806
52 53 54 ---- 0 1 2 3 4 5 6 7 ---- 49 50 51 52 ---- 62 63 0 1 2 3 4
820

FIG. 8

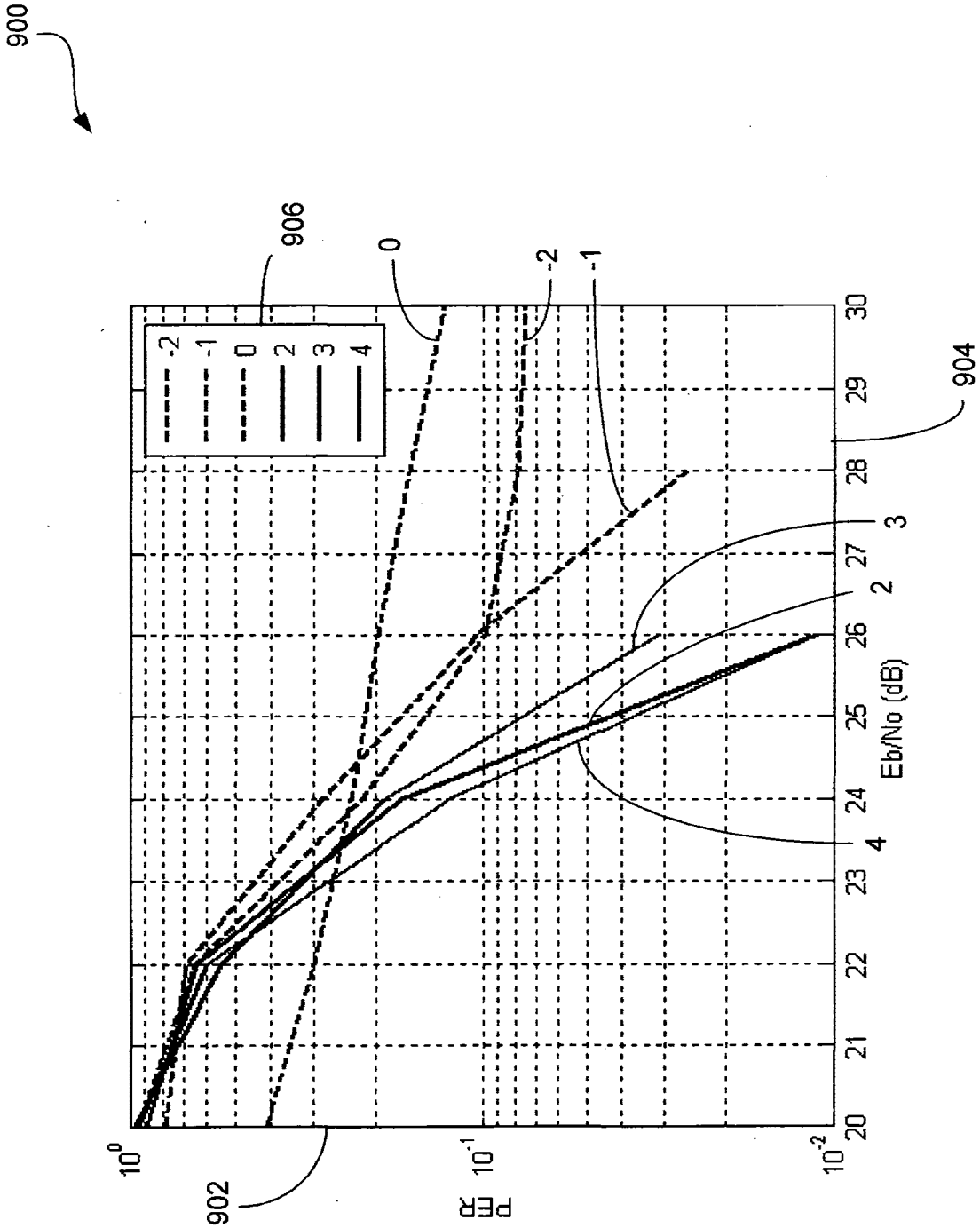

900
906
902
904
-2
-1
0
2
3
4
PER
Eb/No (dB)
10^{0}
10^{-1}
10^{-2}
20
21
22
23
24
25
26
27
28
29
30

FIG. 9

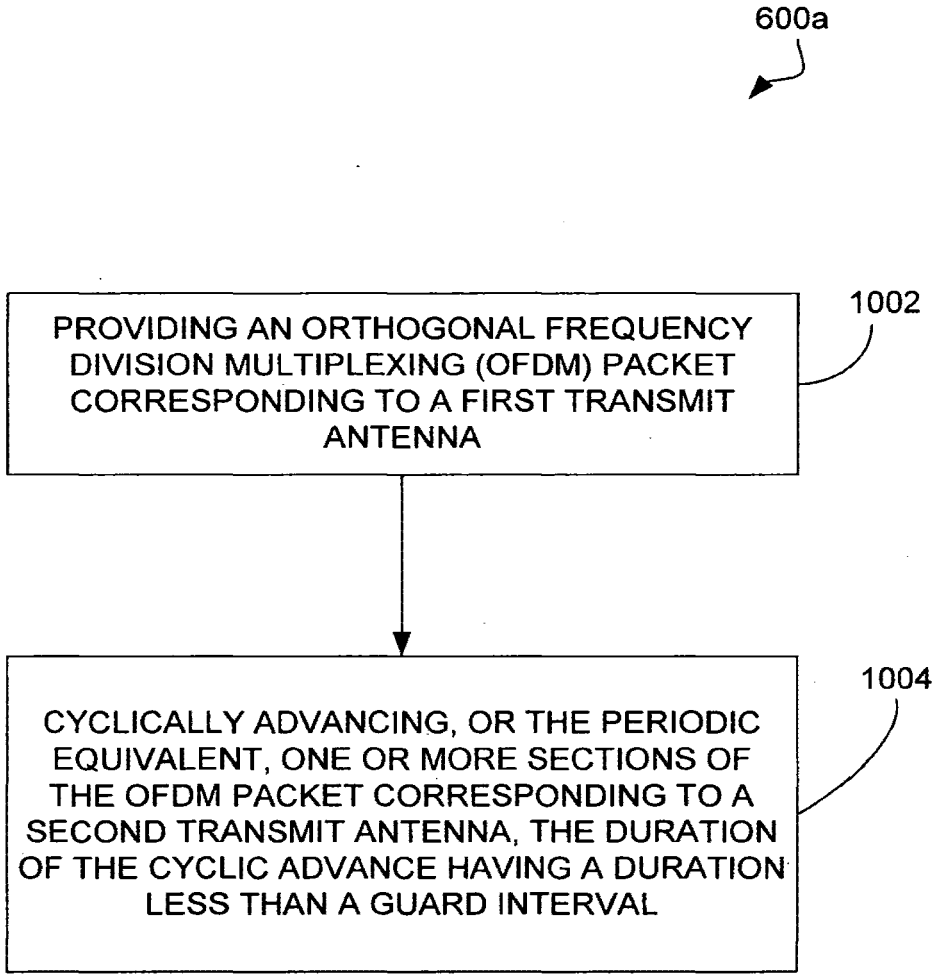

600a
PROVIDING AN ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM) PACKET CORRESPONDING TO A FIRST TRANSMIT ANTENNA
1002
CYCLICALLY ADVANCING, OR THE PERIODIC EQUIVALENT, ONE OR MORE SECTIONS OF THE OFDM PACKET CORRESPONDING TO A SECOND TRANSMIT ANTENNA, THE DURATION OF THE CYCLIC ADVANCE HAVING A DURATION LESS THAN A GUARD INTERVAL
1004

FIG. 10

DECLARATION FOR PATENT APPLICATION

Docket No: 050337-1020 / 04CXT0062WL

As the below named inventors, we hereby declare that:

Our residences, post office addresses and citizenships are as stated below next to our names.

We believe we are the original, first, and joint inventors of the subject matter which is claimed and for which a patent is sought on the invention entitled **CYCLIC DIVERSITY SYSTEMS AND METHODS**, the specification of which:

- ☒ is attached hereto.
- ☐ was filed on _____ as Application Serial No. _____.
- ☐ was filed on _____ under U.S. Express Mail No. _____.
- ☐ is set forth in PCT International Application No. _____; filed on _____ and as amended Under PCT Article 19 on _____ (if any).

I/we hereby state that I/we have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56, including for continuation-in-part applications, material information which became available between the filing date of the prior application and the national or PCT international filing date of the continuation-in-part application.

I/we hereby claim foreign priority benefits under Title 35, United States Code, 119(a)-(d) or (f), or 365(b) of any foreign application(s) for patent, inventor's or plant breeder's rights certificate(s), or 365(a) of any PCT international application which designated at least one country other than the United States of America listed below and have also identified below any foreign application for patent, inventor's or plant breeder's rights certificate(s), or any PCT international application having a filing date before that of the application on which priority is claimed: **NOT APPLICABLE.**

I/we hereby appoint all attorneys and agents of Thomas, Kayden, Horstemeyer & Risley, LLP, who are listed under the USPTO Customer Number shown below as my/our attorneys and agents to prosecute this application and to transact all business in the United States Patent and Trademark Office connected therewith, recognizing that the specific attorneys and agents listed under that Customer Number may be changed from time to time at the sole discretion of Thomas, Kayden, Horstemeyer & Risley, LLP, and request that all correspondence be addressed to the address filed under the same USPTO Customer Number.

24504

and the following attorneys from Conexant Systems, Inc.

Semion Talpalatsky, Reg. No. 35,380; Joseph H. Lee, Reg. No. 37,664.

Please address all telephone calls, in the first instance, to **Scott A. Horstemeyer** at telephone number: **(770) 933-9500. Address all correspondence to:**

Scott A. Horstemeyer
THOMAS, KAYDEN, HORSTEMEYER & RISLEY, L.L.P.
100 Galleria Parkway, N.W., Suite 1750
Atlanta, Georgia 30339-5948

I hereby declare that all statements made herein of my own knowledge are true and 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 statement and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Inventor's Signature: _____ Date: May 2, 2005

Full Name of Second Inventor: **Mark A. Webster**
Residence: **139 Island View Drive, Indian Harbor Beach, FL 32937** Citizenship: **USA**
Post Office Address: **Same as Residence.**

I hereby declare that all statements made herein of my own knowledge are true and 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 statement and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Inventor's Signature: Michael Seals Date: May 2, 2005

Full Name First or Sole Inventor: **Michael J. Seals**
Residence: **3870 Shady Run Road, Melbourne, FL 32934** Citizenship: **USA**
Post Office Address: **Same as Residence.**

PATENT APPLICATION SERIAL NO. _____

U.S. DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICE
FEE RECORD SHEET

05/06/2005 HTECKLU1 00000029 11121661

01 FC:1011	300.00 OP
02 FC:1111	500.00 OP
03 FC:1311	200.00 OP
04 FC:1202	150.00 OP

PTO-1556
(5/87)

*U.S. Government Printing Office: 2002 — 489-267/69033

PATENT APPLICATION FEE DETERMINATION RECORD
Effective December 8, 2004

11121661

CLAIMS AS FILED - PART I

	(Column 1)	(Column 2)
TOTAL CLAIMS	23	
FOR	NUMBER FILED	NUMBER EXTRA
TOTAL CHARGEABLE CLAIMS	23 minus 20=	*
INDEPENDENT CLAIMS	3 minus 3 =	*
MULTIPLE DEPENDENT CLAIM PRESENT		☐

* If the difference in column 1 is less than zero, enter "0" in column 2

SMALL ENTITY TYPE ☐		OR	OTHER THAN SMALL ENTITY	
RATE	FEE		RATE	FEE
BASIC FEE	150.00	OR	BASIC FEE	300.00
X$ 25=		OR	X$50=	150
X100=		OR	X200=	
+180=		OR	+360=	
TOTAL		OR	TOTAL	450

CLAIMS AS AMENDED - PART II

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA
AMENDMENT A	Total	*	Minus	**	=
	Independent	*	Minus	***	=
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM				☐

SMALL ENTITY		OR	OTHER THAN SMALL ENTITY	
RATE	ADDITIONAL FEE		RATE	ADDITIONAL FEE
X$ 25=		OR	X$50=	
X100=		OR	X200=	
+180=		OR	+360=	
TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA
AMENDMENT B	Total	*	Minus	**	=
	Independent	*	Minus	***	=
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM				☐

RATE	ADDITIONAL FEE		RATE	ADDITIONAL FEE
X$ 25=		OR	X$50=	
X100=		OR	X200=	
+180=		OR	+360=	
TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

		(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA
AMENDMENT C	Total	*	Minus	**	=
	Independent	*	Minus	***	=
	FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM				☐

RATE	ADDITIONAL FEE		RATE	ADDITIONAL FEE
X$ 25=		OR	X$50=	
X100=		OR	X200=	
+180=		OR	+360=	
TOTAL ADDIT. FEE		OR	TOTAL ADDIT. FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20."
***If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3."
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In Re Application of:

Webster et al.

Serial No.: TBA

Filed: May 4, 2005

For: Cyclic Diversity Systems and Methods

Confirmation No.: TBA

Group Art Unit: TBA

Examiner: TBA

Docket No.: 50337-1020

INFORMATION DISCLOSURE STATEMENT

Mail Stop Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

Sir:

This information disclosure statement is filed in accordance with 37 C.F.R. §§ 1.56, 1.97, and 1.98, and specifically:

☒ under 37 CFR 1.97(b), or
(within Three months of filing national application; or date of entry of international application; or before mailing date of first office action on the merits; whichever occurs last)

☐ under 37 CFR 1.97(c) together with either a:
- ☐ Statement Under 37 C.F.R. 1.97(e), or
- ☐ a $180.00 fee under 37 CFR 1.17(p), or

(After the CFR 1.97(b) time period, but before the final office action or notice of allowance, whichever occurs first)

☐ under 37 CFR 1.97(d) together with a:
- ☐ Statement under 37 CFR 1.97(e), and
- ☐ a $180.00 petition fee set forth in 37 CFR 1.17(p).

(Filed after final office action or notice of allowance, whichever occurs first, but before payment of the issue fee)

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Enclosed is Credit Card Payment Form (PTO-2038) in the amount of $.

Please charge $ to deposit account . At any time during the pendency of this application, please charge any fees required to Deposit Account pursuant to 37 CFR 1.25. The Commissioner is hereby requested to credit any overpayment to Deposit Account No. .

☒ Applicant(s) submit herewith *Form PTO 1449A - Information Disclosure Statement by Applicant* together with copies (where required) of patents, publications or other information of which applicant(s) are aware, which applicant(s) believe(s) may or may not be material to the examination of this application and for which there may be a duty to disclose in accordance with 37 CFR 1.56. As required by 37 C.F.R. §1.98(a), a legible copy of each document is provided.

☐ A concise explanation of the relevance of foreign language patents, foreign language publications and other foreign language information listed on PTO Form 1449, as presently understood by the individual(s) designated in 37 CFR 1.56(c) most knowledgeable about the content is given on the attached sheet, or where a foreign language patent is cited in a search report or other action by a foreign patent office in a counterpart foreign application, an English language version of the search report or action which indicates the degree of relevance found by the foreign office is listed on the form PTO 1449 and is enclosed herewith.

The following rights are reserved by the Applicant(s): the right to establish the patentability of the claimed invention over any of the listed documents should they be applied as reference, and/or the right to prove that some of these documents may not be prior art, and/or the right to prove that some of these documents may not be enabling for the teachings they purport to offer.

This statement should not be construed as a representation that an exhaustive search has been made, or that information more material to the examination of the present application does not exist. Any statements or identifications regarding the relevance of any portion(s) of cited references should not be construed as a representation that the most relevant portion(s) have been identified, and the absence of such statements or identifications should not be construed as representations that there are no relevant portion(s). The Examiner is specifically requested not to rely solely on the materials submitted herewith. The Examiner is requested to conduct an independent and thorough review of the documents, and to form independent opinions as to their significance.

It is requested that the information disclosed herein be made of record in this application and that the Examiner initial and return a copy of the enclosed PTO-1449 to indicate the documents have been considered.

Respectfully Submitted,

THOMAS, KAYDEN, HORSTEMEYER & RISLEY, L.L.P.

By: _____

David Rodack; Reg. No. 47,034

100 Galleria Parkway, Suite 1750
Atlanta, Georgia 30339-5948
770-933-9500

Form PTO-1449	Attorney Docket No. **50337-1020**	Serial No. **TBA**
INFORMATION DISCLOSURE CITATION	Applicant **Webster, et al.**	
(Use several sheets if necessary)	Filing Date **May 4, 2005**	Group **TBA**

U.S. PATENT DOCUMENTS

Examiner Initials	Item	Document Number	Date	Name	Class	Subclass	Filing Date If Appropriate

FOREIGN PATENT DOCUMENTS

		Document Number	Date	Country	Class	Subclass	Translation	
							Yes	No

OTHER DOCUMENTS *(Including Author, Title, Date, Pertinent Pages, etc.)*

	A	IEEE Std 802®-2001, "802® IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture," IEEE Computer Society, March 8, 2002
	B	Manoneet Singh, et al. and Bruce Edwards, et al., "WwiSE proposal: High throughput extension to the 802.11," IEEE 11-04-0886-00-000n, August 13, 2004.
	C	Syed Aon Mujtaba, "TGn Sync Proposal Technical Specification," IEEE 802.11-04/889r0, August 13, 2004.
	D	Aon Mujtaba, Adrian P. Stephens, Alek Purkovic, Andrew Myles, Brian Johnson, Daisuke Takeda, Darren McNamara, Dongjun (DJ) Lee, David Bagby, Eldad Perahia, Huanchun Ye, Hui-Ling Lou, James Chen, James Mike Wilson, Jan Boer, Jari Jokela, Jeff Gilbert, Joe Pitarressi, Jorg Habetha, John Sadowsky, Jon Rosdahl, Luke Qian, Mary Cramer , Masahiro Takagi, Monisha Ghosh, Nico van Waes, Osama Aboul-Magd, Paul Feinberg, Pen Li, Peter Loc, Pieter-Paul Giesberts, Richard van Leeuwen, Ronald Rietman, Seigo Nakao, Sheung Li, Stephen Shellhammer, Takushi Kunihior, Teik-Kheong, Tomoko Adachi, Tomoya Yamaura, Tsuguhide Aoki, Won-Joon Choi, Xiaowen Wang, Yasuhiko Tanabe, Yasuhiro Tanaka, Yoshiharu Doi, Yichi Morioka, Youngsoo Kim, "TGn Sync Proposal," IEEE 802.11-04/888r0, August 13, 2004.
	E	VK Jones, Neil Hamady, Jason Trachewsky, Michael Seals, Stephan ten Brink, George Vlantis, Sean Coffey, "WwiSE IEEE 802.11n Proposal," IEEE 802.11-04/0935r3, September 16, 2004.

* EXAMINER: Initial if citation considered, whether or not citation is in conformance with MPEP § 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to the applicant.

EXAMINER'S SIGNATURE:	DATE CONSIDERED:

Patent and Trademark Office; U. S. DEPARTMENT OF COMMERCE

IEEE Std 802®-2001
(Revision of IEEE Std 802-1990)

IEEE standards

802®

IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

IEEE

Published by
The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

8 March 2002

Print: SH94947
PDF: SS94947

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IEEE Std 802®-2001
(Revision of IEEE Std 802-1990)

IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture

Sponsor

LAN/MAN Standards Committee
of the
IEEE Computer Society

Approved 6 December 2001

IEEE-SA Standards Board

Abstract: IEEE Std 802-2001, IEEE Standards for Local and Metropolitan Area Networks: Overview and Architecture, provides an overview to the family of IEEE 802 Standards. It defines compliance with the family of IEEE 802 Standards; it describes the relationship of the IEEE 802 Standards to the Open Systems Interconnection Basic Reference Model [ISO/IEC 7498-1:1994] and explains the relationship of these standards to the higher layer protocols; it provides a standard for the structure of LAN MAC addresses; and it provides a standard for identification of public, private, and standard protocols.
Keywords: IEEE 802 standards compliance, Local Area Networks (LANs), LAN/MAN architecture, LAN/MAN reference model, Metropolitan Area Networks (MANs).

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3 Park Avenue, New York, NY 10016-5997, USA

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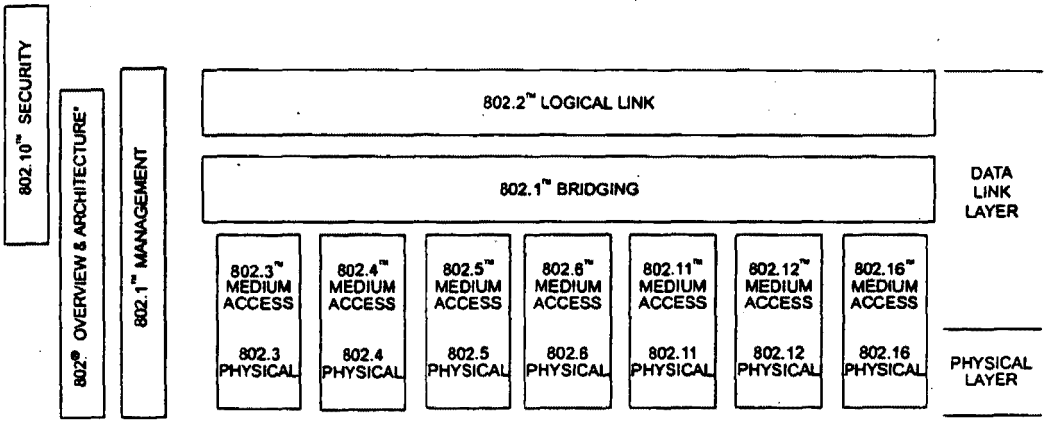
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Introduction

(This introduction is not part of IEEE Std 802-2001, IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture.)

IEEE Std 802-2001 provides an overview to the family of IEEE 802 Standards. It defines compliance with the family of IEEE 802 Standards; it describes the relationship of the IEEE 802 Standards to the Open Systems Interconnection Basic Reference Model [ISO/IEC 7498-1: 1994] and explains the relationship of these standards to higher layer protocols; it provides a standard for the structure of LAN MAC addresses; and it provides a standard for the identification of public, private, and standard protocols.

This standard is part of a family of standards for local and metropolitan area networks. The relationship between the standard and other members of the family is shown below. (The numbers in the figure refer to IEEE standard numbers.[1])



* Formerly IEEE Std 802.1A.

This family of standards deals with the Physical and Data Link Layers as defined by the International Organization for Standardization (ISO) Open Systems Interconnection Basic Reference Model (ISO/IEC 7498-1:1994). The access standards define several types of medium access technologies and associated physical media, each appropriate for particular applications or system objectives. Other types are under investigation.

The standards defining the technologies noted above are as follows:

- IEEE Std 802:[2] — *Overview and Architecture*. This standard provides an overview to the family of IEEE 802 Standards. This document forms part of the IEEE Std 802.1 scope of work.
- IEEE Std 802.1B™ and 802.1K™ [ISO/IEC 15802-2]: — *LAN/MAN Management*. Defines an Open Systems Interconnection (OSI) management-compatible architecture, and services and protocol elements for use in a LAN/MAN environment for performing remote management.

[1]The IEEE Standards referred to in the above figure and list are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

[2]The IEEE 802 Architecture and Overview Specification, originally known as IEEE Std 802.1A, has been renumbered as IEEE Std 802. This has been done to accommodate recognition of the base standard in a family of standards. References to IEEE Std 802.1A should be considered as references to IEEE Std 802.

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• IEEE Std 802.1D™	*Media Access Control (MAC) Bridges*. Specifies an architecture and protocol for the [ISO/IEC 15802-3]: interconnection of IEEE 802 LANs below the MAC service boundary.
• IEEE Std 802.1E™ [ISO/IEC 15802-4]:	*System Load Protocol*. Specifies a set of services and protocol for those aspects of management concerned with the loading of systems on IEEE 802 LANs.
• IEEE Std 802.1F™	*Common Definitions and Procedures for IEEE 802 Management Information*.
• IEEE Std 802.1G™ [ISO/IEC 15802-5]:	*Remote Media Access Control (MAC) Bridging*. Specifies extensions for the interconnection, using non-LAN systems communication technologies, of geographically separated IEEE 802 LANs below the level of the logical link control protocol.
• IEEE Std 802.1H™ [ISO/IEC TR 11802-5]	*Recommended Practice for Media Access Control (MAC) Bridging of Ethernet V2.0 in IEEE 802 Local Area Networks*.
• IEEE Std 802.1Q™	*Virtual Bridged Local Area Networks*. Defines an architecture for Virtual Bridged LANs, the services provided in Virtual Bridged LANs, and the protocols and algorithms involved in the provision of those services.
• IEEE Std 802.2 [ISO/IEC 8802-2]:	*Logical Link Control*.
• IEEE Std 802.3 [ISO/IEC 8802-3]:	*CSMA/CD Access Method and Physical Layer Specifications*.
• IEEE Std 802.4 [ISO/IEC 8802-4]:	*Token Bus Access Method and Physical Layer Specifications*.
• IEEE Std 802.5 [ISO/IEC 8802-5]:	*Token Ring Access Method and Physical Layer Specifications*.
• IEEE Std 802.6 [ISO/IEC 8802-6]:	*Distributed Queue Dual Bus Access Method and Physical Layer Specifications*.
• IEEE Std 802.10:	*Interoperable LAN/MAN Security*. Currently approved: Secure Data Exchange (SDE).
• IEEE Std 802.11: [ISO/IEC 8802-11]	*Wireless LAN Medium Access Control (MAC) Sublayer and Physical Layer Specifications*.
• IEEE Std 802.12: [ISO/IEC 8802-12]	*Demand Priority Access Method, Physical Layer and Repeater Specification*.
• IEEE Std 802.15™:	*Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for: Wireless Personal Area Networks*.
• IEEE Std 802.16:	*Standard Air Interface for Fixed Broadband Wireless Access Systems*.
• IEEE Std 802.17™:	*Resilient Packet Ring Access Method and Physical Layer Specifications*.

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In addition to the family of standards, the following is a recommended practice for a common physical layer technology:

• IEEE Std 802.7™:	*IEEE Recommended Practice for Broadband Local Area Networks.*

The reader of this standard is urged to become familiar with the complete family of standards.

Conformance test methodology

An additional standards series, identified by the number 1802™, has been established to identify the conformance test methodology documents for the IEEE 802 family of standards. Thus the conformance test documents for IEEE 802.3 are numbered 1802.3™, the conformance test documents for IEEE 802.5 will be 1802.5™, and so on. Similarly, ISO will use 18802 to number conformance test standards for 8802 standards.

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IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture

1. Scope

1.1 General

This document serves as the foundation for the family of IEEE 802®[1] Standards published by IEEE for Local Area Networks (LANs) and Metropolitan Area Networks (MANs). It contains descriptions of the networks considered as well as a reference model (RM) for protocol standards. Compliance with the family of IEEE 802 Standards is defined, and a standard for the identification of public, private, and standard protocols is included.

1.2 Key concepts

The LANs described herein are distinguished from other types of data networks in that they are optimized for a moderate-sized geographic area, such as a single office building, a warehouse, or a campus. An IEEE 802 LAN is a peer-to-peer communication network that enables stations to communicate directly on a point-to-point, or point-to-multipoint, basis without requiring them to communicate with any intermediate switching nodes. LAN communication takes place at moderate-to-high data rates, and with short transit delays, on the order of a few milliseconds or less.

A LAN is generally owned, used, and operated by a single organization. This is in contrast to Wide Area Networks (WANs) that interconnect communication facilities in different parts of a country or are used as a public utility.

A MAN is optimized for a larger geographical area than is a LAN, ranging from several blocks of buildings to entire cities. As with local networks, MANs can also depend on communications channels of moderate-to-high data rates. A MAN might be owned and operated by a single organization, but it usually will be used by many individuals and organizations. MANs might also be owned and operated as public utilities. They will often provide means for internetworking of local networks.

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Although primarily aimed at deployment on the scale of a large building or a campus, LANs are also frequently applied in smaller areas, such as small offices or single laboratories, and increasingly in homes. At the small-scale application level, a LAN is different from the type of network, such as a data bus or backplane bus, that is optimized for the interconnection of devices on a desktop or of components within a single piece of equipment. However, desktop-scale applications of LANs are also possible, particularly where the nature of the application is more suited to peer-to-peer communication among autonomous components, as opposed to a system structure with more centralized control.

The original IEEE 802 LAN technologies used shared-medium communication, with information broadcast for all stations to receive. That approach has been varied and augmented subsequently, but in ways that preserve the appearance of simple peer-to-peer communications behavior for end stations. In particular, the use of bridges (see 6.3.2) for interconnecting LANs is now widespread. These devices allow the construction of networks with much larger numbers of LAN end stations, and much higher aggregate throughput, than would be achievable with a single shared-medium LAN. End stations attached to such a bridged LAN can communicate with each other just as though they were attached to a single shared-medium LAN (however, the ability to communicate with other stations can be limited by use of management facilities in the bridges, particularly where broadcast or multicast transmissions are involved). A further stage in this evolution has led to the use of point-to-point full duplex communication in LANs, either between an end station and a bridge or as a typically high-speed link between a pair of bridges.

The basic communications capabilities provided by all LANs and MANs are packet-based, as opposed to either cell-based or isochronous. That is, the basic unit of transmission is a sequence of data octets, which can be of any length within a range that is dependent on the type of LAN; for all LAN types, the maximum length is in excess of 1000 octets. (By contrast, cell-based communication transmits data in shorter, fixed-length units; isochronous communication transmits data as a steady stream of octets, or groups of octets, at equal time intervals.)

An optional function that may be offered by a LAN or a MAN is the provision of local networking of isochronous bearer services that are compatible with, or higher speed versions of, Integrated Services Digital Networks (ISDN) as defined by the ITU-T I-series Recommendations, to support voice, video, and data devices and terminals. These services are based on the use of end-user to end-user isochronous bearers that will span the supporting Integrated Services LAN (ISLAN) or MAN and an intervening ISDN-conformant WAN. Typically, the information streams for packet and isochronous services are multiplexed over the same physical media. In addition, capabilities are specified for a single integrated management of these various streams.

1.3 Application and support

The networks are intended to have wide applicability in many environments. The primary aim is to provide for moderate-cost devices and networks, suitable for commercial, educational, governmental, and industrial applications. Low-cost alternatives are possible for some networks, and application in other environments is not precluded. The following lists are intended to show some applications and devices and, as such, are not intended to be exhaustive, nor do they constitute a set of required items:

- File transfer
- Graphics
- Text processing
- Desktop publishing
- Electronic mail
- Database access
- Transaction processing

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- Multimedia
- Office automation
- Process control
- Robotics
- Integrated Services (voice, video and data) applications
- Client/server applications

The networks are intended to support various data devices, such as the following:

- Computers
- Terminals
- Mass storage devices
- Printers and plotters
- Photocopiers and facsimile machines
- Image and video monitors
- Wireless terminals
- Monitoring and control equipment
- Bridges, routers, and gateways
- Integrated Services devices, including ISDN terminals and end systems supporting combined voice, video, and data applications

1.4 An international family of standards

The terms LAN and MAN encompass a number of data communications technologies and applications of these technologies. So it is with the IEEE 802 Standards. In order to provide a balance between the proliferation of a very large number of different and incompatible local and metropolitan networks, on the one hand, and the need to accommodate rapidly changing technology and to satisfy certain applications or cost goals, on the other hand, several types of medium access technologies are currently defined in the family of IEEE 802 Standards. In turn, these medium access control (MAC) standards are defined for a variety of physical media. A logical link control (LLC) standard, a secure data exchange standard, and MAC bridging standards are intended to be used in conjunction with the MAC standards. In some ISLAN and MAN standards, provisions are made for optionally conveying isochronous bearer services in support of continuous voice, video, and synchronous data applications. An architecture and protocols for the management of IEEE 802 LANs are also defined.

The IEEE 802 Standards have been developed and applied in the context of an increasingly global data communications industry. This global context is recognized in that most IEEE 802 Standards are progressed to become also international standards, within ISO/IEC JTC 1 (Joint Technical Committee 1, Information Technology, of the International Organization for Standardization and the International Electrotechnical Commission); see Clause 2 and Annex A.

2. References

The following publications contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to

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revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below.

ISO/IEC 7498-1:1994, Information technology—Open Systems Interconnection—Basic Reference Model: The basic model.[2]

ISO/IEC 8802-2:1998 (IEEE Std 802.2™-1998), Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 2: Logical Link Control.[3]

ISO/IEC TR 11802-1:1997, Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Technical reports and guidelines—Part 1: The structure and coding of Logical Link Control addresses in Local Area Networks.

ISO/IEC TR 11802-2:1999, Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Technical reports and guidelines—Part 2: Standard Group MAC Addresses.

ISO/IEC 15802-1:1995, Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Common specifications—Part 1: Medium access control (MAC) service definition.

ISO/IEC 15802-3:1998 (IEEE Std 802.1D™-1998), Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Common specifications—Part 3: Media Access Control (MAC) Bridges.

NOTE—Annex A lists, for information, the other LAN/MAN and related standards. Unlike those listed above, they do not contain detailed provisions that are used, by reference, by this standard.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this standard, the following definitions apply. *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition [B2],[4] should be referenced for terms not defined in this clause.

3.1.1 access domain: A set of LAN or MAN stations together with interconnecting data transmission media and related equipment (e.g., connectors, repeaters), in which the LAN or MAN stations use the same MAC protocol to establish the sequence of stations that are in temporary control of the shared transmission media.

3.1.2 bit-reversed representation: The representation of a sequence of octet values in which the values of the individual octets are displayed in order from left to right, with each octet value represented as a two-digit hexadecimal numeral, and with the resulting pairs of hexadecimal digits separated by colons. The order of the hexadecimal digits in each pair, and the mapping between the hexadecimal digits and the bits of the octet value, are derived by reversing the order of the bits in the octet value and interpreting the resulting bit sequence as a binary numeral using the normal mathematical rules for digit significance.

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[2]ISO/IEC publications are available from the ISO Central Secretariat, Case Postale 56, 1 rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iso.ch/). ISO/IEC publications are also available in the United States from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/). Electronic copies are available in the United States from the American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

[3]The IEEE standards referred to in Clause 2 are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

[4]The numbers in brackets correspond to those of the bibliography in Annex A.

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NOTE—The bit-reversed representation is applicable to LAN MAC addresses for use in a Token Ring (IEEE 802.5™) or FDDI environment. See Figure 8 for a comparative example of bit-reversed and hexadecimal representation.

3.1.3 bridge, MAC bridge: A functional unit that interconnects two or more LANs or MANs that use the same Data Link layer protocols above the MAC sublayer, but can use different MAC protocols.

3.1.4 canonical format: The format of a MAC data frame in which the octets of any MAC addresses conveyed in the MAC user data field have the same bit ordering as in the Hexadecimal Representation.

3.1.5 end station: A device attached to a LAN or MAN, which acts as a source of, and/or destination for, data traffic carried on the LAN or MAN.

3.1.6 Ethernet frame: A MAC data frame structured in accordance with ISO/IEC 8802-3 and containing an Ethernet type value in the LENGTH / TYPE field.

3.1.7 fibre distributed data interface (FDDI) frame: A MAC data frame structured in accordance with ISO/IEC 9314-2.

3.1.8 hexadecimal representation: The representation of a sequence of octet values in which the values of the individual octets are displayed in order from left to right, with each octet value represented as a two-digit hexadecimal numeral, and with the resulting pairs of hexadecimal digits separated by hyphens. The order of the hexadecimal digits in each pair, and the mapping between the hexadecimal digits and the bits of the octet value, are derived by interpreting the bits of the octet value as a binary numeral using the normal mathematical rules for digit significance.

NOTE—See Figure 8 for a comparative example of bit-reversed and hexadecimal representation.

3.1.9 IEEE 802.3™ frame, 802.3 frame: A MAC data frame structured in accordance with ISO/IEC 8802-3 and containing a length value in the LENGTH / TYPE field.

3.1.10 IEEE 802.5 frame, 802.5 frame: A MAC data frame structured in accordance with ISO/IEC 8802-5.

3.1.11 IEEE 802.n frame, 802.n frame: A MAC data frame structured in accordance with ISO/IEC 8802-n.

NOTES

1—At the time of publication of this standard, relevant specifications, in addition to those cited explicitly in 3.1.9 and 3.1.10, are for n = 4, 6, 9, and 11.

2—ISO/IEC 8802-12 also defines a MAC protocol, but it does not specify its own MAC data frame format; instead, it uses the IEEE 802.3 and IEEE 802.5 frame formats.

3.1.12 IEEE 802 LAN, 802 LAN: A LAN consisting of an access domain using either a MAC protocol specified in one of the IEEE 802.n and ISO/IEC 8802-n Standards or the FDDI MAC protocol.

3.1.13 IEEE 802 MAN, 802 MAN: A MAN consisting of one or more interconnected subnetworks each using a MAC protocol specified in an IEEE 802 or ISO/IEC 8802 MAN Standard.

NOTE—Part of the data communication capability of an IEEE 802 MAN is the provision of a data service equivalent to that provided by an IEEE 802 LAN, over the extended geographical area of the MAN.

3.1.14 interconnection: The provision of data communication paths between LAN or MAN stations.

3.1.15 interworking: The use of interconnected LAN or MAN stations for the exchange of data, by means of protocols operating over the underlying data transmission paths.

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3.1.16 LAN: A computer network, located on a user's premises, within a limited geographical area.

3.1.17 MAC control frame: A data structure consisting of fields in accordance with a MAC protocol, for the communication of control information, only, in a LAN or MAN.

NOTE—ISO/IEC 8802-5 uses the term "MAC frame" in this sense.

3.1.18 MAC data frame: A data structure consisting of fields in accordance with a MAC protocol, for the communication of user data and control information in a LAN or MAN; one of the fields contains a sequence of octets of user data.

3.1.19 MAC protocol: The protocol that governs access to the transmission medium in a LAN or MAN, to enable the exchange of data between LAN or MAN stations.

3.1.20 MAN: A computer network, extending over a large geographical area such as an urban area and providing integrated communication services such as data, voice, and video.

3.1.21 noncanonical format: The format of a MAC data frame in which the octets of MAC addresses conveyed in the MAC user data field have the same bit ordering as in the Bit-reversed representation.

3.1.22 octet: A sequence of eight bits, the ends of the sequence being identified as the most significant bit (MSB) and the least significant bit (LSB).

NOTE—This identification of the ends of the sequence defines an unambiguous mapping from octet values, via binary numerals, to the integers 0–255, and hence a mapping also from octet values to the expressions of those integers as numerals in hexadecimal notation. See: Hexadecimal Representation.

3.1.23 station: An end station or bridge.

4. Abbreviations and acronyms

CMIP	common management information protocol (ISO/IEC 9596-1)
CSMA/CD	carrier sense multiple access with collision detection (ISO/IEC 8802-3)
DQDB	distributed queue dual bus
FDDI	fibre distributed data interface (ISO/IEC 9314)
IM	implementation model
I/G	individual/group
ISDN	integrated services digital network
ISLAN	integrated services LAN (ISO/IEC 8802-9)
LAN	local area network
LLC	logical link control (ISO/IEC 8802-2)
LSAP	link service access point (ISO/IEC 8802-2)
LSB	least significant bit
MAC	medium access control, media access control[5]
MAN	metropolitan area network

[5]Both forms are used, with the same meaning. This standard uses "medium."

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MIB	management information base
MOCS	managed object conformance statement
MSAP	MAC service access point
MSB	most significant bit
PDU	protocol data unit
PhSAP	physical service access point
PICS	protocol implementation conformance statement
RM	reference model
OSI	open systems interconnection (ISO/IEC 7498-1)
OUI	organizationally unique identifier
SNAP	subnetwork access protocol
SNMP	simple network management protocol (RFC 1157[6])
U/L	universally or locally administered
WAN	wide area network

5. Compliance

NOTE—IEEE policy with respect to claims of compliance, conformance, or compatibility with IEEE standards can be found in the Trademark Policy statement in the front matter. This clause will be deleted in the next revision of this standard.

6. Reference and implementation models

6.1 Introduction

This clause defines the IEEE 802 LAN and MAN RM (LAN&MAN/RM) and implementation model (LAN&MAN/IM). The intent of presenting these models is as follows:

a) To provide an overview of the standard

b) To serve as a guide to reading other IEEE 802 Standards

The IEEE 802 LAN&MAN/RM is patterned after the Open Systems Interconnection (OSI) Basic Reference Model (OSI/RM), ISO/IEC 7498-1. It is assumed that the reader has some familiarity with the OSI/RM and its terminology. The IEEE 802 Standards encompass the functionality of the lowest two layers of the OSI/RM (i.e., Physical layer and Data Link layer) and the higher layers as they relate to LAN management. The LAN&MAN/RM is similar to the OSI/RM in terms of its layers and the placement of its service boundaries.

For the mandatory packet services supported by all LANs and MANs, the Data Link layer is structured as two sublayers, with the LLC sublayer operating over a MAC sublayer. In addition, some IEEE 802 LAN technologies provide direct support by the MAC sublayer for an alternative Ethernet sublayer operating at the same place in the architecture as does LLC; for the other IEEE 802 LAN technologies, the equivalent

[6]See A.1 for information on obtaining RFCs.

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functionality is provided by encapsulation of the Ethernet sublayer information within LLC Protocol Data Units (PDUs), using the Subnetwork Access Protocol specified in Clause 10 of this standard.

Optionally, some Integrated Service LANs and MANs may also support ITU-T compatible isochronous bearer services at the Physical layer.

The OSI/RM is referred to by the IEEE 802 Standards because of the following:

a) The OSI/RM provides a common vehicle for understanding and communicating the various components and interrelationships of the standards.

b) The OSI/RM helps define terms.

c) The OSI/RM provides a convenient framework to aid in the development and enhancement of the standards.

d) The use of the OSI/RM facilitates a higher degree of interoperability than might otherwise be possible.

Figure 1 shows the architectural view of LAN&MAN/RM and its relation to the OSI/RM.

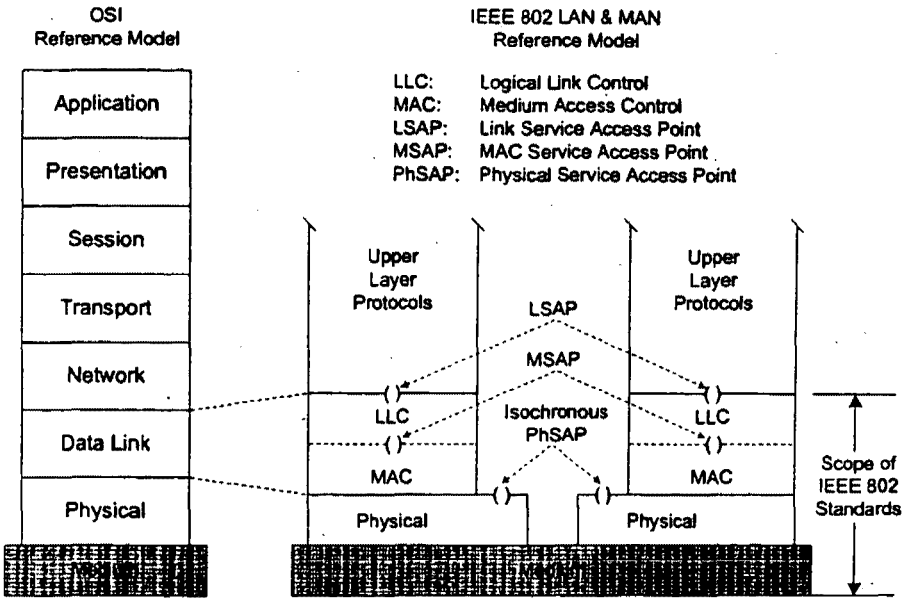


Figure 1—IEEE 802 RM for end stations (LAN&MAN/RM)

The LAN&MAN/IM is more specific than the LAN&MAN/RM, allowing differentiation between implementation approaches (e.g., of carrier sense multiple access with collision detection [CSMA/CD], and token passing). Figure 2 shows two implementation views of LAN&MAN/IMs and their relation to the LAN&MAN/RM.

Both Figure 1 and Figure 2 illustrate the application of the models in LAN end stations. A variation of the model applies within bridges (see 6.3.2). Also, Figure 1 and Figure 2 illustrate only the basic transfer of user data between end stations.

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LLC: Logical Link Control
MAC: Medium Access Control
PHY: Physical Layer
PLS: Physical Layer Signaling
PMA: Physical Medium Attachment

1: Attachment Unit Cable
2: Attachment Unit Connectors
AUI: Attachment Unit Interface
MAU: Medium Attachment Unit
MDI: Medium Dependent Interface

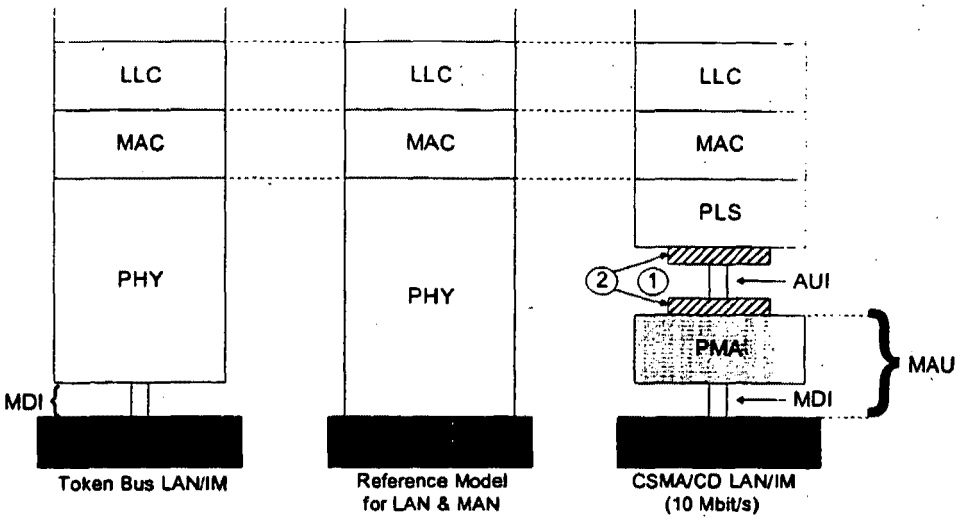


Figure 2—IEEE 802 RM and two examples of end-station implementation model

Considerations of management and security in LANs and MANs are also covered by IEEE 802 standards; these optional features lead to an elaboration of the RM (Figure 3). LAN/MAN management provides a Data Link layer management protocol for exchange of management information between LAN stations; managed objects are defined for all LAN/MAN protocol standards. The Secure Data Exchange (SDE) entity forms part of the LLC sublayer and provides a secure connectionless service immediately above the MAC sublayer.

LMM: LAN/MAN Management
SDE Secure Data Exchange

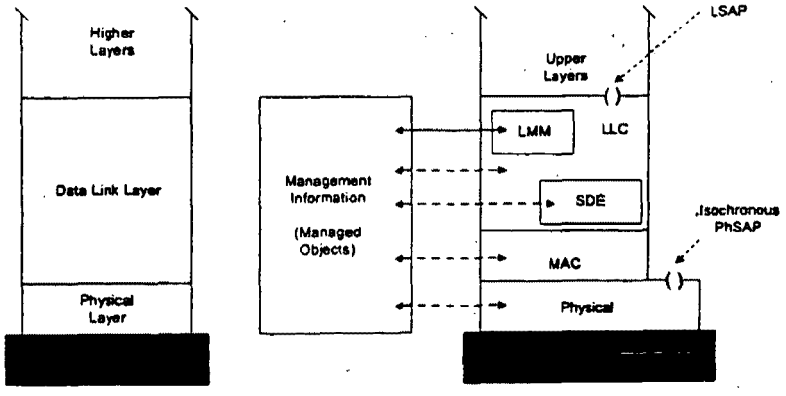


Figure 3—IEEE 802 RM with end-station management and security

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6.2 RM description for end stations

The LAN&MAN/RM maps to the OSI/RM as shown in Figure 1. The applicable part of the OSI/RM consists of the lowest two layers: the Data Link layer and the Physical layer. These map onto the same two layers in the IEEE LAN&MAN/RM. The MAC sublayer of the LAN&MAN/RM exists between the Physical layer and the LLC sublayer to provide a common service for the LLC sublayer (certain MAC types provide additional MAC service features that can be used by LLC, in addition to the common core features). Service access points (SAPs) for addressing endpoints are shown.

6.2.1 Service access points (SAPs)

Multiple-link service access points (LSAPs) provide interface ports to support multiple higher layer users above the LLC sublayer.

The MAC sublayer provides a single MAC service access point (MSAP) as an interface port to the LLC sublayer in an end station. In general, the MSAP is identified (for transmission and reception) by a single individual MAC address and (for reception) by the LAN-wide broadcast MAC address; it can also be identified (for reception) by one or more group MAC addresses. Clause 9 provides details of how these MAC addresses are constructed and used; see also ISO/IEC 15802-1.

A user of LLC is identified by, at a minimum, the logical concatenation of the MAC address field and the LLC address field in a frame. See ISO/IEC 8802-2 and ISO/IEC TR 11802-1 for a description of LLC addresses.

The Physical layer provides an interface port to a single MAC station, and in the case of ISLANs and MANs, it may optionally offer isochronous bearer services at multiple Physical service access points (PhSAPs). See 11.3 for a more detailed description of ISLAN and MAN PhSAP addressing requirements.

6.2.2 LLC sublayer

The LLC sublayer standard, ISO/IEC 8802-2, describes three types of operation for data communication between service access points: unacknowledged connectionless-mode (type 1), connection-mode (type 2), and acknowledged connectionless-mode (type 3).

With type 1 operation, information frames are exchanged between LLC entities without the need for the prior establishment of a logical link between peers. The LLC sublayer does not provide any acknowledgments for these LLC frames, nor does it provide any flow control or error recovery procedures.

LLC type 1 also provides a TEST function and an Exchange Identification (XID) function. The capability to act as responder for each of these functions is mandatory: This allows a station that chooses to support initiation of these functions to check the functioning of the communication path between itself and any other station, to discover the existence of other stations, and to find out the LLC capabilities of other stations.

With type 2 operation, a logical link is established between pairs of LLC entities prior to any exchange of information frames. In the data transfer phase of operation, information frames are transmitted and delivered in sequence. Error recovery and flow control are provided, within the LLC sublayer.

With type 3 operation, information frames are exchanged between LLC entities without the need for the prior establishment of a logical link between peers. However, the frames are acknowledged to allow error recovery and proper ordering. Further, type 3 operation allows one station to poll another for data.

NOTE—ISO/IEC 8802-2 defines four classes of LLC, each of which groups together support for a different combination of LLC types. All classes include mandatory support of type 1.

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The Secure Data Exchange (SDE) entity forms part of the LLC sublayer and provides a secure connectionless service immediately above the MAC sublayer. The operation of the SDE entity is described in IEEE Std 802.10™.

6.2.3 MAC sublayer

The MAC sublayer performs the functions necessary to provide packet-based, connectionless-mode (datagram style) data transfer between stations in support of the LLC sublayer or of the Ethernet sublayer (see 6.1) for LANs that support it. The term *MAC frame*, or simply *frame*, is used to describe the packets transferred within the MAC sublayer. In some MAC types (e.g., Token Ring), some MAC frames are used in support of the MAC sublayer functionality itself, rather than for transfer of LLC data.

The principal functions of the MAC sublayer comprise the following:

- Frame delimiting and recognition
- Addressing of destination stations (both as individual stations and as groups of stations)
- Conveyance of source-station addressing information
- Transparent data transfer of LLC PDUs, or of equivalent information in the Ethernet sublayer
- Protection against errors, generally by means of generating and checking frame check sequences
- Control of access to the physical transmission medium

Other functions of the MAC sublayer—applicable particularly when the supporting implementation includes interconnection devices such as hubs or bridges—include flow control between an end station and an interconnection device (see 6.3), and filtering of frames according to their destination addresses to reduce the extent of propagation of frames in parts of a LAN or MAN that do not contain communication paths leading to the intended destination end station(s).

The functions listed are those of the MAC sublayer as a whole. Responsibility for performing them is distributed across the transmitting and receiving end stations, and any interconnection devices such as bridges. Devices with different roles therefore can behave differently in support of a given function. For example, transmission of a MAC frame by a bridge is very similar to transmission by an end station, but not identical. Principally, the handling of source-station addressing is different.

The various MAC specifications all specify MAC frame formats in terms of a serial transmission model for the service provided by the supporting Physical layer. This model supports concepts such as "first bit (e.g., of a particular octet) to be transmitted," and a strict order of octet transmission, in a uniform manner. However, the ways in which the model has been applied in different MAC specifications are not completely uniform with respect to bit-ordering within octets (see Clause 9, and particularly 9.5, for examples and explanation).

NOTE—The serial transmission model does not preclude current or future MAC specifications from using partly or wholly octet-oriented specifications of frame formats or of the interface to the Physical layer.

6.2.4 Physical layer

The Physical layer provides the capability of transmitting and receiving bits between Physical layer entities. A pair of Physical layer entities identifies the peer-to-peer unit exchange of bits between two MAC users, and in the case of ISLANs and MANs, it may optionally support the exchange of bits with end-to-end timing preserved between isochronous-service PhSAPs.

The Physical layer provides the capability of transmitting and receiving modulated signals assigned to specific frequency channels, in the case of broadband or wireless, or to a single-channel band, in the case of baseband.

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Note that, whereas the service offered to the MAC sublayer is expressed as the transfer of bits (in sequences representing MAC frames), the actual symbols that are encoded for transmission do not always represent individual bits. Particularly at speeds of 100 Mbit/s and above, or for wireless transmission, the Physical layer can map blocks of several bits (e.g., 4, 5, or 8 bits) to different multi-element symbols. In some Physical-layer encodings, these symbols are subject to further transformation before transmission, and in some cases, the transmission is spread over multiple physical data paths. The actual transmission on physical media can therefore be far removed from the simple bit-serial representation of a MAC frame (as was specified, for example, in the original ISO/IEC 8802-3 and ISO/IEC 8802-5 Physical layers).

6.2.5 Layer and sublayer management

The LLC sublayer, MAC sublayer, and Physical layer standards also include a management component that specifies managed objects and aspects of the protocol machine that provides the management view of these resources. See Clause 8 for further information.

6.3 Interconnection and Interworking

In some cases, the end systems on a LAN or MAN have no need to communicate with end systems on other networks (other LANs, WANs, etc.). However, this is not expected to be the norm; there are many cases in which end stations on a LAN or MAN will need to communicate with end systems on other networks and so devices that interconnect the LAN or MAN with other kinds of networks are required. In addition, several standard methods have been developed that permit a variety of interconnection devices to operate transparently to end stations on a LAN or MAN in order to extend the LAN/MAN capabilities available to end stations, particularly in terms of the geographical extent and/or total number of end stations that can be supported.

Standard methods of interworking fall into the following three general categories, depending on the layer at which the corresponding interconnection devices operate:

— Physical-layer interconnection, using devices usually termed *repeaters* or *hubs* (6.3.1)

— MAC-sublayer interconnection, using devices termed *bridges* (6.3.2)

— Network-layer interconnection, using devices usually termed *routers* (6.3.3)

See also Clause 11 of this standard, for an outline of the optional methods by which ISLANs and MANs may support isochronous interworking with WANs and with remote ISLANs and MANs.

6.3.1 Physical-layer interconnection: repeaters and hubs

The original IEEE 802 LAN specifications were for end stations attached to a shared communication medium. This basic LAN configuration is referred to as a single *access domain*; the domain consists of the set of LAN stations such that at most one can be transmitting at a given time, with all other stations acting as (potential) receivers.

A repeater is a device used to interconnect segments of the physical communications media, for example, to extend the range of a LAN when the physical specifications of the technology would otherwise be exceeded, while providing a single access domain for the attached LAN stations. Repeaters used in support of multiple end stations attached by star-wired network topologies are frequently referred to as hubs.

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6.3.2 MAC-sublayer interconnection: bridges

6.3.2.1 Bridges and bridged LANs

Bridges (see 3.1.3) are devices that interconnect multiple access domains. ISO/IEC 15802-3 provides the basic specification for bridge interworking among IEEE 802 networks. A *bridged* LAN (see 3.1 of ISO/IEC 15802-3) consists of one or more bridges together with the complete set of access domains that they interconnect. A bridged LAN provides end stations belonging to any of its access domains with the appearance of a LAN that contains the whole set of attached end stations.

A bridged LAN can provide for the following:

— Communication between stations attached to LANs of different MAC types

— An increase in the total throughput of a LAN

— An increase in the physical extent of, or number of permissible attachments to, a LAN

— Partitioning of the physical LAN for administrative or maintenance reasons

The term *switch* is often used to refer to some classes of bridge. However, there is no consistent meaning applied to the distinction between the terms bridge and switch, and ISO/IEC 15802-3 does not make any such distinction. Hence, this standard only uses the term bridge.

6.3.2.2 Relaying and filtering by bridges

A bridge processes protocols in the MAC sublayer and is functionally transparent to LLC and higher layer protocols. MAC frames are forwarded between access domains, or filtered (i.e., not forwarded to certain access domains), on the basis primarily of MAC addressing information. Figure 4 shows the position of the bridging functions within the MAC sublayer; note particularly that the relaying and filtering functions are considered to belong entirely within the MAC sublayer.

Filtering by bridges tends to confine traffic to only those parts of the bridged LAN that lie between transmitting end stations and the intended receivers. This permits a bridged LAN to support several transmitting end stations at any given time (up to the total number of access domains present).

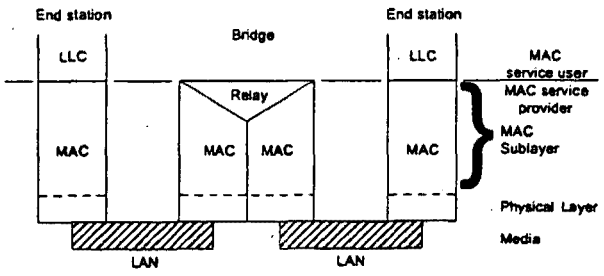


Figure 4—Internal organization of the MAC sublayer with bridging

6.3.2.3 The Spanning Tree Protocol

A key aspect of ISO/IEC 15802-3 is its specification of the Spanning Tree Protocol, which is used by bridges to configure their interconnections in order to prevent looping data paths in the bridged LAN. In the event that the basic interconnection topology of bridges and LANs contains multiple possible paths between certain points, use of the Spanning Tree Protocol blocks some paths in order to produce a simply connected

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active topology for the flow of MAC user traffic between end stations. For each point of attachment of a bridge to a LAN, the Spanning Tree Protocol selects whether or not MAC user traffic is to be received and transmitted by the bridge at that point of attachment.

The Spanning Tree Protocol adapts to changes in the configuration of the bridged LAN, maintaining connectivity while avoiding data loops. Some configuration changes can cause temporary interruptions of connectivity between parts of the bridged LAN, typically lasting for a few tens of seconds at most.

6.3.2.4 Transparent bridging and source routing

ISO/IEC 15802-3 specifies *transparent bridging* operation, so called because the MAC bridging function does not require the MAC user frames transmitted and received to carry any additional information relating to the operation of the bridging functions; end-station operation is unchanged by the presence of bridges.

Also specified, in an annex to ISO/IEC 15802-3, is the operation of a Source Routing Transparent (SRT) bridge. This adds the ability for a *source-routing* function in a bridge to use explicit MAC-sublayer routing information contained in MAC user frames; this source-routing information is inserted by the transmitting end station. Source routing is specified only for ISO/IEC 8802-5 Token Ring and ISO/IEC 9314 FDDI LANs, and for IEEE 802.12™ Demand Priority LANs when operating with 8802-5 format frames.

6.3.2.5 Remote MAC bridging

ISO/IEC 15802-5 extends the specification in ISO/IEC 15802-3 to cover remote MAC bridging, where non-IEEE 802 communications technologies are used to interconnect bridges, for example, to allow a bridged LAN to include WAN links to provide greatly extended geographical range. Figure 5 shows the corresponding organization of the MAC sublayer.

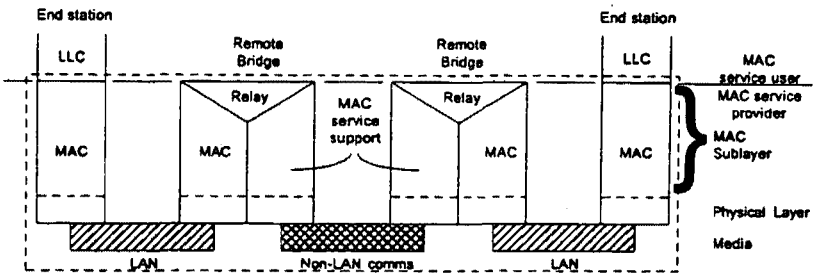


Figure 5—Internal organization of MAC sublayer with remote bridges

6.3.2.6 Bridging example

Some bridges are used to interconnect access domains each containing a very small number of end stations (often, a single end station). Others interconnect multiple access domains containing principally other bridges, thus, forming a backbone for the bridged LAN. (Hybrid configurations, with characteristics of both kinds of bridge, are of course possible.) Bridged LAN configurations involving these kinds of interconnection have become widespread as the IEEE 802 LAN technologies have developed. As noted in 1.2, they allow the construction of networks with much larger numbers of end stations and much higher aggregate throughput than was previously achievable.

Figure 6 illustrates the kind of bridged LAN that can be configured with bridge-style interconnection. The bridges A and B, and the CSMA/CD LAN configurations to which they attach, are typical of the older style of bridged LAN in which a bridge interconnects a small number of access domains each containing many end stations, as is similar with K, L, and M and their Token Ring LANs. On the other hand, the bridges S, T,

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and U function as bridges in a high-speed backbone that combines FDDI and 100-Mbit/s IEEE 802.3 LANs. S is a backbone bridge, handling a number of high-speed LAN attachments. T and U are bridges that support multiple end stations, with connection to the backbone. B and K also provide access to the backbone. The end station shown connected to S by a point-to-point link could be a server system, as might the end stations attached to the FDDI LAN.

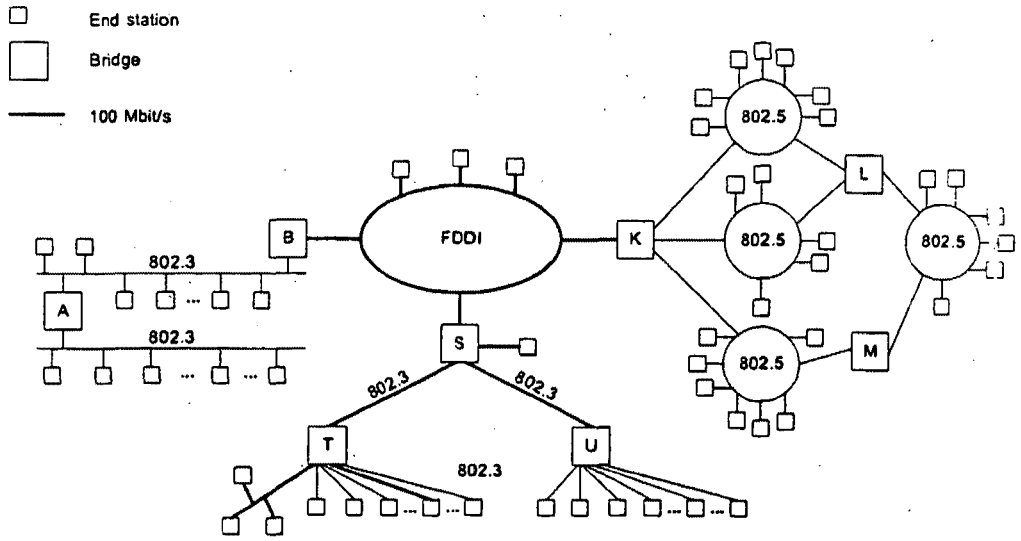


Figure 6—A bridged LAN

6.3.3 Network-layer interconnection: routers

The third category of interconnection uses Network-layer interconnection devices, generally known as routers, that operate as LAN/MAN end stations. These process Network layer protocols that operate directly above the LLC sublayer or equivalent, with forwarding decisions based on Network layer addresses. Details of this kind of interconnection lie outside of the scope of IEEE 802 LAN/MAN Standards, but the various standard and proprietary Network-layer protocols involved represent a very substantial part of the user traffic on many real IEEE 802 networks. In particular, IEEE 802 LANs and MANs are often interconnected by routers for the Internet Protocol (IP) and its related routing and management protocols, either directly to other LANs or by means of WAN links.

7. General requirements for an 802 LAN or MAN

7.1 Services supported

With the descriptions in Clause 6 as a basis, an IEEE 802 LAN or MAN can be characterized as a communication resource that provides sufficient capabilities to support the MAC service defined in ISO/IEC 15802-1, between two or more MSAPs. In particular, this requires the ability to convey LLC data from one MSAP to *n* other MSAPs, where *n* can be any number from 1 to all of the other MSAPs on the network. An IEEE 802 LAN is required, at a minimum, to support both LLC Type 1 and the MAC Internal Sublayer Service defined in ISO/IEC 15802-3. In addition, an ISLAN or MAN may optionally support isochronous bearer services compatible with ISDN services as defined in the ITU-T I-series Recommendations.

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7.2 Size and extent

The original IEEE 802 LAN and MAN technologies were designed to be capable of supporting access domains containing at least 200 end stations and with geographical extent of at least 2 km for LANs (using Physical-layer repeaters if necessary) and 50 km for MANs. Subsequent developments in IEEE 802 LAN technology and performance have been accompanied by a reduction in the size and extent required in individual access domains, recognizing that these can readily and cost-effectively be interconnected in bridged LANs that are capable of offering at least the original minimum size and extent, with increased overall bandwidth and performance. Size and extent requirements for future IEEE 802 LAN technologies are, similarly, expected to be determined by application needs and opportunities.

7.3 Error rates

Error performance of IEEE 802 LANs and MANs is required to be such as follows:

a) For wired or optical fiber physical media: Within a single access domain, the probability that a transmitted MAC frame (excluding any preamble) is not reported correctly at the Physical Service interface of an intended receiving peer MAC entity, due only to operation of the Physical layer, shall be less than 8×10^{-8} per octet of MAC frame length.

b) For wireless physical media: Within a single access domain, the probability that a MAC Service Data Unit (MSDU) is not delivered correctly at an MSAP of an intended receiving MAC service user, due to the operation of the Physical layer and the MAC protocol, shall be less than 8×10^{-8} per octet of MSDU length.

NOTE—The performance measure stated in (a) defines a highly desirable characteristic of LAN performance, as it has a bearing on other aspects of the delivered service, such as frame loss and transmission delays caused by the need to retransmit. However, this measure is not realistic for all physical media; for example, wireless media may be unable to meet this level of physical layer performance due to the inherent transmission characteristics of the medium. In such cases, the operation of the MAC protocol must employ additional mechanisms, for example, error detection and correction mechanisms, in order to enable the MAC service provider to meet the performance levels implied by this condition in the service offered at the MAC service boundary.

c) The probability that an MSDU delivered at an MSAP contains an undetected error, due to operation of the MAC service provider, shall be less than 5×10^{-14} per octet of MSDU length.

NOTE—For example, (a) the worst-case probability of losing a maximum-length IEEE 802.3 frame (1518 octets) through physical-layer damage is to be less than 1.21×10^{-4}, or approximately 1 in 8250; (c) the worst-case probability that a similar frame, which contains an MSDU of 1500 octets, is delivered with an undetected error is to be less than 7.5×10^{-11}, or approximately 1 in 13 300 000 000.

7.4 Service availability

Insertion of a device into, or removal of a device from, a LAN or MAN shall cause at most a transient loss of availability of the access domain(s) to which the device attaches, lasting not more than 1 s. Failure of a device, including loss of power, shall not cause more than a transient fault for the access domain(s) to which it attaches, with duration of order 1 s.

NOTE—In a bridged LAN, reconfiguration of the topology in response to logical insertion or removal of a bridge, or to changes in a bridge's configuration parameters, can cause loss of communication between some access domains for longer periods, typically a few tens of seconds; ISO/IEC 15802-3 contains the full specification.

7.5 Safety, and lightning and galvanic protection

Equipment implementing IEEE 802 LAN and MAN standards is typically subject to guidance and requirements relating to safety and to protection of the equipment and its users from lightning and galvanic effects. Such guidance and requirements are outside of the scope of IEEE 802 standardization; they are

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typically specified by other organizations with different legal, geographical, and industrial scope. However, the general underlying concerns can have an influence on the Physical layer aspects of IEEE 802 LAN and MAN standards.

7.6 Regulatory requirements

Equipment implementing IEEE 802 LAN and MAN standards may be subject to regulations imposed within particular geographical and political domains. For example, the deployment of equipment implementing IEEE 802 wireless LAN standards may be subject to local regulations that pertain to the use of radio-frequency transmission. Such regulations are outside of the scope of IEEE 802 standardization; they are typically specified by other organizations with different legal, geographical, and industrial scope. However, the general underlying concerns can have an influence on the Physical layer aspects of IEEE 802 LAN and MAN standards.

8. LAN/MAN management

The provision of an adequate means of remote management is an important factor in the design of today's LAN equipment. Such management mechanisms fall into two broad categories: those that provide general-purpose management capability, allowing control and monitoring for a wide variety of purposes, and those that provide specific capabilities aimed at a particular aspect of management. These aspects of management are discussed in 8.1 and 8.2, respectively.

8.1 General-purpose LAN/MAN management

This subclause introduces the functions of management to assist in the identification of the requirements placed on IEEE 802 LAN/MAN equipment for support of management facilities, and it identifies general-purpose management standards that may be used as the basis of developing management specifications for such equipment.

8.1.1 Management functions

Management functions relate to users' needs for facilities that support the planning, organization, supervision, control, protection and security of communications resources, and account for their use. These facilities may be categorized as supporting the functional areas of configuration, fault, performance, security, and accounting management. These can be summarized as follows.

- Configuration management provides for the identification of communications resources, initialization, reset and close-down, the supply of operational parameters, and the establishment and discovery of the relationships between resources.
- Fault management provides for fault prevention, detection, diagnosis, and correction.
- Performance management provides for evaluation of the behavior of communications resources and of the effectiveness of communication activities.
- Security management provides for the protection of resources.
- Accounting management provides for the identification and distribution of costs and the setting of charges.
- Management facilities in LAN/MAN equipment will address some or all of these areas, as appropriate to the needs of that equipment and the environment in which it is to be operated.

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8.1.2 Management architecture

The management facilities defined in IEEE 802 LAN and MAN standards are based on the concept of managed objects, which model the semantics of management operations. Operations on a managed object supply information concerning, or facilitate control over, the process or entity associated with that object.

Operations on a managed object can be initiated by mechanisms local to the equipment being managed (e.g., via a control panel built into the equipment), or can be initiated from a remote management system by means of a general-purpose management protocol carried using the data services provided by the LAN or MAN to which the equipment being managed is connected.

There are two general-purpose management protocols of relevance to the management of LAN/MAN equipment, as follows:

— The Simple Network Management Protocol (SNMP), as described in RFC 1157

— The OSI common management information protocol (CMIP), as described in ISO/IEC 9595 and ISO/IEC 9596 and related standards

NOTE—In addition to operation of CMIP over a full OSI protocol stack, two standards define the use of CMIP over simpler protocol support. ISO/IEC 15802-2 (IEEE Std 802.1B™-1995) defines a means of using CMIP over a simple Data Link layer protocol stack in LANs; RFC 1095 describes the use of CMIP over a TCP/IP protocol stack.

Of the two protocols, SNMP is the more significant in terms of its wide application across the spectrum of LAN/MAN products in today's marketplace; however, in some markets, and where it is desirable to integrate LAN management with management of wide-area networking and telephony equipment, use of the OSI management protocols may be important.

8.1.3 Managed object definitions

In order for an IEEE 802 standard to specify management facilities, it is necessary for them to define managed objects that model the operations that can be performed on the communications resources specified in the standard. There are essentially two components to a managed object definition, as follows:

1) A definition of the functionality provided by the managed object, and the relationship between this functionality and the resource to which it relates

2) A definition of the syntax that is used to convey management operations, and their arguments and results, in a management protocol

The functionality of a managed object can be described in a manner that is independent of the protocol that will be used; this abstract definition can then be used in conjunction with a definition of the syntactic elements required in order to produce a complete definition of the object for use with specific management protocols.

Each management protocol has its notation for defining managed objects, as follows:

a) SNMP has standards for the structure of management information known as SMIv1 (RFC 1155, RFC 1212 and RFC 1215) and SMIv2 (RFC 1902, RFC 1903 and RFC 1904), which provides ASN.1-based macros for defining managed objects.

b) CMIP has a standard language, known as GDMO (ISO/IEC 10165-4), which is used along with ASN.1 to define both the syntactic and semantic aspects of managed objects.

The choice of notational tools for defining managed objects will depend on which of the available management protocols the standard will support.

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NOTES

1—IEEE Std 802.1F™ provides additional guidance for use of GDMO in LAN/MAN standards.

2—Some IEEE 802 standards have used GDMO as the notation for their managed object definitions, with SNMP management information base (MIB) definitions being developed subsequently within the IETF, using automatic tools for translating GDMO definitions into equivalent SNMP definitions.

8.2 Special-purpose LAN/MAN management standards

Special-purpose protocols relating to the management functionality of IEEE 802 stations can be developed where the use of a general-purpose management protocol is inappropriate. An example of a special-purpose management protocol is ISO/IEC 15802-4, which defines the services and protocols for remote station loading in a LAN/MAN environment. This protocol permits the simultaneous loading of multiple stations by use of the group-addressing capability in IEEE 802 technologies.

9. Universal addresses and protocol identifiers

The IEEE makes it possible for organizations to employ unique individual LAN MAC addresses, group addresses, and protocol identifiers. It does so by assigning Organizationally Unique Identifiers (OUIs), which are three octets (24 bits) in length. Because the assignment of the OUI in effect reserves a block of each derivative identifier (i.e., blocks of individual LAN MAC addresses, group addresses, and protocol identifiers), the address space of the OUI is chosen to be large. Although the OUIs are 24 bits in length, their true address space is 22 bits. The LSB of the first octet can be set to 1 or 0 depending on the application. The next-to-LSB of the first octet is 0, for all assignments. The remaining 22 bits, which shall not be changed by the assignee, result in 2 22 (approximately 4 million) identifiers; see Figure 7.

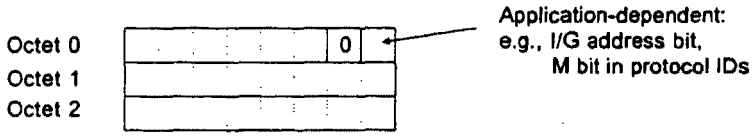


Figure 7—OUI

The universal administration of LAN MAC addresses began with the Xerox Corporation administering Block Identifiers (Block IDs) for Ethernet addresses. Block IDs were assigned by the Ethernet Administration Office and were 24 bits in length (three octets). An organization developed addresses by assigning the remaining 24 bits. For example, the address as represented by the six octets P-Q-R-S-T-U comprises the Block ID, P-Q-R, and the locally assigned octets S-T-U.

The IEEE, because of the work in Project 802 on standardizing LAN technologies, has assumed the responsibility of defining and carrying out procedures for the universal administration of addresses for IEEE and ISO/IEC LANs (e.g., CSMA/CD, Token Bus, Token Ring, and FDDI). In carrying out the procedures, the IEEE acts as the Registration Authority for OUIs.[7] The responsibility for defining the procedures is discharged by the IEEE Registration Authority Committee (RAC), which is chartered by the IEEE Standards Association Board of Governors.

The IEEE honors the Block ID assignments made by the predecessor administration office where those assignments fall—as the great majority of them do—within the space administered by the IEEE. The Block ID is referred to as the OUI by the IEEE.

[7] Interested applicants should contact the IEEE Registration Authority, Institute of Electrical and Electronic Engineers Inc., 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

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9.1 OUI

OUIs allow a general means of assuring unique identifiers for a number of purposes. Currently, the IEEE assigns OUIs to be used for generating LAN MAC addresses and protocol identifiers. Assuming correct administration by the IEEE Registration Authority and the assignee, the LAN MAC addresses and protocol identifiers will be universally unique.

OUIs are assigned as three-octet values. Both values (0, 1) are assigned to the LSB of the first octet. The next-to-LSB of the first octet is set to 0; this bit of the OUI being set to 0 indicates that the assignment is universal. Three-octet values occupying the same fields as OUIs can occupy, but with the next-to-LSB of the first octet set to 1, are locally assigned and have no relationship to the IEEE-assigned values (as described herein).

The standard representation of the OUI is as a string of three octets, using the hexadecimal representation (see 3.1.8).

9.2 48-bit universal LAN MAC addresses

9.2.1 Concept

The concept of universal addressing is based on the idea that all potential members of a network need to have a unique identifier (if they are going to coexist in the network). The advantage of a universal address is that a station with such an address can be attached to any LAN in the world with an assurance that the address is unique.

A 48-bit universal address consists of two parts. The first 24 bits correspond to the OUI as assigned by the IEEE, except that the assignee may set the LSB of the first octet to 1 for group addresses or set it to 0 for individual addresses. The second part, comprising the remaining 24 bits, is administered by the assignee. In the 48-bit LAN MAC address, an example of which is shown in Figure 8, the OUI is contained in octets 0, 1, 2, and the value assigned by the assignee is contained in octets 3, 4, 5. This address, including its OUI, is used throughout this document as the basis for examples of LAN MAC addresses and protocol identifiers.

NOTE–The requirement for the use of 64-bit addresses in new applications is under consideration by the IEEE Registration Authority (RAC).

The standard representation of a 48-bit LAN MAC address is as a string of six octets, using the hexadecimal representation (3.1.8). In certain contexts associated with use of IEEE 802.5 frame formats, LAN MAC addresses may be represented using the alternative bit-reversed representation (3.1.2). See 9.5 for further specification relating to use of the bit-reversed representation.

NOTE—The upper, bit-stream representation of the universal address in Figure 8 shows the LSB of each octet first; this corresponds to the data-communications convention for representing bit-serial transmission in left-to-right order, applied to the model for transmission of LAN MAC address fields (see 6.2.3). See also 9.5 for further discussion of bit-ordering issues. The lower, octet-sequence representation shows the bits within each octet in the usual order for binary numerals; the order of octet transmission is from the top downward.

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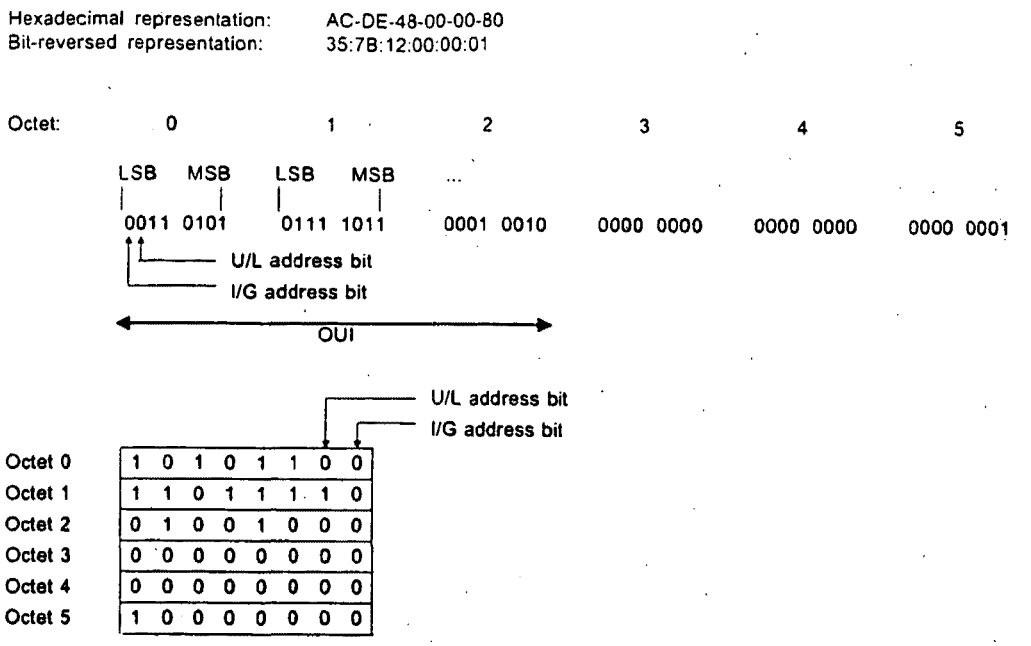


Figure 8—Universal address

The Individual/Group (I/G) address bit (LSB of octet 0) is used to identify the destination address as an individual address or a group address. If the I/G address bit is 0, it indicates that the address field contains an individual address. If this bit is 1, the address field contains a group address that identifies one or more (or all) stations connected to the LAN. The all-stations broadcast address is a special, predefined group address of all 1's.

The Universally or Locally administered (U/L) address bit is the bit of octet 0 adjacent to the I/G address bit. This bit indicates whether the address has been assigned by a local or universal administrator. Universally administered addresses have this bit set to 0. If this bit is set to 1, the entire address (i.e., 48 bits) has been locally administered.

9.2.2 Assignment by organizations

Varying the last 24 bits in the block of MAC addresses for a given OUI allows the OUI assignee approximately 16 million unique individual addresses and 16 million unique group addresses that no other organization may assign (i.e., universally unique). The IEEE intends not to assign additional OUIs to any organization unless the organization has exhausted this address block. Therefore, it is important for the IEEE to maintain a single point of contact with each assignee to avoid complicating the assignment process. It is important to note that in no way should these addresses be used for purposes that would lead to skipping large numbers of them (for example, as product identifiers for the purpose of aiding company inventory procedures). The IEEE asks that organizations not misuse the assignments of the last 24 bits and thereby unnecessarily exhaust the block. There are sufficient identifiers to satisfy most needs for a long time, even in volume production; however, no address space is infinite.

The method that an assignee uses to ensure that no two of its devices carry the same address will, of course, depend on the assignment or manufacturing process, the nature of the organization, and the organization's philosophy. However, the users of networks worldwide expect to have unique addresses. The ultimate responsibility for assuring that user expectations and requirements are met, therefore, lies with the organization offering such devices.

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9.2.3 Uniqueness of address assignment

An issue to be considered is the nature of the device to which uniqueness of address assignment applies.

The recommended approach is for each device associated with a distinct point of attachment to a LAN to have its own unique MAC address. Typically, therefore, a LAN adapter card (or, e.g., an equivalent chip or set of chips on a motherboard) should have one unique MAC address for each LAN attachment that it can support at a given time.

NOTE—It is recognized that an alternative approach has gained currency in some LAN implementations, in which the device is interpreted as a complete computer system, which can have multiple attachments to different LANs. Under this interpretation, a single LAN MAC address is used to identify all of the system's points of attachment to the LANs in question. This approach, unlike the recommended one, does not automatically meet the requirements of IEEE Std 802.1D-1998 MAC bridging.

9.3 Protocol identifiers

Clause 10 specifies the Subnetwork Access Protocol (SNAP), which permits multiplexing and demultiplexing of private and public protocols (see 10.1) among multiple users of a data link. An organization that has an OUI assigned to it may use its OUI to assign universally unique protocol identifiers to its own protocols, for use in the protocol identification field of SNAP PDUs (see 10.3).

The protocol identifier is five octets (40 bits) in length and follows the LLC header in a frame. The first three octets of the protocol identifier consist of the OUI in exactly the same fashion as in 48-bit LAN MAC addresses. The remaining two octets (16 bits) are administered by the assignee. In the protocol identifier, an example of which is shown in Figure 9, the OUI is contained in octets 0, 1, 2 with octets 3, 4 being assigned by the assignee of the OUI.

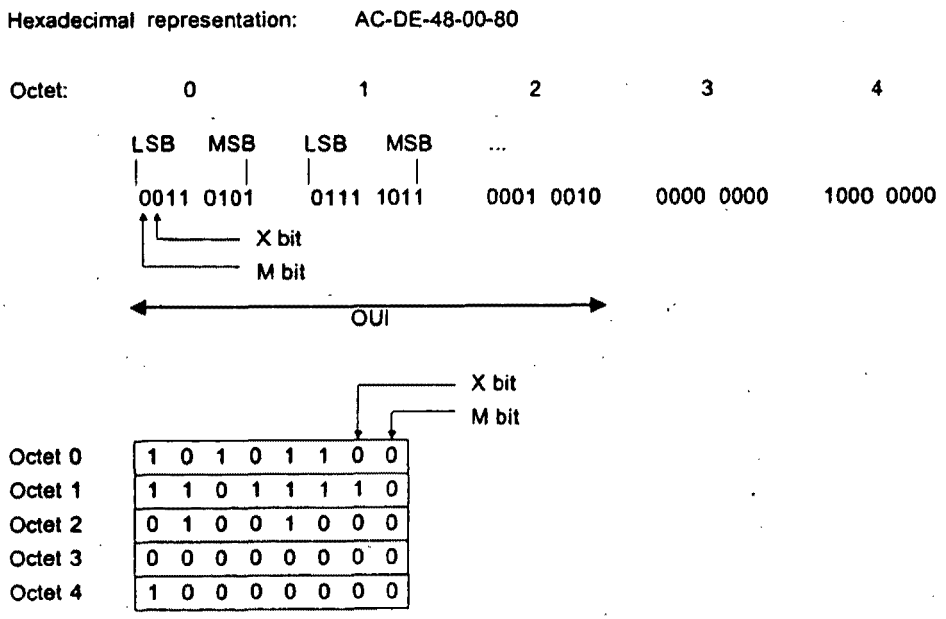


Figure 9—Protocol identifier

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The standard representation of a protocol identifier is as a string of five octets, using the hexadecimal representation (3.1.8).

The LSB of the first octet of a protocol identifier is referred to as the M bit. All identifiers derived from OUIs assigned by the IEEE shall have the M bit set to 0. Values with the M bit set to 1 are reserved.

Protocol identifiers may be assigned universally or locally. The X bit of a protocol identifier is the bit of the first octet adjacent to the M bit. All identifiers derived from OUIs assigned by the IEEE will have the X bit set to 0 and are universally assigned. Values with the X bit set to 1 are locally assigned and have no relationship to the IEEE-assigned values. They may be used, but there is no assurance of uniqueness.

9.4 Standard group MAC addresses

The previous subclauses described the assignment of individual and group MAC addresses, and protocol identifiers for public or private use by private organizations. There is also a need for standard group MAC addresses to be used with standard protocols. The administration of these addresses, including the procedure for application and a list of currently assigned values, is defined in ISO/IEC TR 11802-2. These standard group MAC addresses come from a block of universally administered LAN MAC addresses derived from an OUI that has been assigned by the IEEE for this purpose.

ISO/IEC 8802-5 also defines *functional addresses*, for use in Token Ring LAN environments to identify well-known functional entities. These addresses are a subset of the locally administered group MAC addresses, identified by having the 15 address bits that follow the I/G and U/L address bits set to zero. Certain values are used consistently throughout Token Ring LAN environments and, therefore, play a very similar role to standard group MAC addresses; these functional address values are also recorded in ISO/IEC TR 11802-2.

9.5 Bit-ordering and different MACs

NOTE—Throughout this subclause, considerations relating to the order of bit and/or octet transmission refer to the basic bit-serial model of transmission that applies to the representation of MAC frames at the boundary between the MAC sublayer and the Physical layer; see 6.2.3.

9.5.1 General considerations

The transmission of data on IEEE 802.3 and 802.4™ LAN types is represented (6.2.3) as occurring LSB first within each octet. This is true for the entire frame: LAN MAC address fields (source and destination), MAC-specific fields (e.g., length field in IEEE 802.3 LANs), and the MAC Information field. (The MAC Information field is defined to be that part of the frame starting directly after the MAC header and ending immediately before the frame check sequence: e.g., LLC information, such as the Protocol Identification field, is contained in the MAC Information field.)

On some other LAN types, for which IEEE 802.5 is here used as the typical example, each octet of the MAC Information field is represented as being transmitted MSB first. The LAN MAC address fields (source and destination), however, are represented as being transmitted with the LSB of each octet first. Thus, the first bit transmitted is the I/G Address Bit, as on IEEE 802.3 and IEEE 802.4 LANs. For frames that originate within the MAC (e.g., MAC-embedded management frames), the ordering of bits within the MAC Information field is defined by the MAC specification—ISO/IEC 8802-5, etc.

For most purposes, the difference in the bit-orderings used to represent transmission of the octets of the MAC Information field is of no consequence, whether considered within a given MAC type, or across different MAC types. Each octet of user data is mapped to and from the appropriate ordering, symmetrically by the transmitting and receiving MAC entities. An unfortunate exception has occurred, however, where the octets concerned are those of a MAC address that is embedded, as user data, in the MAC Information field.

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The consequences particularly affect the use of MAC addresses in mixed environments containing Token Ring LANs and non-Token-Ring LANs.

The following subclauses describe the problem and some of the issues arising from it.

9.5.2 Illustrative examples

This subclause illustrates the various bit- and octet-transmission scenarios that can occur, and it is intended as a basis for clarifying the issue of bit ordering for LAN MAC addresses across different MACs. Throughout, the examples make use of the OUI value AC-DE-48, introduced in 9.2.1. This three-octet value is considered in its two possible roles: as the first part of a five-octet protocol identifier, and as the first part of a six-octet LAN MAC address. The consistent representations of the OUI in its role as part of a protocol identifier are contrasted with the sometimes variable representations that apply to its role as part of a MAC address.

NOTE—Protocol identifiers always form part of the normal user data in a MAC Information field; hence, there is nothing special about OUI octets in their protocol identifier role.

For the examples, the bit significance of an OUI in general is defined to be as in Figure 10.

	MSB							LSB
Octet 0	h	g	f	e	d	c	b	a
Octet 1	p	o	n	m	l	k	j	i
Octet 2	x	w	v	u	t	s	r	q

When used in LAN MAC addresses:
Bit "a" of the OUI = I/G address bit. Bit "b" of the OUI = U/L address bit.

When used in protocol identifiers:
Bit "a" of the OUI = M bit. Bit "b" of the OUI (always zero) = X bit.

Figure 10—Bit significance of an OUI

When transmitted on an IEEE 802.3 or IEEE 802.4 LAN (all data octets transmitted LSB first), the OUI portions of a protocol identifier and of a LAN MAC address appear as in Figure 11. When transmitted on an IEEE 802.5 LAN (data octets in the MAC Information field transmitted MSB first), the OUI portions of a protocol identifier, and of a LAN MAC address contained in a MAC Address field, appear as in Figure 12

In some circumstances, it is necessary to convey LAN MAC addresses as data within MAC Information fields, e.g., as part of a management protocol or a Network layer routing protocol.

For LAN types in which Figure 11 applies, such as IEEE 802.3, the bit ordering within the octets of a LAN MAC address conveyed as data is the same as both the ordering when the address appears in a MAC address field and the ordering for octets of nonaddress information (see Figure 13).

For LAN types in which Figure 12 applies, such as IEEE 802.5 and FDDI, there appears to be a choice of representations for MAC addresses conveyed as data, as follows:

a) The octets of the MAC address can be treated like any other data octets and transmitted with the bit-ordering of Figure 12 (A)

b) The bit-ordering of Figure 12 (B) can be treated as a property of the MAC address rather than of the MAC address field as transmitted in MAC frames, and the MAC address octets can be transmitted with the bit-ordering reversed compared with normal data octets

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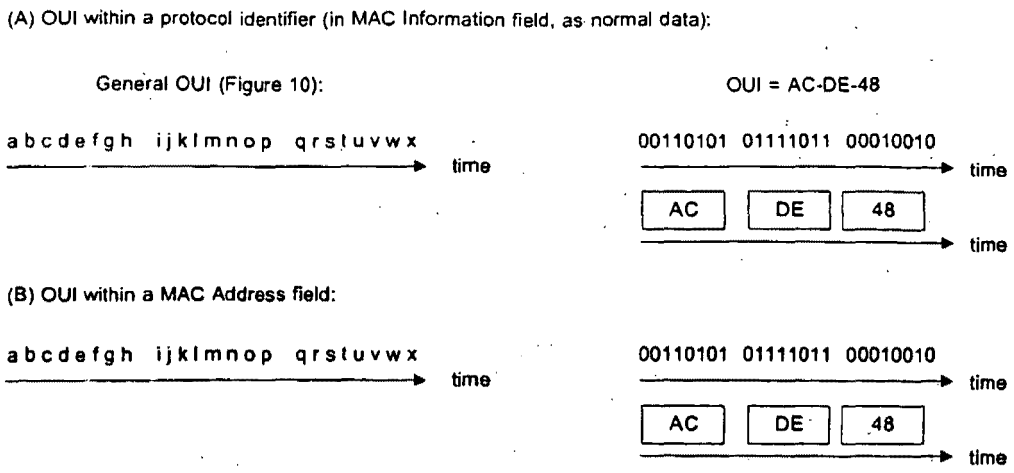


Figure 11—IEEE 802.3, etc., frame: Order of bit and octet transmission for an OUI

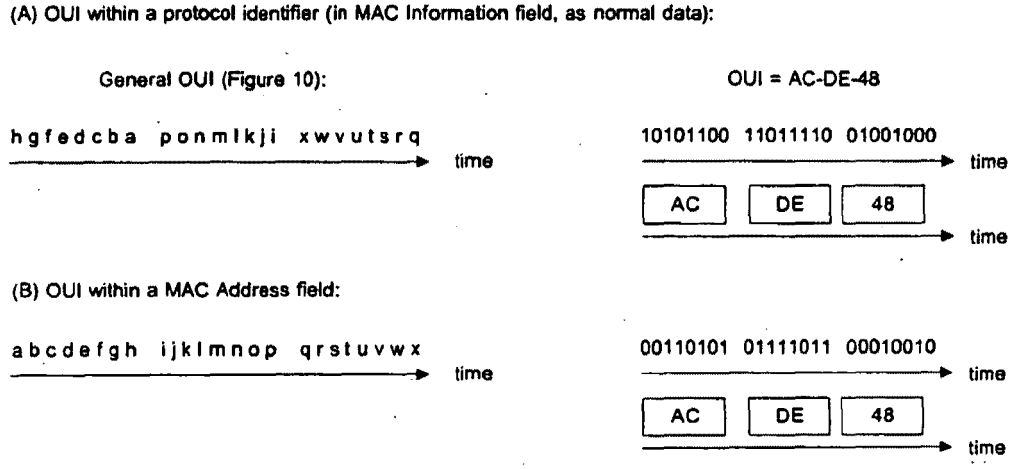
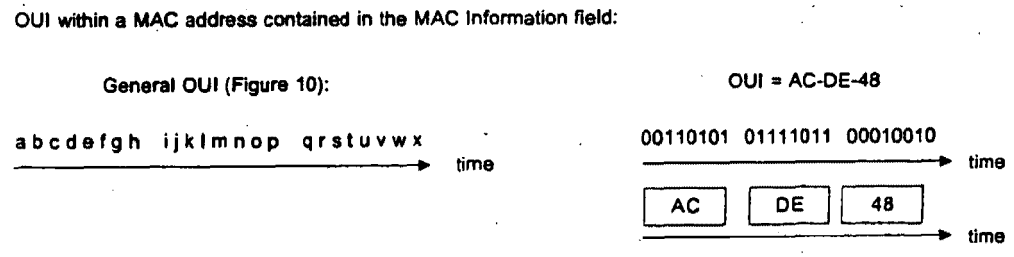


Figure 12—IEEE 802.5, etc., frame: Order of bit and octet transmission for an OUI



igure 13—IEEE 802.3, etc., frame: Order of bit and octet transmission for an OUI in a MAC address contained in a MAC Information field

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In the case of IEEE 802.5 Token Ring LANs, approach b) was adopted early in the development and deployment of Token Ring technology. This has the unfortunate consequence that applications operating in environments containing a mixture of LAN types have to handle different representations of MAC addresses, according to the environment in which the MAC address is to be used; see Figure 14.

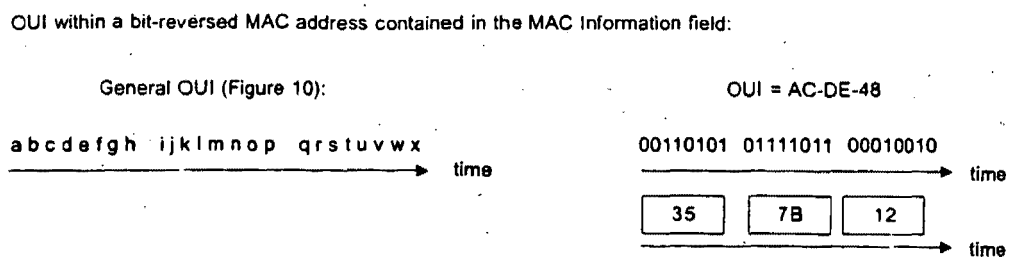


Figure 14—IEEE 802.5, etc., frame: Order of bit and octet transmission for an OUI in a MAC address contained in a MAC Information field (noncanonical format)

For other LAN types in which Figure 12 applies, including, in particular, FDDI, approach a) was adopted (Figure 15), at least in environments involving interconnection with IEEE 802.3, and so on, LANs. However, where FDDI LANs are used in an IEEE 802.5 Token Ring environment, approach b) is used for consistency with the interconnected IEEE 802.5 LANs. In a mixed environment of FDDI, IEEE 802.3 and IEEE 802.5 LANs, frames constructed according to both approaches can occur on the FDDI LANs, at least; some care is needed in managing such an installation to avoid confusion between the formats.

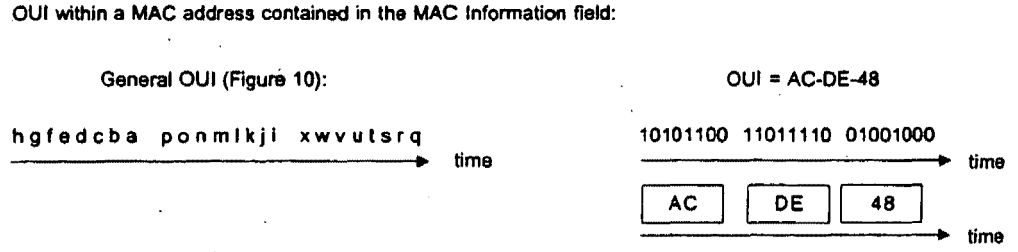


Figure 15—FDDI frame: Order of bit and octet transmission for an OUI in a MAC address contained in a MAC Information field (canonical format)

In Figure 11 through Figure 15, it can be seen that the interpretation of OUI bits as octet values is consistent in every case except Figure 14, in which the octet values are bit reversed. This reversal of the bit order applies only to all six octets (not just the OUI) of a MAC address placed in the MAC Information field of a frame by a protocol that uses the Token Ring Bit-reversed view of MAC addresses derived from Figure 12 (B). Frames containing, or possibly containing, such MAC addresses are described as having noncanonical format. Frames (on any LAN or LAN type) that cannot contain such MAC addresses are described as having canonical format.

Note that there is no way of knowing, from MAC layer information only, whether a particular frame is in canonical or noncanonical format. In general, this depends on which higher layer protocols are present in the frame.

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9.5.3 Recommendation

Designers of protocols that operate above the Data Link layer are strongly recommended to avoid specifying new protocols that result in frames of noncanonical format, except where such a protocol is clearly an extension of existing practice in a strongly Token Ring environment.

10. Protocol discrimination above the MAC sublayer: Subnetwork Access Protocol (SNAP) and Ethernet types

10.1 Introduction

This clause outlines the mechanisms for the coexistence of multiple standard, public, and private network layer protocols within a single 802 station (10.2). It then describes the functions, features, and protocol format conventions for public and private protocols sharing a single LSAP (10.3). All public and private protocols using the IEEE 802 reserved LLC address assigned for public and private protocol use shall conform to this standard.

This clause further describes Ethernet types used to identify different protocols operating over the alternative Ethernet sublayer (10.4), and it describes the standard encapsulation specified for conveyance of such Ethernet-supported protocols on IEEE 802 LANs that do not intrinsically support an Ethernet sublayer (10.5).

A standard protocol is defined to be a protocol whose specification is published and known to the public but controlled by a standards body. A public protocol is defined to be a protocol whose specification is published and known to the public, but controlled by an organization other than a formal standards body. A private protocol is defined to be a protocol whose use and specification are controlled by a private organization.

By providing for the coexistence of multiple Network layer protocols, the migration of existing LANs to future standard protocols is facilitated, and multiple higher layer protocols are more easily accommodated.

10.2 Basic concepts

10.2.1 Coexistence of multiple protocols

Within a given layer, entities can exchange data by a mutually agreed upon protocol mechanism. A pair of entities that do not support a common protocol cannot communicate with each other. For multiple protocols to coexist within a layer, it is necessary to determine which protocol is to be invoked to process a service data unit delivered by the lower layer.

The following subclauses specify mechanisms for use when the LLC sublayer is present above the MAC layer, and when the alternative Ethernet sublayer is present above the MAC sublayer.

10.2.2 Multiple protocols above the LLC sublayer

Standard Network layer protocols have been assigned reserved LLC addresses, as recorded in ISO/IEC TR 11802-1. These addresses permit multiple standard network layer protocols to coexist at a single MAC station. One half of the LLC address space is reserved for such assignment.

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Other protocols are accommodated in two ways. One way is by local assignment of LSAPs, for which the other half of the LLC address space is available. Thus, users can agree to use locally assigned LSAPs for either an instance of communication or a type of communication.

The second way is through the use of a particular reserved LLC address value that has been assigned for use in conjunction with the Subnetwork Access Protocol (SNAP, specified in 10.3), which provides for multiplexing and demultiplexing of public and private protocols among multiple users of a data link.

10.2.3 Multiple protocols above the Ethernet sublayer

The Ethernet MAC frame format includes a 16-bit type value, whose function is to identify the particular protocol pertaining to the user data contained in the frame. See 10.4 for further details.

10.3 Subnetwork Access Protocol

10.3.1 SNAP address

The reserved LLC address for use with SNAP is called the SNAP address. It is defined to be the bit pattern (starting with the LSB) Z1010101, in which the symbol Z indicates that either value 0 or 1 can occur, depending on the context in which the address appears (as specified in ISO/IEC 8802-2). The two possible values have Hexadecimal Representation AA and AB.

The SNAP address identifies, at each MSAP, a single LSAP for standard, public, and private protocol usage. To permit multiple public and private network layer protocols to coexist at one MSAP, each public or private protocol using SNAP must employ a protocol identifier that enables SNAP to discriminate among these protocols.

10.3.2 SNAP PDU format

Each SNAP PDU shall conform to the format shown in Figure 16 and shall form the entire content of the LLC information field.

In Figure 16, the Protocol Identification field is a five-octet field containing a protocol identifier whose format and administration are as described in 9.3. The Protocol Data field is a field whose length, format, and content are defined by a public or private protocol specification. Each public or private protocol begins its PDU format with the Protocol Identification field, which shall contain the protocol identifier assigned to the protocol.

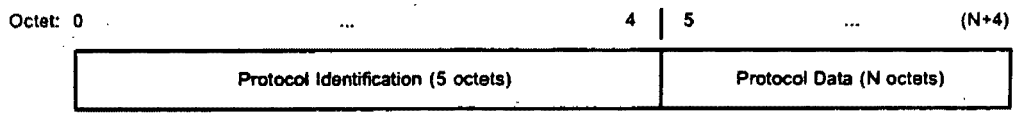


Figure 16—SNAP PDU format

Figure 17 illustrates how a SNAP PDU appears in a complete MAC frame (the IEEE 802.3 MAC format is used for the example). The LLC control field (CTL) is shown for PDU type UI, Unnumbered Information, which is the most commonly used PDU type in this context; however, other information-carrying LLC PDU types may also be used with SNAP.

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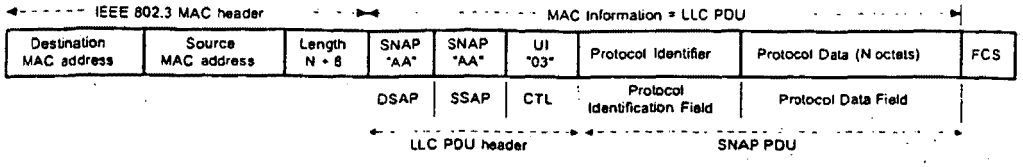


Figure 17—SNAP PDU in IEEE 802.3 MAC frame

10.4 Ethernet types: Format, function, and administration

The IEEE 802.3 MAC frame format is compatible with the alternative Ethernet MAC frame format, in the sense that frames of both formats can be freely intermixed on a given LAN and at a given LAN station. The service provided by use of the Ethernet frame format differs from the ISO/IEC 15802-1 MAC service in that there is a 16-bit type value associated with each frame transferred, and that the minimum amount of MAC-sublayer user data transferred is 64 octets.

An Ethernet type value is a sequence of two octets, interpreted as a 16-bit numeric value with the first octet containing the most significant 8 bits and the second octet containing the least significant 8 bits. Values in the range 0–1535 are not available for use.

The function of the Ethernet type value is to identify the protocol that is to be invoked to process the user data in the frame.

As with OUIs, administration of Ethernet types was originally undertaken by the Xerox Corporation, and it is now the responsibility of the IEEE using procedures defined by the IEEE RAC (see Clause 9). All assignments of Ethernet types made by the predecessor administration remain in effect under the IEEE's administration.

10.5 Encapsulation of Ethernet frames over LLC

This subclause specifies the standard method for conveying Ethernet frames across IEEE 802 LANs that offer only the LLC sublayer, and not the Ethernet sublayer, directly above the MAC sublayer.

An Ethernet frame conveyed on an LLC-only LAN shall be encapsulated in a SNAP PDU contained in an LLC PDU of type UI, as follows (see Figure 18):

a) The Protocol Identification field of the SNAP PDU shall contain a protocol identifier in which
   1) The three OUI octets each take the value zero.
   2) The two remaining octets take the values, in the same order, of the two octets of the Ethernet frame's Ethernet type.

b) The Protocol Data field of the SNAP PDU shall contain the user data octets, in order, of the Ethernet frame.

c) The values of the Destination MAC Address and Source MAC Address fields of the Ethernet frame shall be used in the Destination MAC Address and Source MAC Address fields, respectively, of the MAC frame in which the SNAP PDU is conveyed.

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NOTES

1—This encapsulation was originally specified in RFC 1042, which contains recommendations relating to its use. Further recommendations are contained in RFC 1390.

2—ISO/IEC TR 11802-5 (IEEE Std 802.1H™-1997) contains recommendations for bridges, addressing the consequences of certain problems that arose from differing interpretations of RFC 1042.

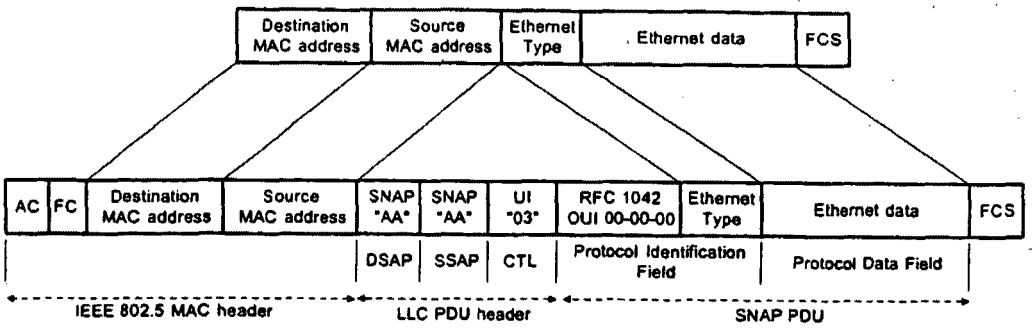


Figure 18—Ethernet frame SNAP-encapsulated in IEEE 802.5 frame

11. ISLAN and MAN support for isochronous bearer services

In addition to the mandatory LAN and MAN services described so far, some IEEE 802 LANs and MANs, notably, ISO/IEC 8802-9 and ISO/IEC 8802-6, also make provision for supporting isochronous bearer services. Isochronous bearer services are distinctive relative to packet services such as the MAC service and LLC, in that they maintain a flow of service data units at constant time intervals from a transmitter to a receiver for the duration of a service. In almost all circumstances, such isochronous bearer services are carried over duplex bidirectional connections thereby providing effective and efficient means of supporting the ubiquitous WAN voice telephony services. IEEE 802 ISLANs and MANs provide isochronous bearer services designed to interwork readily with these WAN services as standardized by ITU-T, in particular, as defined in the I series of ITU-T Recommendations.

NOTE—Use of an end-to-end physical-layer isochronous bearer service, which intrinsically delivers data with timing preserved, needs to be distinguished from use of a packet-based service for conveyance of time-sensitive data such as voice or video. The latter approach can be successful, given adequate bandwidth in the LANs and bridges, and provided that bridges do not introduce the possibility of excessive delay for packets carrying the time-sensitive data.

11.1 Key concepts

Applications requiring sustained periodic use of end-to-end network bandwidth are common. Two of the IEEE 802 standards address this requirement; both the ISO/IEC 8802-9 ISLAN standard and the optional isochronous service on an ISO/IEC 8802-6 Distributed Queue Dual Bus (DQDB) MAN use synchronously cyclic methods to ensure precise timing of the acceptance, transfer, and delivery of continuous streams of information. This applies whether or not asynchronous packet services are also provided concurrently.

The ISLAN employs a time-division multiplex (TDM) bearer mechanism within the Physical layer. The isochronous service on a DQDB MAN uses a Pre-Arbitrated function to ensure precisely timed access to the media, as distinct from the packet-service Queued Arbitrated function. In each case, this permits the support and delivery of a plurality of transparent isochronous service channels, the provision of an octet alignment signal for these channels, and a facility to provide and accept these precise timing signals. It is the provision of the timing signal that principally distinguishes the isochronous services from the asynchronous packet services that are provided from the ISLAN Physical layer.

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Both methods for providing isochronous bearer services require the prior establishment of a connection for each isochronous information flow. For the DQDB MAN isochronous services, the mechanisms used for establishing and clearing connections are left outside of the scope of the IEEE 802 Standard. For ISLAN, see 11.4 below for an overview of the mechanisms used.

11.2 Applications

Applications for isochronous bearer services include the following:

— PBX interconnections at DS1 (1.544 Mbit/s) or E1 (2.048 Mbit/s) rates

— Low (384 kbit/s) to medium (44.2097 Mbit/s) bandwidth constant bit-rate compressed video

— Channels with bandwidth in multiples of 56 or 64 kbit/s for conveyance of voice and audio

— Multimedia combinations of these along with data services

Multimedia applications can require simultaneous, integrated use of two or more of these audio/voice, video, text, and graphics information streams. This can require the conveyance over common bearer channels of multiple isochronous and bursty information streams, in distinct channels with specific timing relationships. This provides the main rationale for incorporating isochronous services in LANs and MANs.

The provision of isochronous (TDM bearer) services enables direct interworking with a WAN network such that the access unit or hub (LAN/WAN interworking unit) can forward information in its native form, so that ISLAN terminals and access units do not have to provide gateway functions to transform the user information streams. In addition, the provision of isochronous bearer services greatly reduces the latency as information is queued/dequeued at the Physical service interface. This is of value in meeting established norms of loop delay on end-to-end connections for many human interactive services.

Typical isochronous services include the following:

— Unrestricted 64 kbit/s information transfer

— Restricted 56 kbit/s information transfer

— Synchronous data

— Facsimile data

— Wideband video and image transfer

The ISO/IEC 8802-9 ISLAN is specifically designed to provide concurrent support for LLC conformant packet services and narrowband ITU-T conformant ISDN services, both packet and isochronous, as defined in ITU-T I-series Recommendations.

11.3 Isochronous service access points and PhSAPs

The ISLAN and DQDB MAN standards both support concurrent packet and isochronous services within the Physical layer by means of convergence functions. In both cases, there is therefore a need for explicit identification of the distinct packet and isochronous channels provided over the common media supporting the ISLAN or MAN. In addition, both offer support for multiple isochronous bearer channels, and thus, there is a need to distinguish among multiple Physical service connections.

In the ISLAN standard, multiple PhSAPs are used to provide for the plurality of connections at the Physical service boundary, and for access by the user to the Physical-layer services for packet transfer and for

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D channel signaling (see Figure 19). For the DQDB MAN isochronous services, Connection Endpoint (CEs) identifiers are used for a similar purpose.

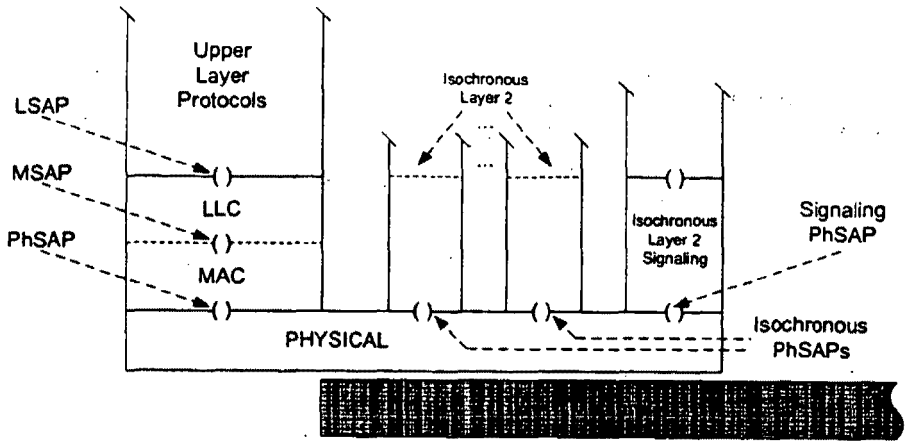


Figure 19—ISLAN RM (end station)

PhSAPs and CEs are the architectural mechanism by which symbol streams are passed to the Physical service provider by the Physical service user, and to the Physical service user by the Physical service provider. The distinction of different PhSAPs at a single ISLAN Physical service boundary is required because that service boundary is used simultaneously to provide both packet-mode and (multiple) circuit-mode Physical services.

It is a function of the layer management of the PHY multiplexing sublayer to provide each Physical service user with both the information stream and a channel identifier that is mapped onto the PhSAP relevant to the service provided to that user.

11.4 ISLAN signaling

The ISLAN standard provides for direct interworking with ITU-T conformant ISDN I.series Recommendations. These require means of establishing, maintaining, and disestablishing end-to-end connections across (in the ISLAN case) both the ISLAN and intervening WAN. To this end, ISO/IEC 8802-9 includes specifications for extensions to the ITU-T I- and Q-series signaling protocols carried in a signaling-specific D channel. This is a packet-based protocol, but to achieve interworking with the ITU-T Recommendations, it is distinct from the LLC packet service provided over ISLAN.

The signaling service provided by the protocols carried in the D channel permits negotiation of end-to-end network resources such that a guaranteed service can be provided to the users of an end-to-end isochronous channel. Thus, the ISLAN management signalling entity is responsible, as a management agent, for performing the following tasks:

— Negotiation of bandwidth (configuration) management, fault management, performance management, and security management of the access link between device and hub

— Negotiation of service provisioning over the local ISLAN interface in order to access the WAN-based ISDN services

The ISLAN signaling message elements are provided in compliance with international (ITU-T) network signaling methods with appropriate protocol extensions.

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Annex A

(informative)

Bibliography (Additional references for LAN/MAN-related standards)

A.1 General LAN/MAN standards and specifications

[B1] *Ethernet Version 2.0, A Local Area Network—Data Link Layer and Physical Layer Specifications.* Digital Equipment Corp., Intel Corp., and Xerox Corp., November 1982.

[B2] IEEE 100™, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition.[8]

[B3] IEEE Std 802.10-1992, IEEE Standards for Local and Metropolitan Area Networks: Interoperable LAN/MAN Security (SILS) (includes IEEE Std 802.10b™-1992).[9]

[B4] ISO/IEC TR 8802-1:1997, Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Technical reports and guidelines—Part 1: Overview of Local Area Network Standards.

[B5] ISO/IEC 8802-3:1999 (IEEE Std 802.3-1998), Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications.

[B6] ISO/IEC 8802-4:1990 (IEEE Std 802.4-1990), Information processing systems—Local area networks—Part 4: Token-passing bus access method and physical layer specifications.

[B7] ISO/IEC 8802-5:1998 (IEEE Std 802.5-1998), Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 5: Token ring access method and physical layer specifications.

[B8] ISO/IEC 8802-6:1994 (IEEE Std 802.6™-1994), Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 6: Distributed Queue Dual Bus (DQDB) access method and physical layer specifications.

[B9] ISO/IEC 8802-9:1996 (IEEE Std 802.9™-1996), Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 9: Integrated Services (IS) LAN Interface at the Medium Access Control (MAC) and Physical (PHY) Layers.

[B10] ISO/IEC 8802-11:1999 (IEEE Std 802.11™-1999), Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications.

[8]The IEEE standards and products referred to in Annex A are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

[9]IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

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[B11] ISO/IEC 8802-12:1998 (IEEE Std 802.12-1998), Information technology — Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 12: Demand-Priority access method, physical layer and repeater specifications.

[B12] ISO 9314-1:1989, Information processing systems—Fibre Distributed Data Interface (FDDI)—Part 1: Token Ring Physical Layer Protocol (PHY).

[B13] ISO 9314-2:1989, Information processing systems—Fibre Distributed Data Interface (FDDI)—Part 2: Token Ring Media Access Control (MAC).

[B14] ISO 9314-3:1990, Information processing systems—Fibre Distributed Data Interface (FDDI)—Part 3: Token Ring Physical Layer Medium Dependent (PMD).

[B15] ISO 9314-6:1989, Information processing systems—Fibre Distributed Data Interface (FDDI)—Part 6: Token Ring Station Management (SMT).

[B16] ISO/IEC TR 11802-5:1997 (IEEE Std 802.1H-1997), Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Technical reports and guidelines—Part 5: Media Access Control (MAC) Bridging of Ethernet V2.0 in Local Area Networks.

[B17] ISO/IEC 15802-5:1998 (IEEE Std 802.1G™-1998), Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Common specifications—Part 5: Remote Media Access Control (MAC) Bridging.

[B18] RFC 1042, A Standard for the Transmission of IP Datagrams over IEEE 802 Networks. Postel, J., and Reynolds, J., February 1988.[10]

[B19] RFC 1390, Transmission of IP and ARP over FDDI Networks. Katz, D., January 1993.

A.2 Management

NOTE—Many of the standards listed in Clause 2 and A.1 contain specifications of their managed objects.

[B20] IEEE Std 802.1F-1993, IEEE Standards for Local and Metropolitan Area Networks: Common Definitions and Procedures for IEEE 802 Management Information.

NOTE—Some of the content of IEEE Std 802.1F-1993 is also included in ISO/IEC 10742.

[B21] ISO/IEC 7498-4:1989, Information processing systems—Open Systems Interconnection—Basic Reference Model—Part 4: Management framework.

[B22] ISO/IEC 8824-1:1995, Information technology—Abstract Syntax Notation One (ASN.1)—Specification of basic notation.

[B23] ISO/IEC 8824-2:1995, Information technology—Abstract Syntax Notation One (ASN.1)—Information object specification.

[10]Internet RFCs are available from the Internet Engineering Task Force on the World Wide Web browser at http://www.ietf.org/rfc/rfcnnnn.txt (where nnnn is the four-digit RFC number, padded with leading zeros if necessary). For more information, call the IETF secretariat at +1-703-620-8990.

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[B24] ISO/IEC 8824-3:1995, Information technology—Abstract Syntax Notation One (ASN.1)—Constraint specification.

[B25] ISO/IEC 8824-4:1995, Information technology—Abstract Syntax Notation One (ASN.1)—Parameterization of ASN.1 specifications.

[B26] ISO/IEC 8825-1:1995, Information technology—ASN.1 encoding rules: Specification of Basic Encoding Rules (BER), Canonical Encoding Rules (CER) and Distinguished Encoding Rules (DER).

[B27] ISO/IEC 9595:1991, Information technology—Open Systems Interconnection—Common management information service definition.

[B28] ISO/IEC 9596-1:1991, Information technology—Open Systems Interconnection—Common management information protocol—Part 1: Specification

[B29] ISO/IEC 10040:1992, Information technology—Open Systems Interconnection—Systems management overview.

[B30] ISO/IEC 10164-1/8:1993, Information technology—Open Systems Interconnection—Systems management: [various functions].

[B31] ISO/IEC 10165-1:1993, Information technology—Open Systems Interconnection—Structure of management information: Management information model.

[B32] ISO/IEC 10165-2:1992, Information technology—Open Systems Interconnection—Structure of management information: Definition of management information.

[B33] ISO/IEC 10165-4:1992, Information technology—Open Systems Interconnection—Structure of management information: Guidelines for the definition of managed objects.

[B34] ISO/IEC 10742:1994, Information technology—Telecommunications and information exchange between systems—Elements of management information related to OSI Data Link Layer standards.

[B35] ISO/IEC 15802-2:1995 (IEEE Std 802.1B-1995), Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Common specifications—Part 2: LAN/MAN management, service and protocol.

[B36] ISO/IEC 15802-4:1994 (IEEE Std 802.1E™-1994), Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Common specifications—Part 4: System load protocol.

[B37] RFC 1095, The Common Management Services and Protocol over TCP/IP (CMOT). Warrior, U., and Besaw, L., April 1989.

[B38] RFC 1155, Structure and Identification of Management Information for TCP/IP-based Internets. Rose, M., and McCloghrie, K., May 1990.

[B39] RFC 1157, A Simple Network Management Protocol (SNMP). Case, J., Fedor, M., Schoffstall, M., and Davin, J., May 1990.

[B40] RFC 1212, Concise MIB Definitions. Rose, M., and McCloghrie, K. (Editors), March 1991.

[B41] RFC 1215, A Convention for Defining Traps for use with the SNMP. Rose, M., March 1991.

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[B42] RFC 1493, Definitions of Managed Objects for Bridges. Decker, E., Langille, P., Rijsinghani, A., and McCloghrie, K., July 1993.

[B43] RFC 1643, Definitions of Managed Objects for the Ethernet-like Interface Types. Kastenholtz, F., July 1994.

[B44] RFC 1902, Structure of Management information for Version 2 of the Simple Network Management Protocol (SNMPv2). Case, J., McCloghrie, K., Rose, M., and Waldbusser, S., January 1996.

[B45] RFC 1903, Textual Conventions for Version 2 of the Simple Network Management Protocol (SNMPv2). Case, J., McCloghrie, K., Rose, M., and Waldbusser, S., January 1996.

[B46] RFC 1904, Conformance Statements for Version 2 of the Simple Network Management Protocol (SNMPv2). Case, J., McCloghrie, K., Rose, M., and Waldbusser, S., January 1996.

[B47] RFC 1905, Protocol Operations for Version 2 of the Simple Network Management Protocol (SNMPv2). Case, J., McCloghrie, K., Rose, M., and Waldbusser, S., January 1996.

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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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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.

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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.

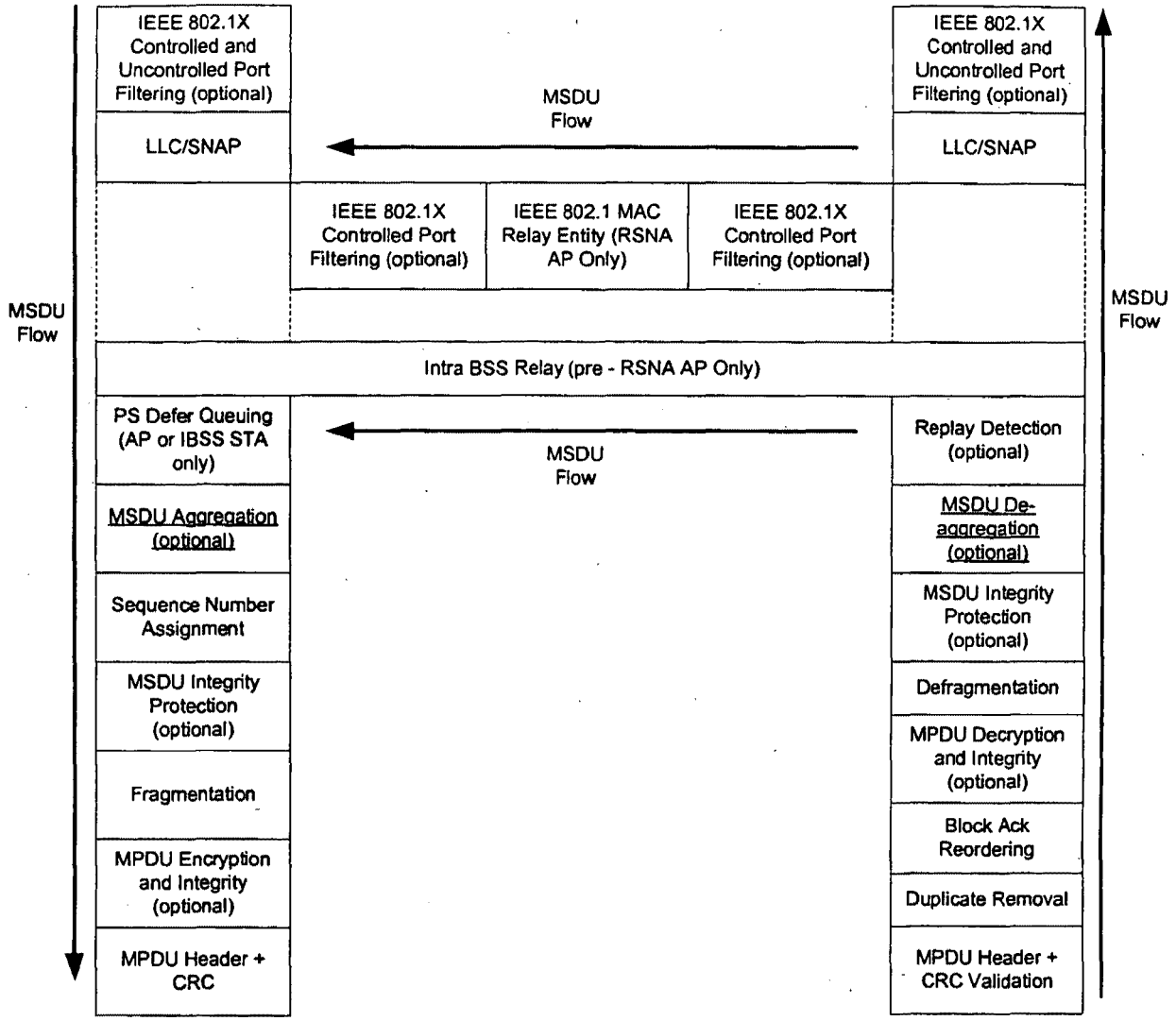


Figure 11g – MAC data plane architecture

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:

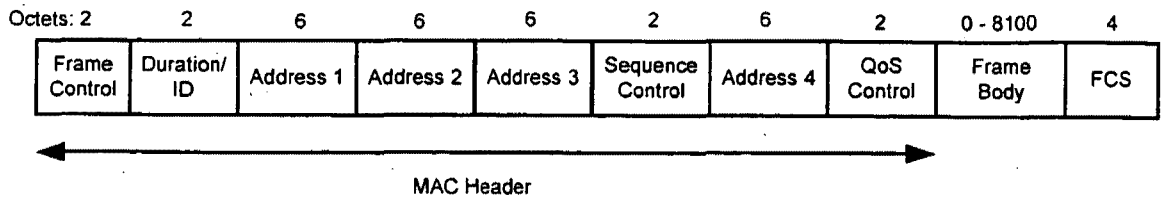


Figure 12 – MAC frame format

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:

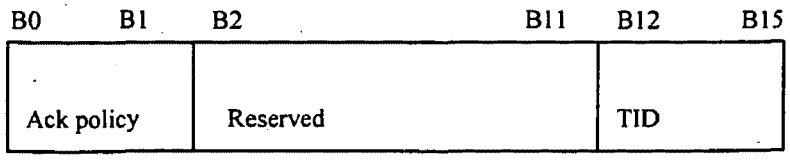


Figure 21.2– BAR Control Field

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. 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 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.

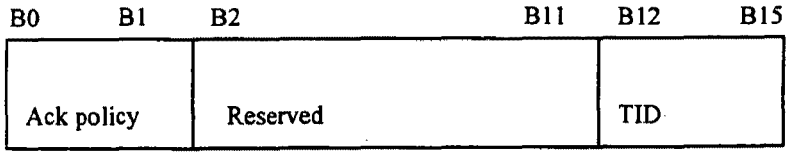


Figure 21.5 – BA Control Field

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. 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 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.

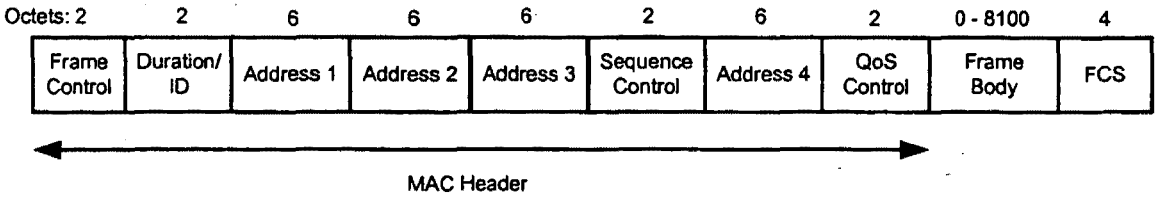


Figure 22 – Data frame

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

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		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.

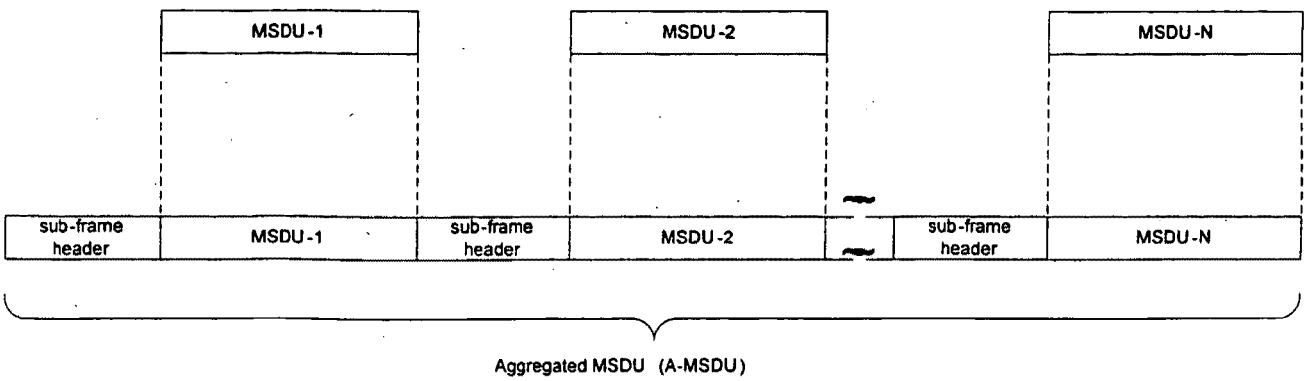


Figure 001n – Formation of an A-MSDU

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.

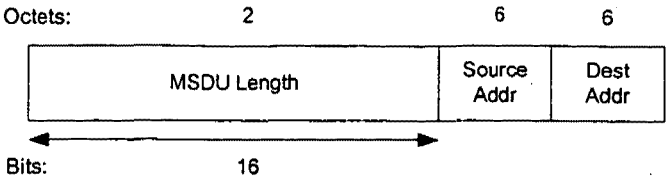


Figure 002n – Sub-Frame Header

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.

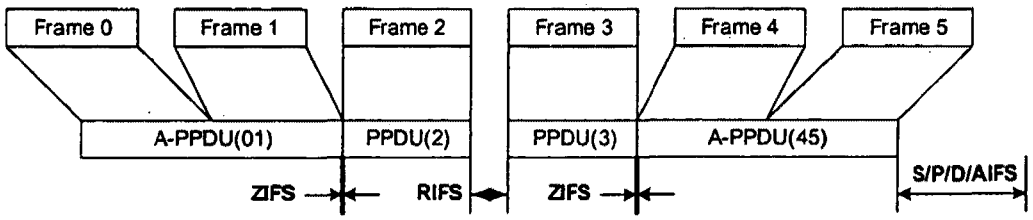


Figure 003n – HTP Burst transmission

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, 18, 22, 24, 36, 44, 48, 66, 72, 73-92, 96, 97-106, 108, 109-121	Selects among rates and transmission modes 02 = 1 Mbit/s 04 = 2 Mbit/s 11 = 5.5 Mbit/s 12 = 6 Mbit/s

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			18 = 9 Mbit/s 22 = 11 Mbit/s 24 = 12 Mbit/s 36 = 18 Mbit/s 44 = 22 Mbit/s 48 = 24 Mbit/s 66 = 33 Mbit/s 72 = 36 Mbit/s 96 = 48 Mbit/s 108 = 54 Mbit/s 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 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 Range: 1-8191
TRANSMISSION_ MODE	The mode used for transmission of the PPDU. Determines the preamble type used. 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 Values: 0 (convolutional), 1 (LDPC)
SERVICE	The scrambler initialization vector. 16 null bits
TXPWR_LEVEL	The transmit power level. The definition of these levels is up to the implementer. Range: 1-8
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 used when a mixed mode TRANSMISSION_MODE is selected. 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 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. 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. Values: 1,2,3,4.
CODE_TYPE	Convolutional or LDPC 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. 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.

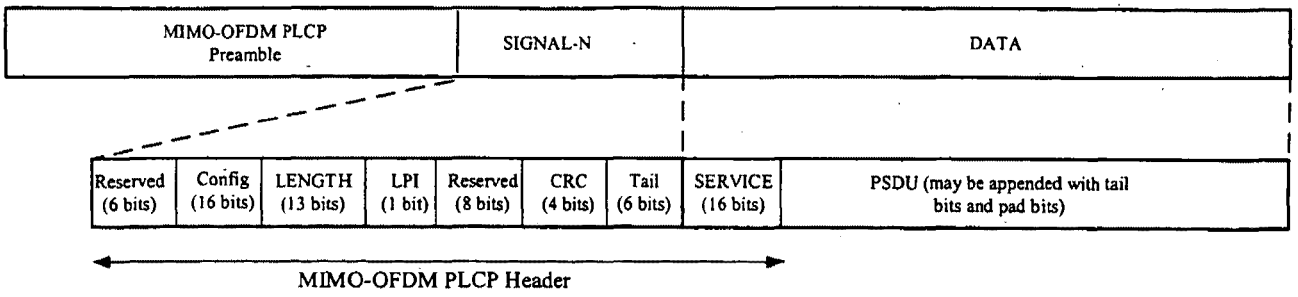


Figure 001 – PPDU frame format: Greenfield access in the 1TX (40 MHz) and 2TX (20 and 40 MHz) modes

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.

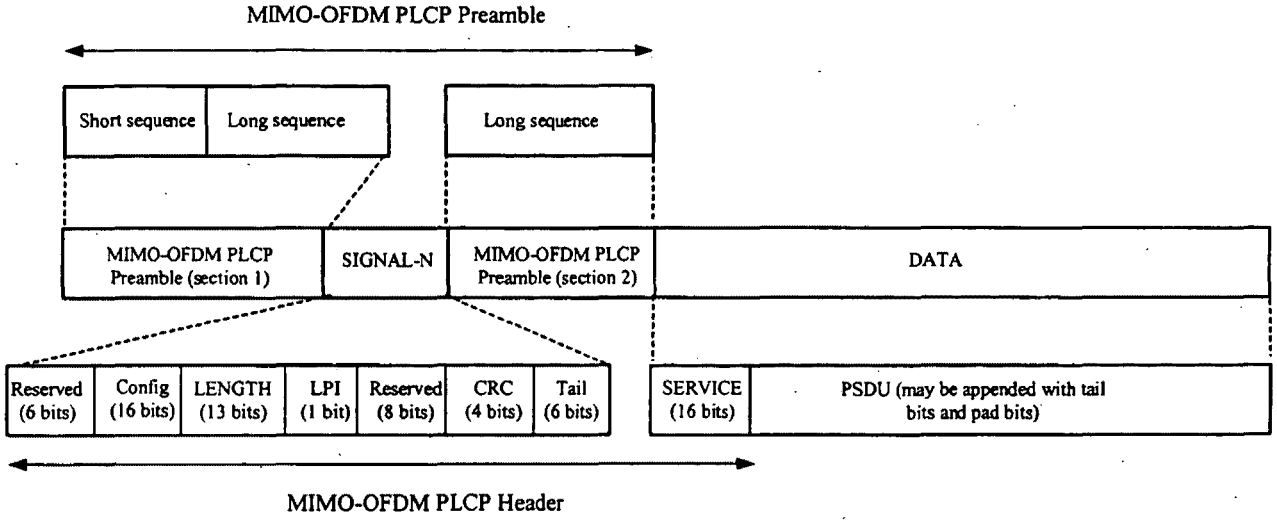


Figure 002 – PPDU frame format: Greenfield access in the 3TX and 4TX modes (20 and 40 MHz)

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.

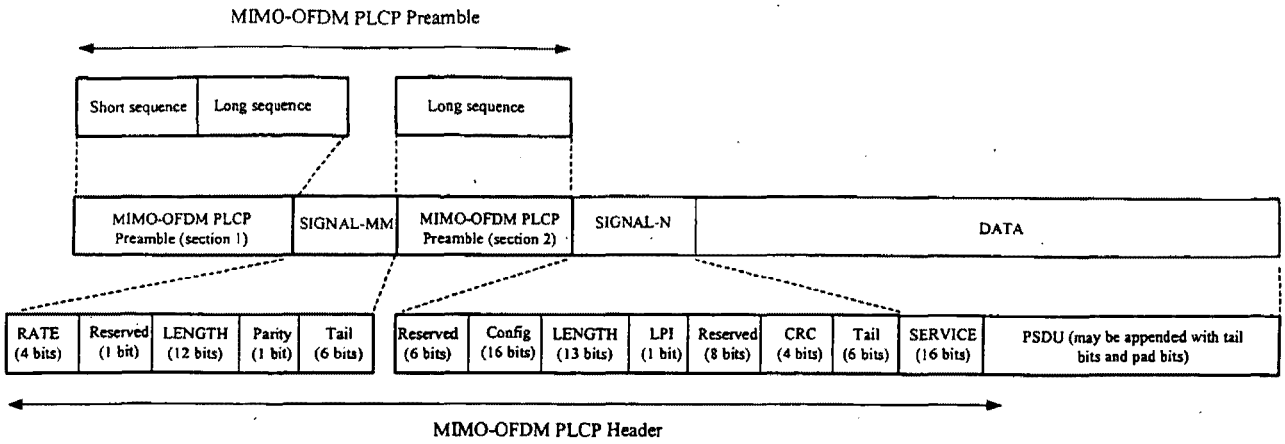


Figure 003 – PPDU frame format: Mixed mode access in the 1TX (40 MHz) and 2TX (20 and 40 MHz) modes

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.

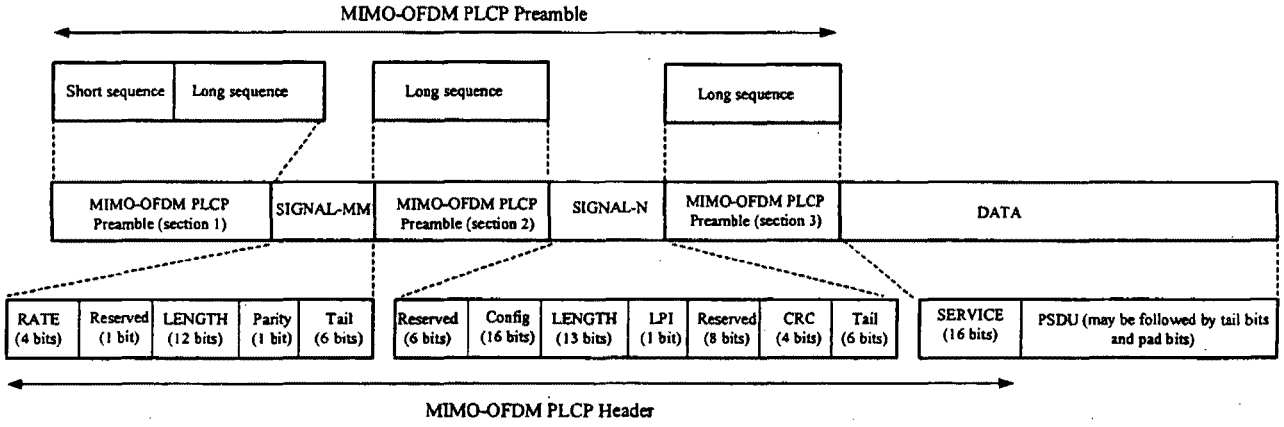


Figure 004– PPDU frame format: Mixed mode access in the 3TX and 4TX modes (20 MHz)

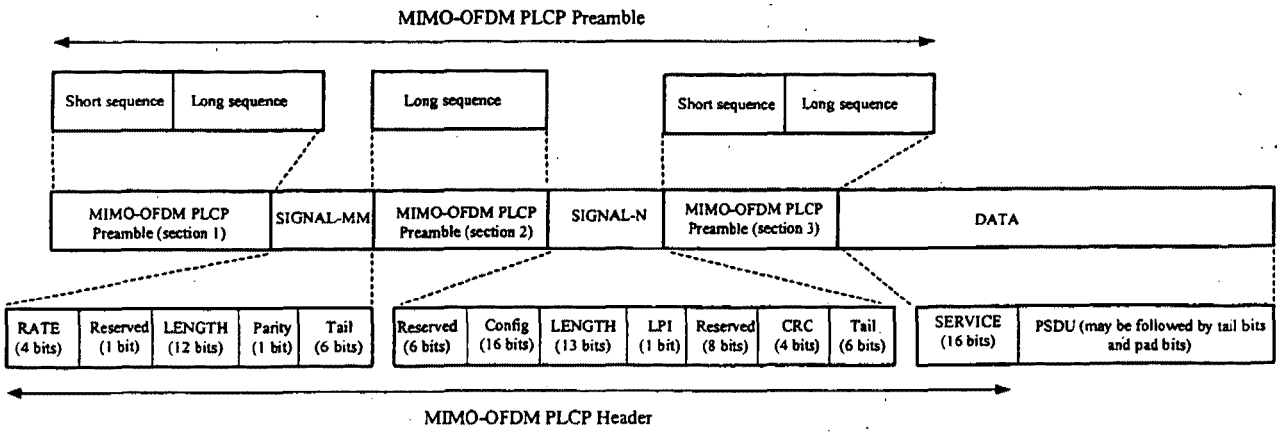


Figure 005– PPDU frame format: Mixed mode access in the 3TX and 4TX modes (40 MHz)

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})	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
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})	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
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})	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	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})	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
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})	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	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})	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	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})	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	
Δ_F: Subcarrier frequency spacing	0.3125 MHz	0.3125 MHz	Δ_F = 20/64 = 40/128 MHz

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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 Δ_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.

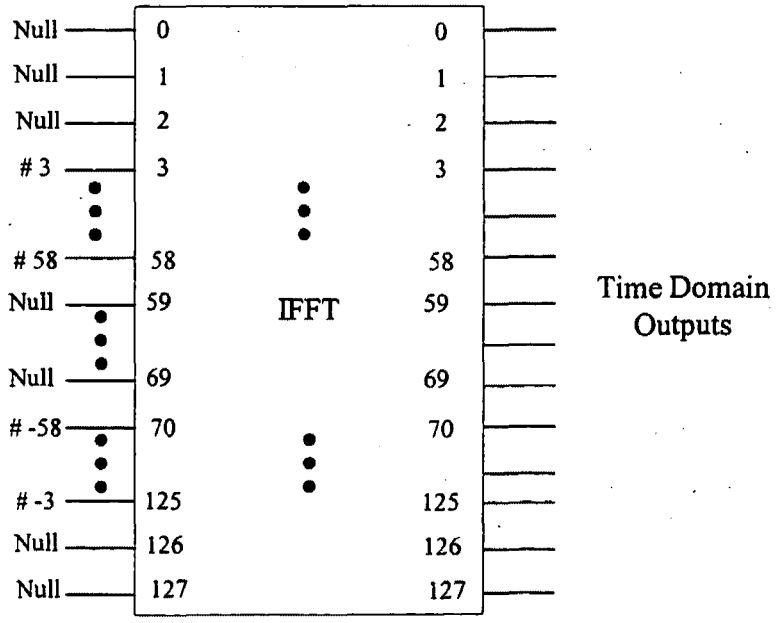


Figure 006– Inputs and outputs of 128-point IDFT for 40 MHz data transmission

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

$SS_{40GF}[-58,58] = \sqrt{2} \times$ {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, 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} (6)

on the subcarriers of the OFDM signal. The ensuing long sequence for 40 MHz greenfield operation is defined by the sequence

$LS_{40GF}[-58..58] = \{1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, -1, 1, -1, -1, 1, 1, -1, 1, -1, 1,$
$-1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1; 1, 1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1,$
$1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, -1, -1\}.$ (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:

$SS_{40MM}[-58..58] = \sqrt{7/3} \times \{0, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, -$
$1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 0, 0, -$
$1-j, 0, 0, 0, 1+j, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 0, 0, -1-j, 0, 0, 0, 1+j, 0, 0, 0, 1+j, 0, 0, 0, 1+j,$
$0, 0, 0, 1+j, 0, 0, 0, 0\},$ (8)

$LS_{40MM}[-58..58] = \{1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 0, 1, -1, -1, 1, 1, -1, 1, -1, 1,$
$-1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, -1, -1, -1, -1, -1, 0, 0, 0, 0, 0, 1, 1, 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1,$
$1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1, 1, 1, 1, 1, 0, 1, -1, -1, 1, 1, -1, 1, -1, 1, -1, -1, -1, -1, -1, 1, 1, -1, -1, 1, -1, 1, -1, 1, 1, 1, 1, -1, -1\}.$ (9)

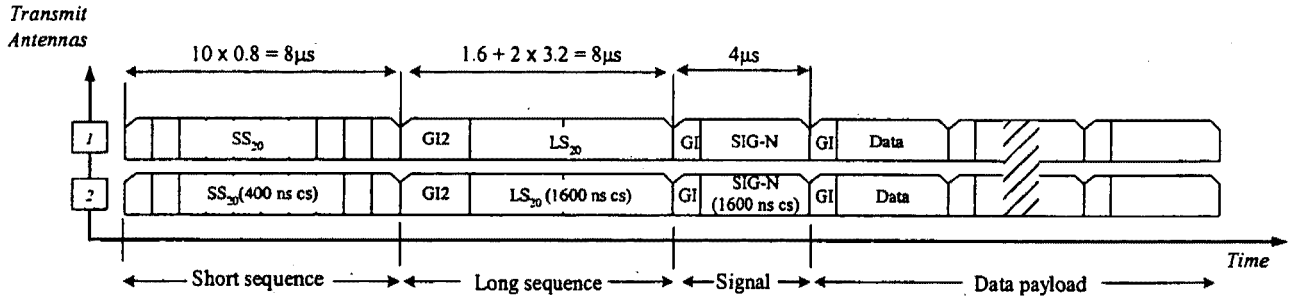


Figure 007 – MIMO-OFDM Training structure for N_{TX} = 2, 20 MHz, greenfield operation

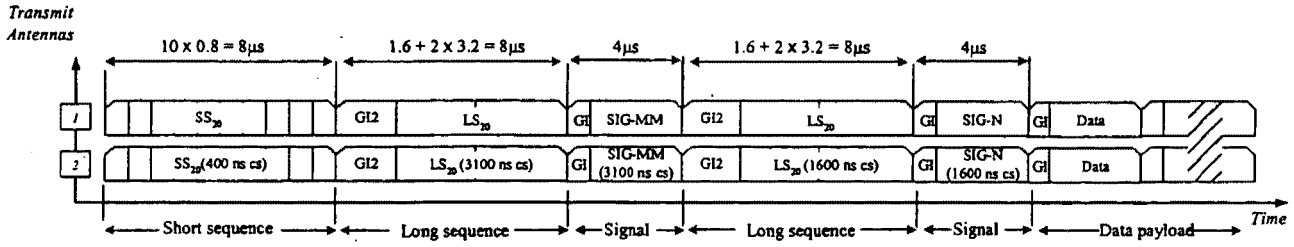


Figure 008 – MIMO-OFDM Training structure for N_{TX} = 2, 20 MHz, mixed mode operation

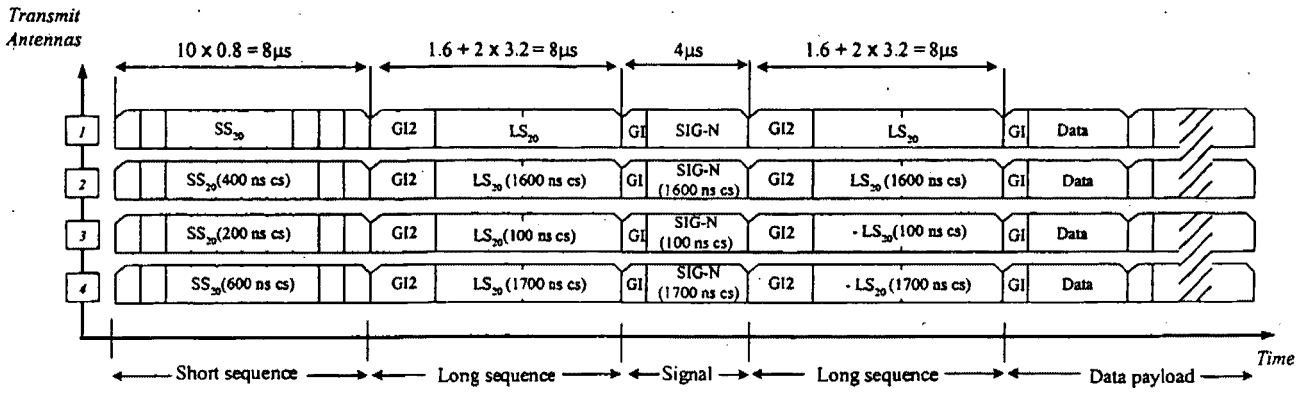


Figure 009 – MIMO-OFDM Training structure for N_{TX} = 3 and 4, 20 MHz, greenfield operation

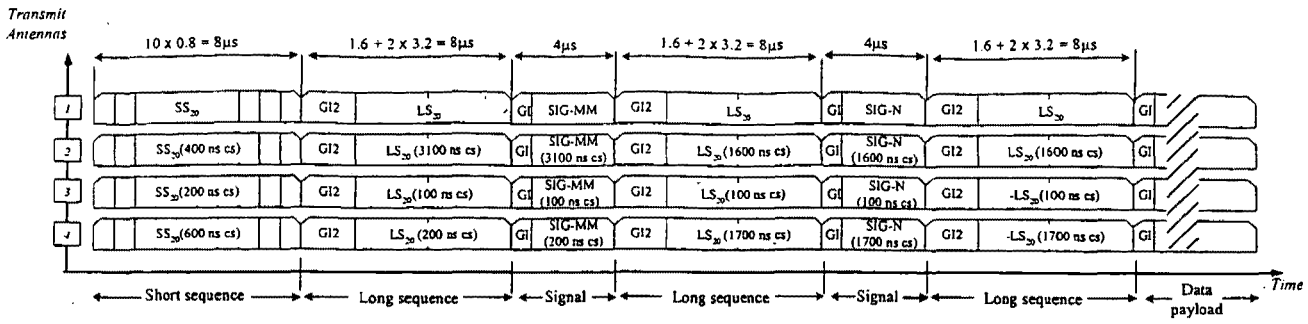


Figure 010 – MIMO-OFDM Training structure for N_{TX} = 3, 4, 20 MHz, mixed mode operation

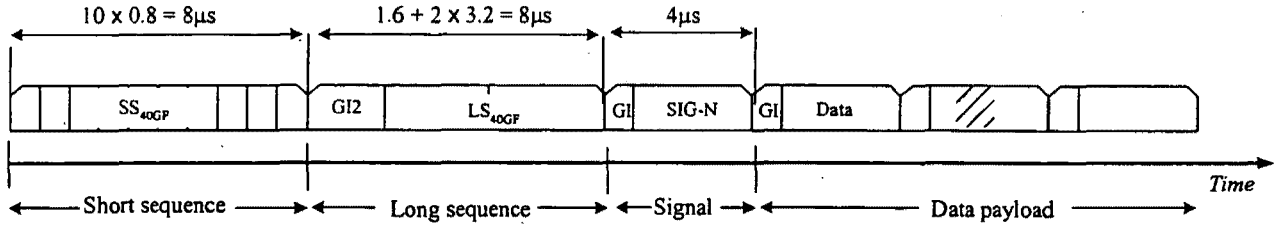


Figure 011 – MIMO-OFDM Training structure for N_{TX}=1, 40 MHz, greenfield operation

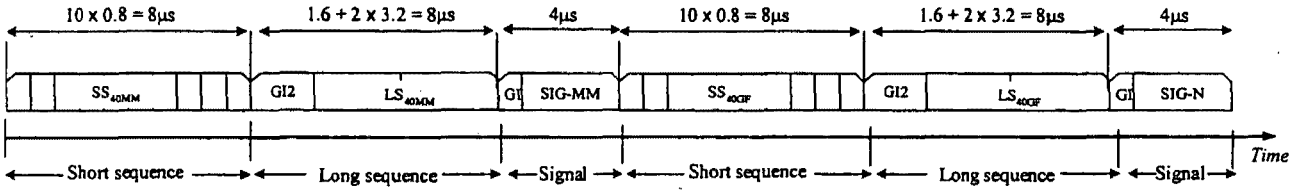


Figure 012 – MIMO-OFDM Training structure for N_{TX}=1, 40 MHz, mixed mode operation

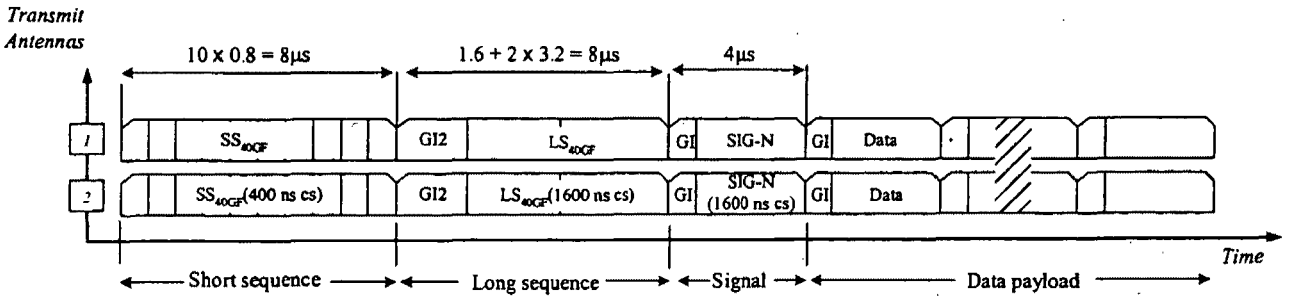


Figure 013 – MIMO-OFDM Training structure for N_{TX} = 2, 40 MHz, greenfield operation

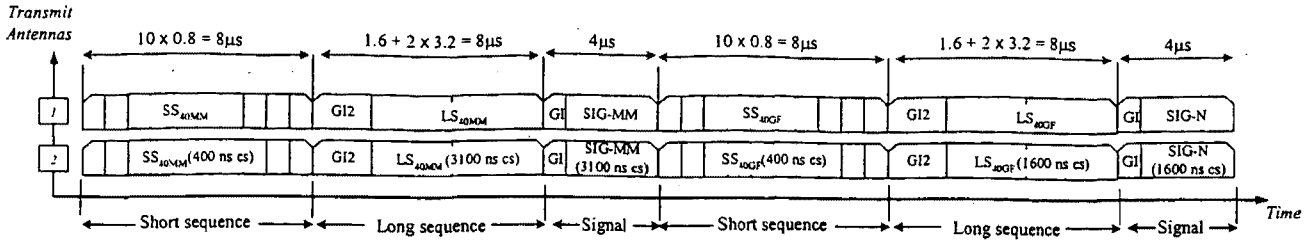


Figure 014 – MIMO-OFDM Training structure for N_{TX} = 2, 40 MHz, mixed mode operation

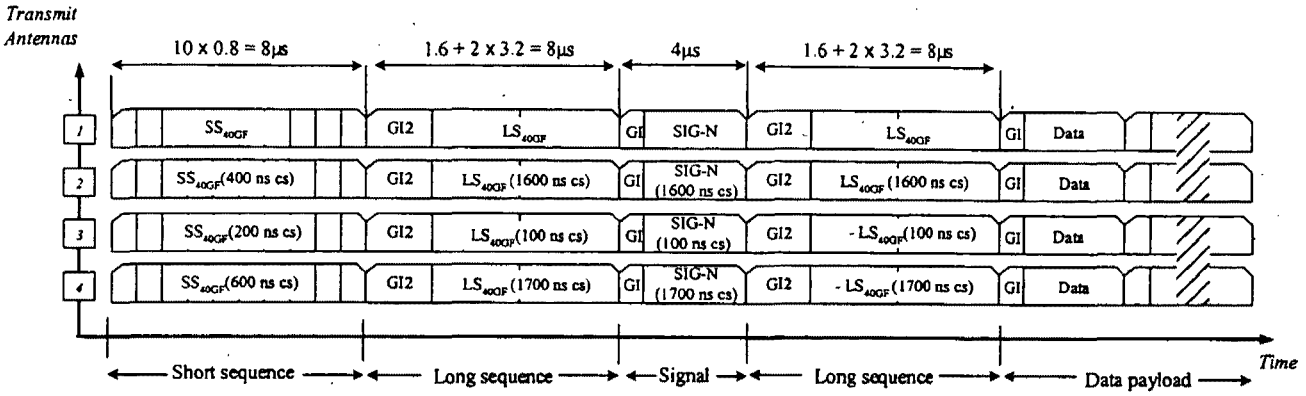


Figure 015 – MIMO-OFDM Training structure for N_{TX} = 3 and 4, 40 MHz, greenfield operation

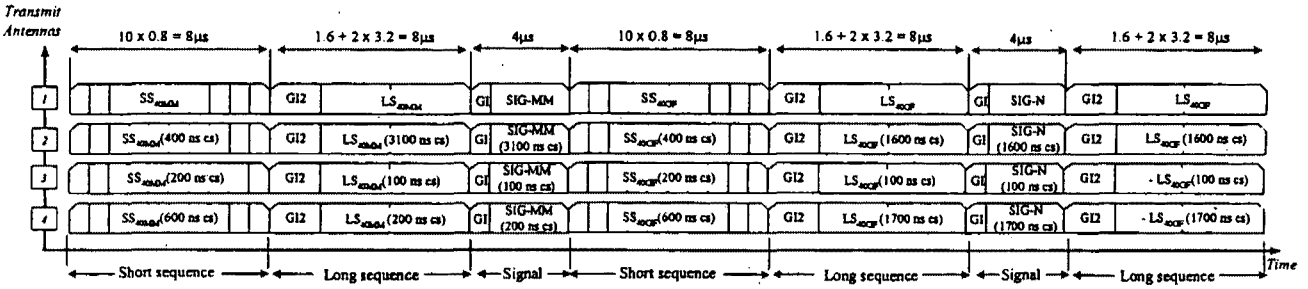


Figure 016 – MIMO-OFDM Training structure for N_{TX} = 3, 4, 40 MHz, mixed mode operation

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.

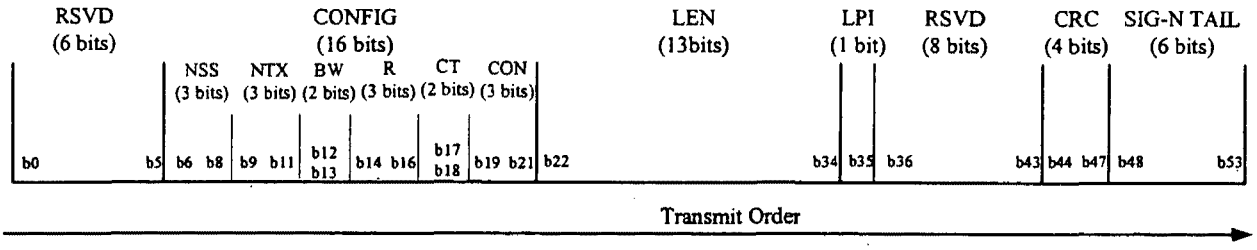


Figure 017 – SIG-N field bit assignment

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:

$$N_{SYM} = \text{Ceiling}\left((16 + 8 \times \text{LENGTH} + 6 \times N_{ES})/N_{DBPS}\right) \quad (10)$$

$$N_{DATA} = N_{SYM} \times N_{DBPS} \quad (11)$$

$$N_{PAD} = N_{DATA} - (16 + 8 \times \text{LENGTH} + 6 \times N_{ES}) \quad (12)$$

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.

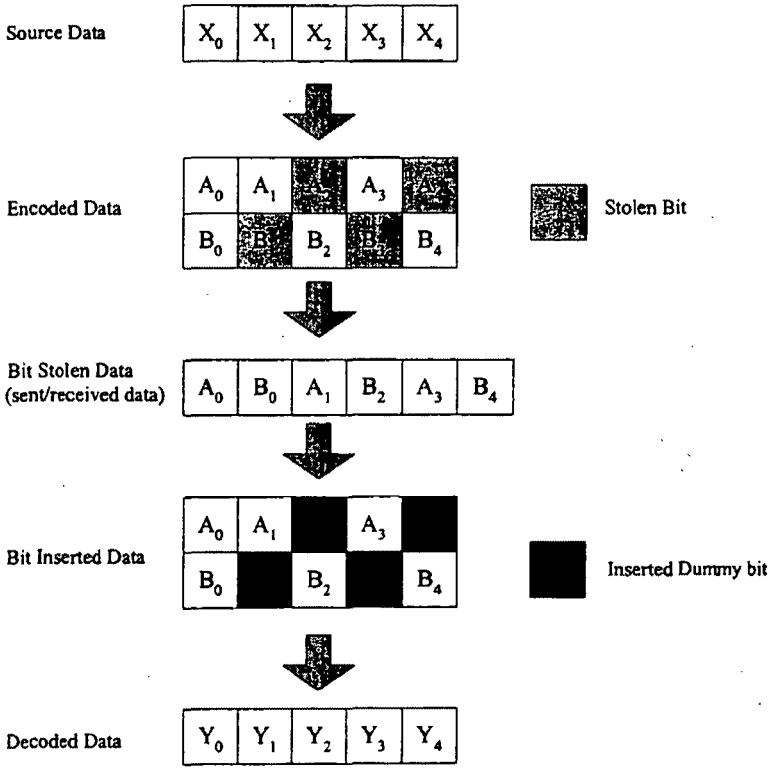


Figure 018 – An illustration of the bit stealing and bit insertion procedure for R = 5/6

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 nth spatial stream. This is illustrated in Figure 019.

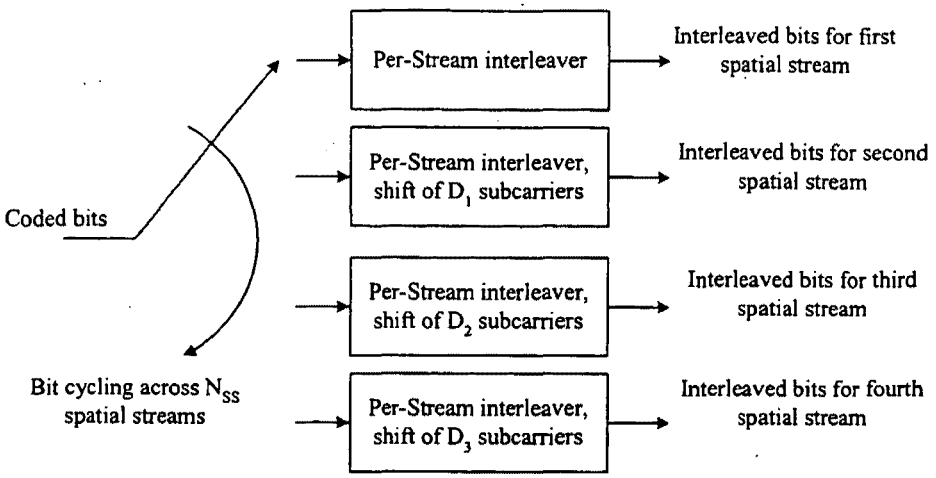


Figure 019 – Illustration of the interleaver function

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.

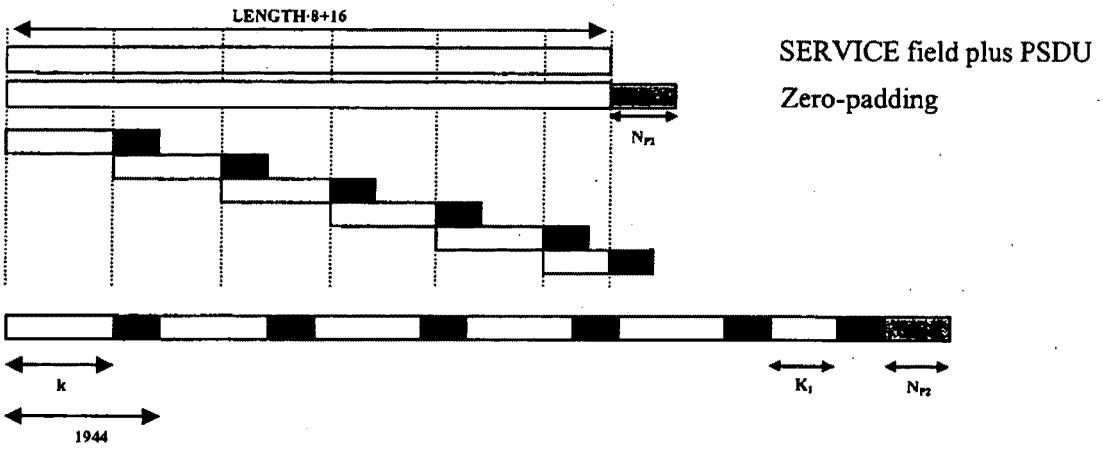


Figure 020 – LDPC PPDU encoding

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, $\mathbf{I}=(i_0, i_1, \ldots i_{(k-1)})$ 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.

$$B_{(n-k)\times(n-k)} = \begin{pmatrix} b_{11} & 0 & & L & & 0 \\ b_{21} & b_{22} & 0 & & & \\ & b_{32} & O & O & & M \\ M & & O & O & 0 & \\ & & & O & & 0 \\ b_{(n-k)1} & & L & & & b_{(n-k)(n-k)} \end{pmatrix},$$

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).

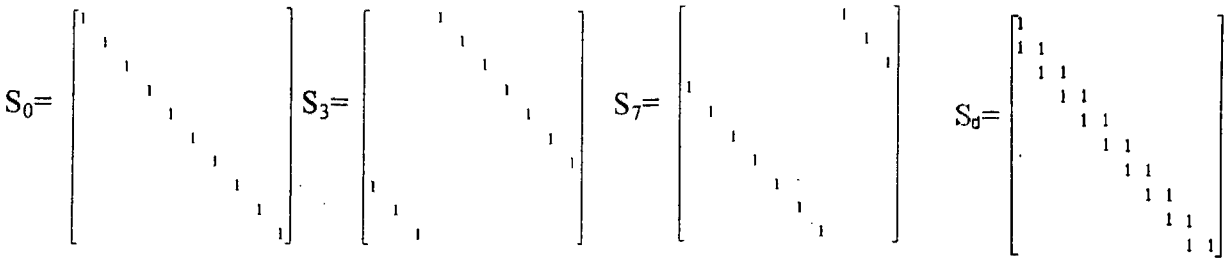


Figure 022 – Structure of the cyclic permutations of the identity matrix. Matrix S_i is produced by cyclically shifting the columns of the identity matrix to the right *i* places.

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 nth element of the sequence $p_{0...126v}$ 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 ith row and jth 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 mth antenna ($m = 1, 2, ...4$) during the nth 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

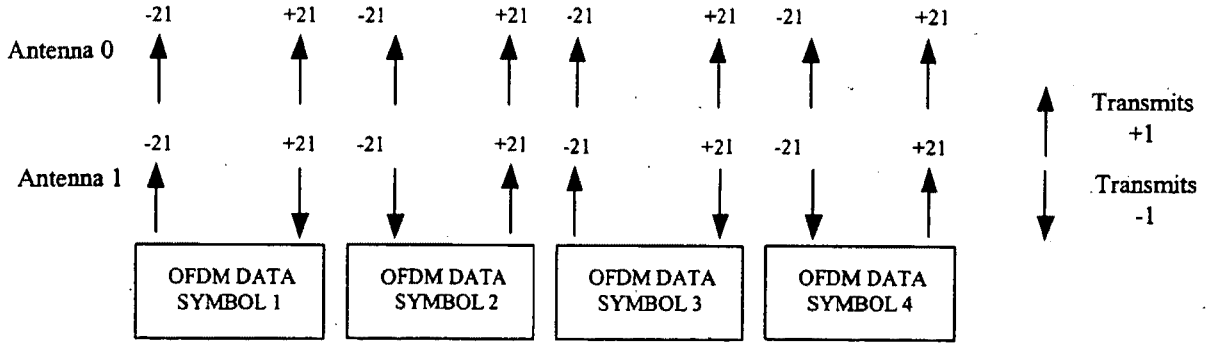


Figure 023 – An illustration of the relative polarity of pilot signals in the 2TX, 20 MHz mode. "-21" and "+21" indicate the subcarrier indexes on which pilot signals are sent

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	Number of data subcarriers	Number of pilots	Coded bits per MIMO-OFDM	Data bits per MIMO-OFDM	Clause 10.4.4.2 rate

			per antenna (N_{BPSC})	(N_{SD})	(N_{SP})	symbol (N_{CBPS})	symbol (N_{DBPS})	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

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.

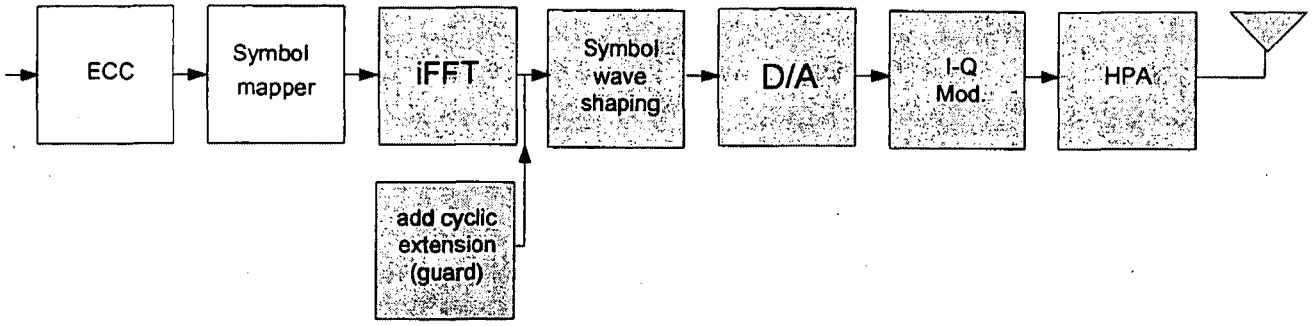


Figure 024 – Transmitter block diagram for the MIMO-OFDM PHY

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:

$$\text{Channel center frequency} = 5000 + (\text{channel number}) \times 5 \text{ (MHz)} \quad \text{for center frequency} > 5000 \text{ MHz} \tag{24}$$

$$\text{Channel center frequency} = 4000 + (\text{channel number}) \times 5 \text{ (MHz)} \quad \text{for } 4900 \leq \text{center frequency} \leq 5000 \text{ MHz} \tag{25}$$

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.

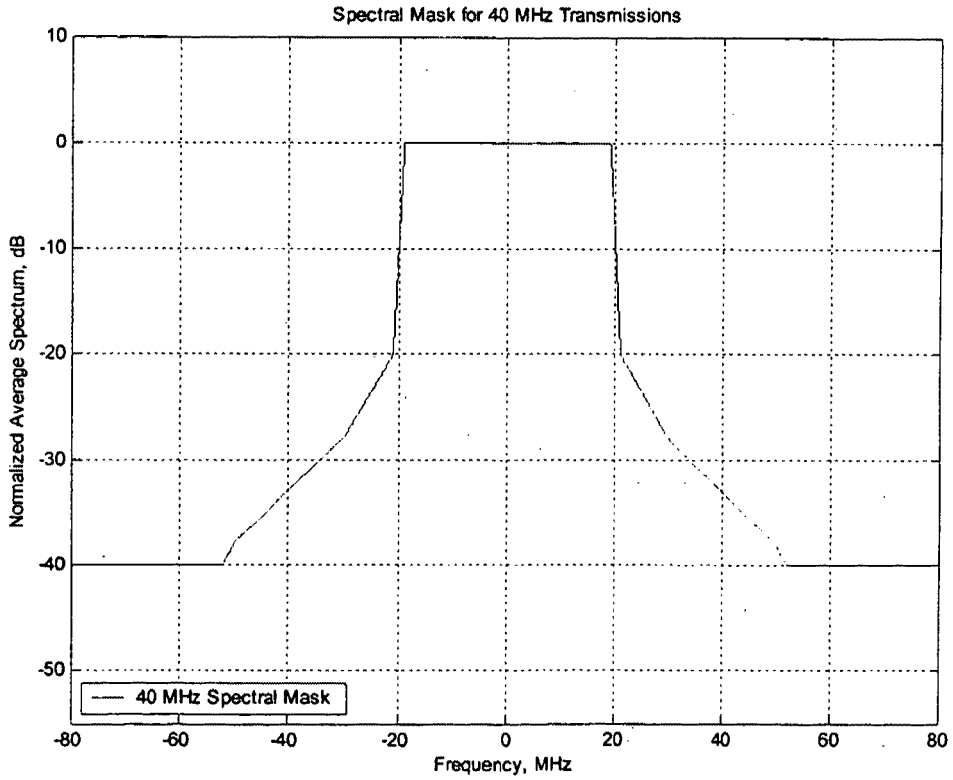


Figure 025 –Transmit spectrum mask for 40 MHz transmissions

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

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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 jth transmitter to the ith receiver, where h_{ij} is the element of the ith 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.

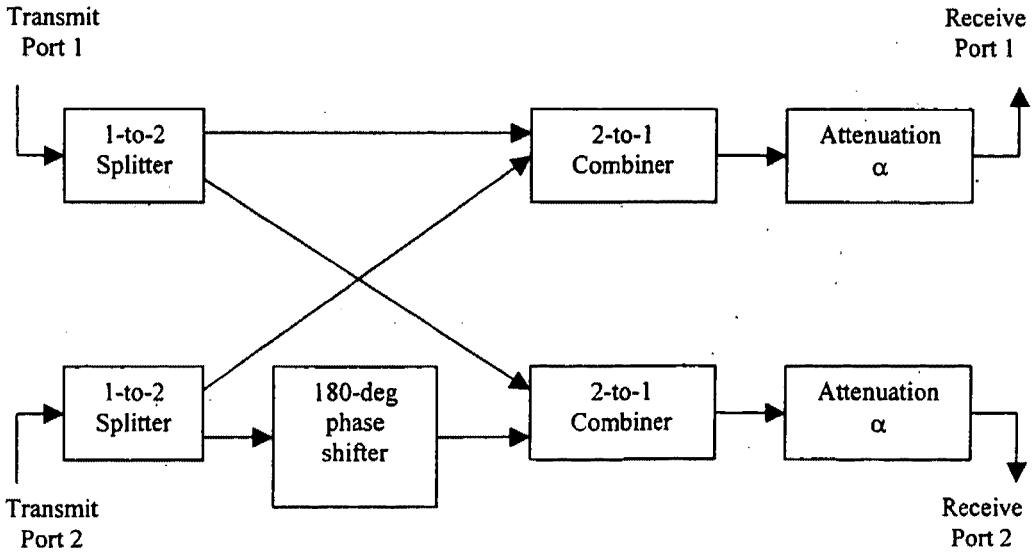


Figure 026 –EVM test setup

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 ith 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 ith 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.

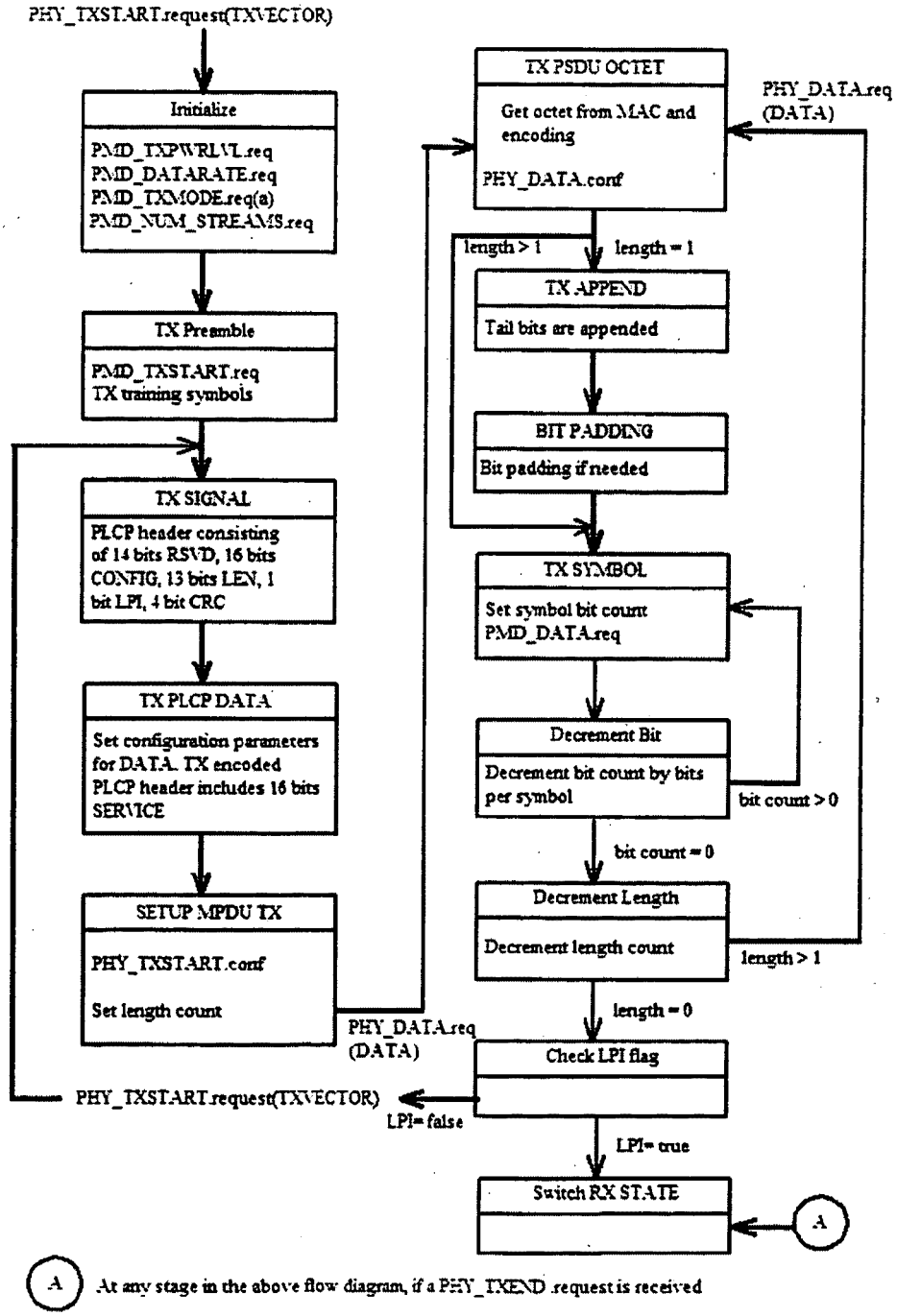


Figure 027 –PLCP transmit state machine

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.

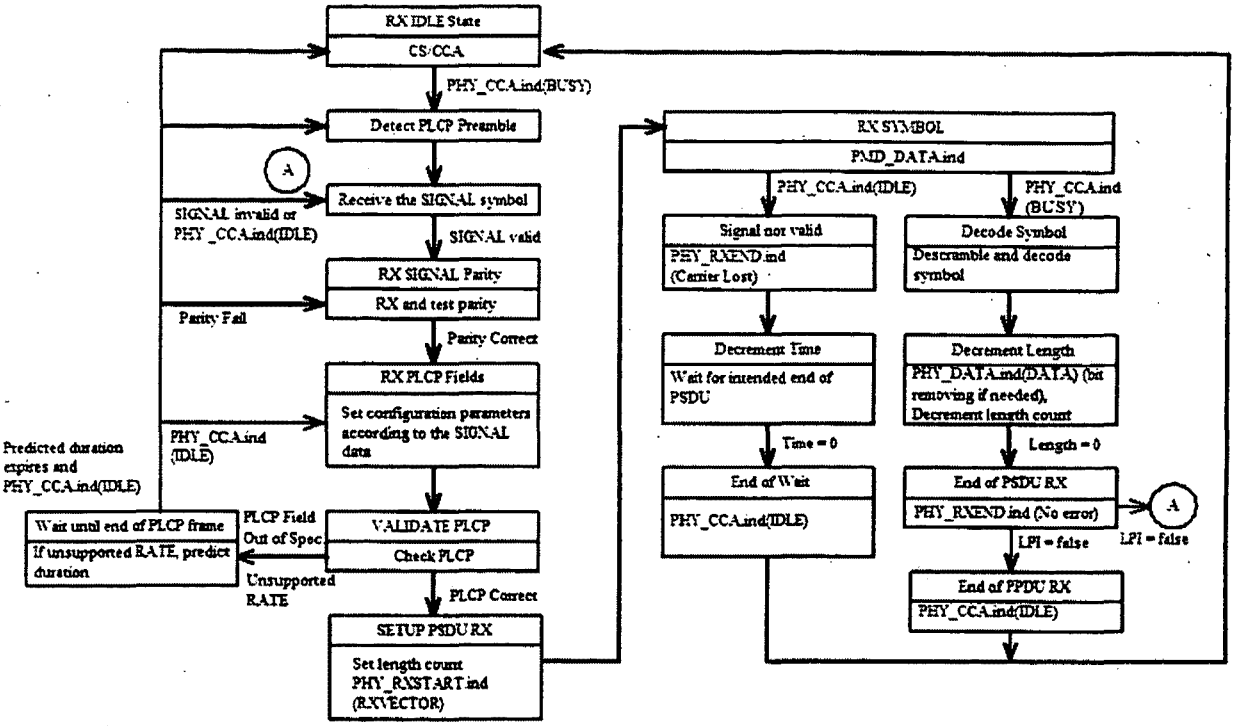


Figure 028 – PLCP receive state machine

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.

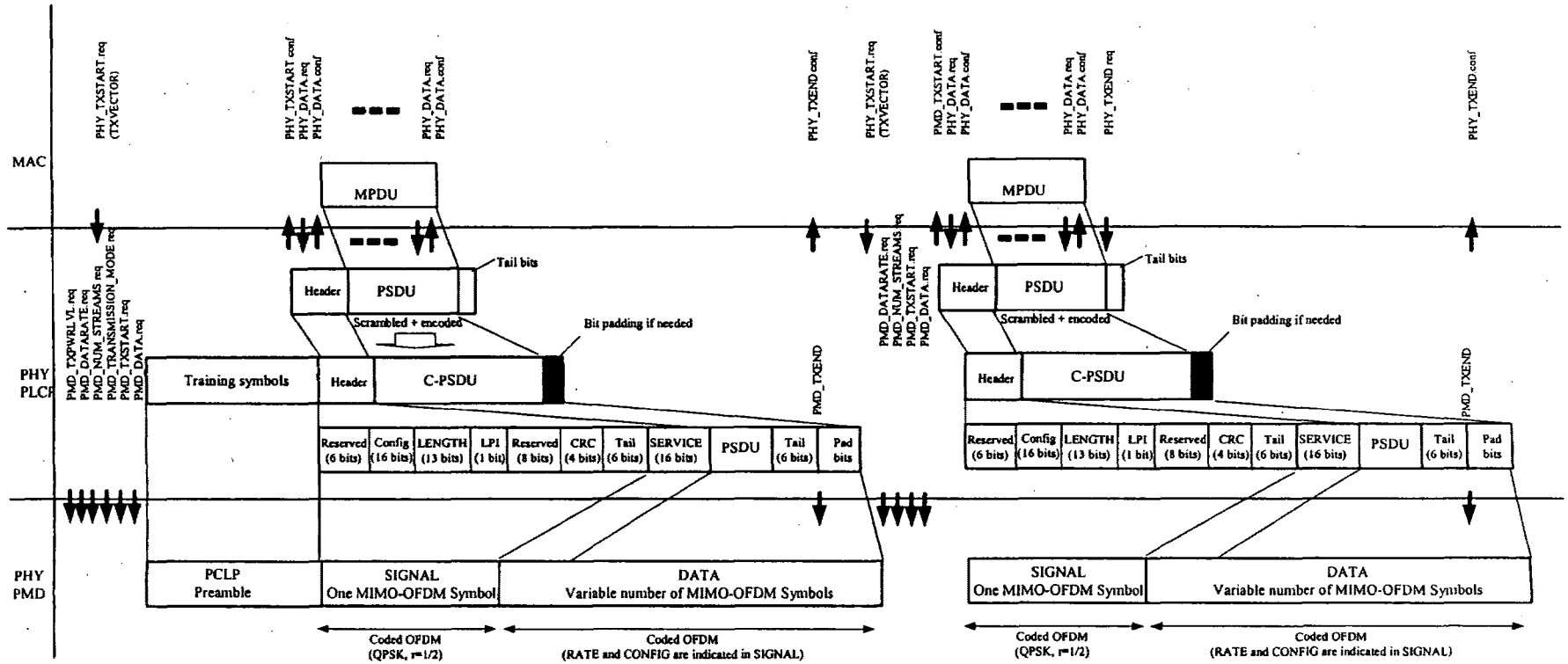


Fig. 029 PLCP transmit procedure for A-PPDU transmission in greenfield 20 MHz modes

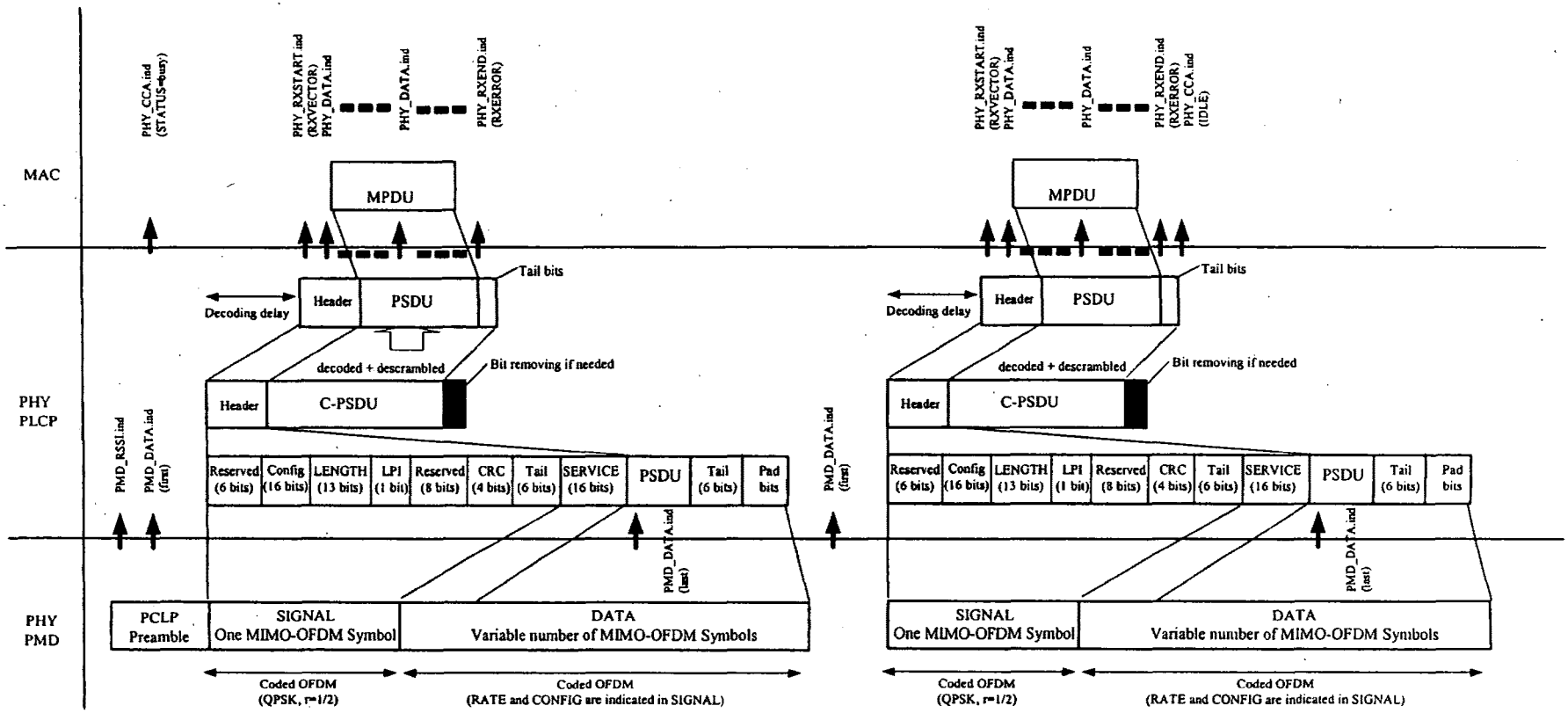


Fig. 030 PLCP receive procedure for A-PPDU reception in greenfield 20 MHz modes

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 X'1' = Support 1, 2, and 3 streams X'2' = Support 1, 2, and 4 streams X'3' = Support 1, 2, 3, and 4 streams	Static
dot11SupportedCodeTypes	X'0' = convolutional only 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:

$$TXTIME = TXTIME_{CONV} \text{ if CODE\_TYPE is convolutional and } TXTIME_{LDPC} \text{ if CODE\_TYPE is LDPC}$$

where

$$TXTIME_{CONV} = T_{MIXED} + T_{PREAMBLE} + T_{SIGNAL} + T_{SYM} \cdot \text{Ceiling}\left((16 + 8 \cdot LENGTH + 6)/N_{DBPS}\right)$$

$$TXTIME_{LDPC} = T_{MIXED} + T_{PREAMBLE} + T_{SIGNAL} + T_{SYM} \cdot N_{SI}$$

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_{SI} 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

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2 **Table A.2 – Description of the**
3 **matrix prototype of the rate**
4 **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

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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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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.

The MAC and PHY sections that follow identify the baseline TGn Sync technical approach, which consists of the sum of all mandatory features. Together, they define a system that achieves the throughput, the robustness and the efficiency that satisfy market expectations while also insuring low design complexity. Each section also identifies optional features that address specific needs of burgeoning WLAN markets (VoIP, A/V applications, robust public access, etc.) and extensibility for growth in the future.

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.

[4] contains a summary presentation (in power point format) giving the highlights of the proposal. [5] is a longer version containing more detail.

[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.

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Pairwise Spoofing: A PHY layer protection mechanism described in 7.1.7.3.

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)

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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

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L-STF	Legacy Short Training Field
MAC	Medium Access Controller
MCS	Modulation Coding Scheme – includes modulation order (BPSK, QPSK, etc.), FEC code and code rate, number of spatial streams (MIMO) and number of TX antennas.
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_{TX}	Total 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
TBC	To be confirmed – need to check this definition
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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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.

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- 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, our proposal introduces two primary techniques:

- Transmission of Multiple Spatial Streams via Multiple Transmit Antennas. Our recommendation is to make 2 antennas mandatory, with the option to scale to 4 antennas. Our proposal is a MIMO evolution of the 802.11a PHY.

- 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:

- A reduced guard interval of 400ns, channel dispersion permitting (e.g. TGn channel model B)

- Higher channel coding rate of 7/8

- 256-QAM in certain advanced transmission modes

Due to the susceptibility of a wireless channel to multipath fading, especially with multiple antennas (and multiple spatial streams), our proposal also introduces several 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 (such as LDPC). Such codes have 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 MIMO channel.

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- Advanced Transmitter beamforming techniques. These include water-filling concepts in the spatial domain, such as unequal power ratios and different choice of modulation-coding schemes on the various spatial streams.

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.

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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

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 Tests state of NAV in the receiver Sets NAV reservation near Transmitter (LongNAV)
TRQ – MIMO training request	Request to train the channel Used for MIMO with implicit Feedback.
MRQ – MCS request	Indicates a request for MCS feedback
MFB – Use this MCS selection	Closed loop channel adaptation feedback Contains values from which the MCS, which will be used for the next PPDU, may be derived deterministically. 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 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

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	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.

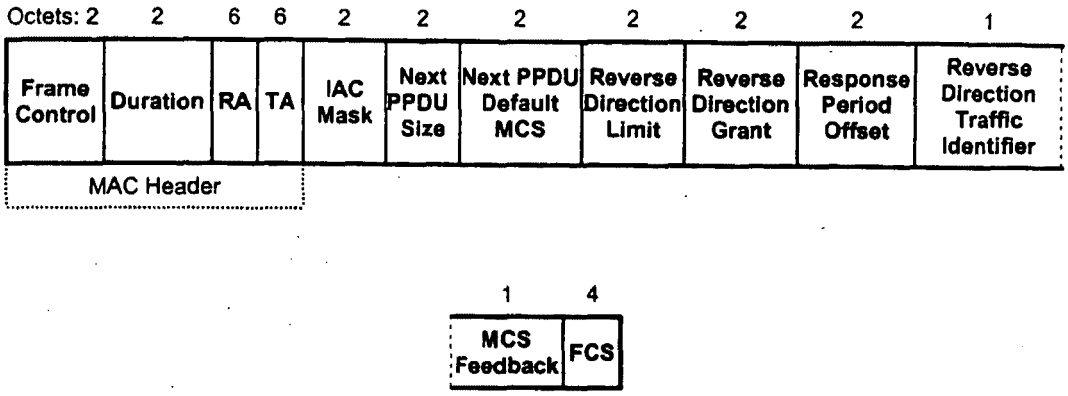


Figure 1 – IAC MPDU

Field	Size (bytes)	Purpose
Frame Control	2	
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). This is interpreted along with the Next PPDU default MCS to determine the duration of the next PPDU. 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.

		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. 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. 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. This value shall be no less than SIFS. Present when RDG is indicated, otherwise undefined.
Reverse Direction Traffic Identifier (RDTID)	1	Indicates one of: • An AC for which reverse direction grant is valid • A TSID indicating a specific TS for which the reverse direction grant is valid • Unconstrained Present when RDG is indicated, otherwise undefined.
MCS Feedback	1	Contains a recommended MCS value. Present when MFB is indicated, otherwise undefined.
FCS	4	

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. 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.

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 to Send	Valid	Valid (see note below)	Not Valid
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	Valid	Valid	Not Valid

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direction grant			

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 – yes the channel is clear	Response to RTS
TRQ – MIMO training request	Request to train the channel Used for MIMO with implicit Feedback.
MRQ – MCS request	Indicates a request for MCS feedback
MFB – Use this MCS selection	Closed loop channel adaptation feedback Contains values from which the MCS, which will be used for the next PPDU, may be derived deterministically. 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 Contains requested total data MPDU length (bytes) and default MCS

Because the training response data may be large, a variable structure is defined to hold it.

6.1.2.2 Format of RAC MPDU

This section defines the format of the RAC MPDU.

The RAC MPDU has a fixed structure. Fields that are not used are present, but reserved.

Octets: 2	2	6	6	2	2	2	1	4

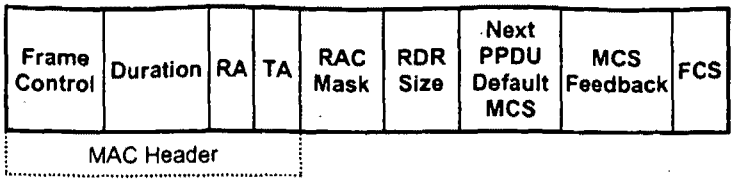


Figure 2 – RAC MPDU

Field	Size (bytes)	Purpose
Frame Control	2	
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. This is interpreted along with the Next PPDU default MCS to determine the duration of the next PPDU. 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 Present when RDR is indicated, otherwise undefined.
MCS Feedback	1	Contains a recommended RCS value.. 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. 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.

1

2 **6.1.2.2.2 MCS Feedback Field**

3 As defined in IAC MPDU.

4 **6.1.3 Multiple Receiver Aggregate Descriptor (MRAD) MPDU**

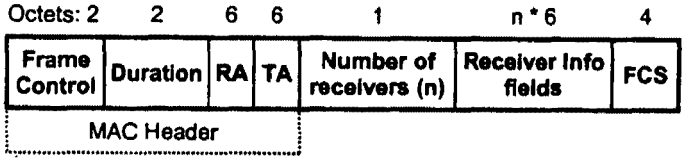
5 **6.1.3.1 Introduction**

6 The MRAD MPDU is the first frame inside a MRA aggregate. It contains an overview of the
7 contents of the aggregate. The MRAD may be used by a receiving STA to save power. Based on
8 the contents of the MRAD, the receiving STA may disable its receiver after it has received any
9 broadcast frames or frames addressed to its unicast address.

10 **6.1.3.2 Format of MRAD MPDU**

11 This section defines the format of the MRAD MPDU.

12



13 **Figure 3 – MRAD MPDU**

14

Field	Size (bytes)	Purpose
Frame Control	2	Frame type is Control.
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	

15 The order of the Receiver Info fields is equal to the order in which MPDUs for the corresponding
16 receivers appear in the MRA aggregate.

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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.

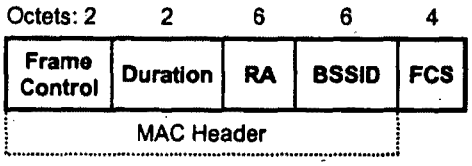


Figure 4 – ICB MPDU

Field	Size (bytes)	Purpose
Frame Control	2	Frame type is Control.
Duration	2	
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 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.

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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.

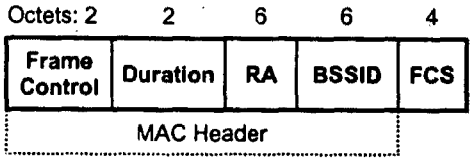


Figure 5 – DCB MPDU

Field	Size (bytes)	Purpose
Frame Control	2	Frame type is Control.
Duration	2	
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 is giving this duration in TUs.

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.

6.2.1 MAC Header (MHDR) MPDU

6.2.1.1 Introduction

This MPDU provides the MAC header for subsequent CHDATA MPDUs.

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6.2.1.2 Format of MHDR MPDU

This section defines the format of the MHDR MPDU.

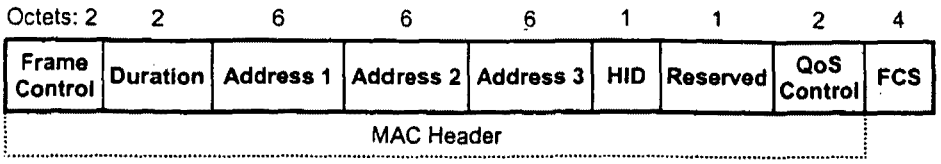


Figure 6 – MHDR MPDU

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.

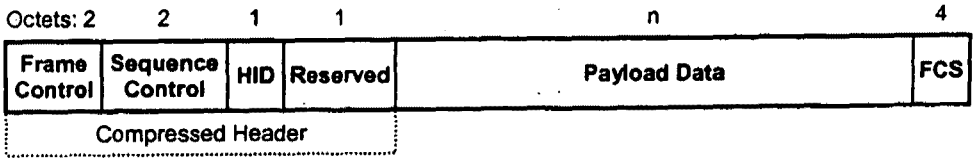


Figure 7 – CHDATA MPDU

Field	Size (bytes)	Purpose
Frame Control	2	Frame type is Data..
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 Capabilities

Support for any optional features or behavior will be declared through a STA's capabilities or management elements.

Table 1 – Additional HT Capabilities

Capability	Contents
HT Supported	Indicates that the device is an HT device, supporting all the mandatory features of this document
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. See section 11.2.1.4.2.2 for a list of MCSs.
Advanced Coding Capability	Advanced Coding Capability Indicates support for advanced coding. 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: {20} for a device only capable of 20MHz operation {20, 40} for a device capable of both 20MHz and 40MHz operation.

AP Capabilities are determined by a STA through listening to beacons or performing a directed or broadcast probe request.

STA Capabilities are determined by an AP when the STA performs an association request.

STA Capabilities may be determined by a STA using a directed probe request to generate a probe response.

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 8.

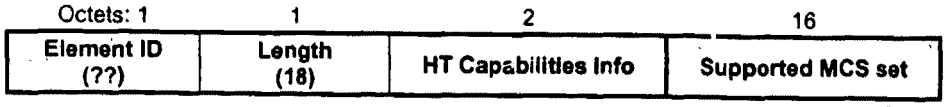


Figure 8 – HT Capability element format

The HT Capabilities Info field is 2 octets in length, and contains capability information bits as defined in Figure 9.

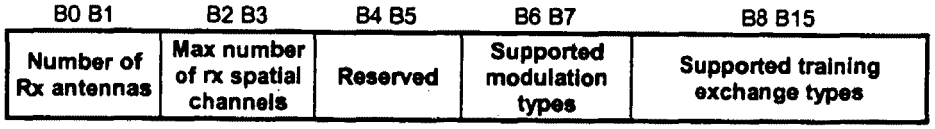


Figure 9 – HT Capabilities Info field

Note: All APs and STAs support TRMS operation in other STAs with a zero stay-awake time.

6.3.2 Information Elements

The AP will signal information in new information elements to manage the BSS.

This information is defined in the table below.

Table 2 – Additional HT Information Elements

Name	Description	Use
Control Channel	Channel number of the control 20MHz channel	In a mixed mode, all broadcast and unaggregated 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. Value of 0 indicates no extension channel is present.	To locate the 40MHz channel in combination with the control channel
Permitted Width Set	Defines the channel widths that may be used in the BSS. Values: {20} or {20,40}	A STA can use any channel width in transmitting a unicast non-control frame supported by the destination STA, and present in the permitted width set.

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Operating Mode	Either: Mixed: (there are legacy devices co-channel) Pure: (there are no legacy devices co-channel or the AP is operating internally in managed mixed mode) Base-20 Managed mixed: (there may be legacy devices in both the control and the extension channel, see section 8.1.3.4) Mixed-Capable IBSS	Used to control the use of protection mechanisms (see section7.1.7). 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 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 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. 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 Beacon	Indicates that this beacon is a duplicate transmitted as part of managed mixed mode operation. HT STAs should ignore duplicate legacy beacons regardless of BSSID.	Present in legacy beacons transmitted by a HT AP during managed mixed mode operation. (See section 8.1.3.3.)

1

2 **6.3.2.1 TRMS Information Element**

3 The TRMS feature is managed by the TRMS information element defined below.

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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. All APs and STAs support TRMS operation in other STAs with a hold-on time of zero. It is an option of a STA to support TRMS tracking for non-zero values of the hold-in time.

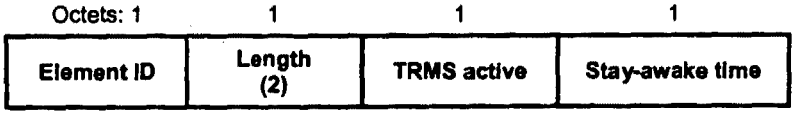


Figure 10 – TRMS element format

6.3.3 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.

This frame is an action frame using the 802.11e Action frame format. A Category code needs to be defined for HT and an action code for this frame.

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].

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6.3.4 TSPEC Modifications

In order to support modified behavior defined in section 7.4, the TSPEC is modified to carry the following additional items.

Table 3 – Additional HT TSPEC Fields

Item	Type	Description
QAP Renegotiation upwards	Flag	If set, this flag permits the QAP to initiate TSPEC parameter negotiation to give the QSTA increased resources as they become available
QAP Renegotiation downwards	Flag	If set, this flag permits the QAP to initiate TSPEC parameter negotiation to give the QSTA decreased resources according to the reasons defined below.
Renegotiation reason	Enumeration	Reason for renegotiation: Increased resources are available The QSTA cannot maintain its negotiated minimum PHY rate The QAP cannot gain access to the medium to service this TSPEC Bandwidth is required for some other TSPEC
Renegotiation response	Enumeration	Response to renegotiation request: Accepted Counter proposal. Only valid if the counter proposal consumes less resources than the proposal. Rejected. Valid for all upward negotiations. Valid for a downward negotiation only if the reason is bandwidth is required for some other TSPEC.
PLR Enabled	Flag	When enabled, indicates that MSDUs may be discarded from this TS based on their packet loss priority value as defined in section 7.4.4.

6.3.4.1 Periodic RDR

6.3.4.1.1 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 to collect the first transmissions of data during a known service period. The HC also allows in the

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scheduling of the service period enough time to send 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.

6.3.4.1.2 TSPEC Element Modifications for Periodic RDR

Add a new field to the TSPEC Info Field called Periodic RDR.

This field takes values 0 and 1.

When 1, the TSID is associated with a Periodic RDR. This is valid only with TSPECs indicating periodic uplink. This is interpreted by the HC as meaning that, instead of delivering a QoS CF-Poll to the STA, it periodically delivers an IAC containing an RDG for the specified TSPEC.

6.3.4.1.3 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 ensures 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 correctly received and acknowledged all data sent to it by the initiator, and may go to sleep as soon as it has received acknowledgement for all data it has sent.

6.4 Frame aggregation format

6.4.1 Introduction to Aggregation (Informative)

Aggregation is described in here as a MAC layer function.

The MAC interprets the PSDU as a single MPDU, or a sequence of MPDUs according to the *Aggregate* TXVECTOR/RXVECTOR parameter, that is robustly transported in the PLCP header.

The MAC separates the MPDUs of an aggregate PSDU 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.

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Note, MPDUs are separately protected by a CRC. Loss of an individual MPDU does not imply loss of all MPDUs in a PPDU.

The MAC Header Duration fields of all MPDUs in an aggregate carry the same value.

6.4.2 Aggregated PSDU format

An aggregate PSDU 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 it a multiple of 4 octets in length.

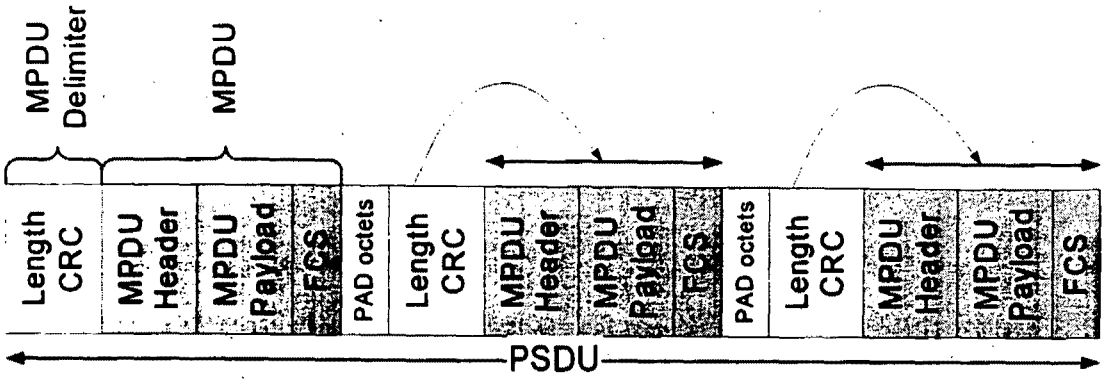


Figure 11 – Aggregated PSDU format

The MPDU delimiter is 4 octets in length and contains the fields defined below:

Table 4 – 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. 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.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.

6.4.2.1 Deaggregation (Informative)

The receiver checks the MPDU delimiter for validity based on the CRC. It can also check that the length indicated is within the PSDU HT length indicated in RXVECTOR. If the MPDU

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		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.
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 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. These MPDUs can come from multiple TCs, provided that they comply with the TC policy of the current TXOP. Apart from regular Data MPDUs the aggregate may also contain MHDR- and CHDATA MPDUs (both of Type 'Data').
BAR	At most one per Block ACK agreement (immediate Block ACK).	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. 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 which 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 shall contain the following MPDUs in the order defined below.

Table 6: Multiple Receiver Aggregation 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.

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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 5.

A No Response Receiver Group shall contain the following MPDUs, addressed to the same receiver, in the order defined below.

Table 7 No Response Receiver Group MPDUs

MPDU	Multiplicity	Description
IAC	At most one	Initiator aggregate control MPDU 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	No limit, except as constrained by Block ACK protocol and TXOP duration 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. These MPDUs can come from multiple TCs, provided that they comply with the TC policy of the current TXOP. Apart from regular Data MPDUs the aggregate may also contain MHDR- and CHDATA MPDUs (both of Type 'Data').

The MRA aggregate shall contain the following (groups of) MPDUs in the order defined below.

Table 8 MRA Aggregate MPDUs

MPDU	Multiplicity
MRAD	One
Broadcast/Multicast Data Group	One per broadcast or multicast destination address. Only permitted when the BSS is operating in pure mode.
Scheduled Response Receiver Group or No Response Receiver Group	One per receiver address.

Scheduled Response Receiver Groups and No Response Receiver Groups may be mixed in any order.

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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.

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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 receiver 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 unaggregated MPDU or a single receiver aggregate PPDU addressed to the initiating HT STA. This response shall begin no earlier than the schedule response period and end no later than the end of the scheduled response period. If the IAC contained 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 always respond to the MRA initiator at the starting time of its granted response period, even if it is receiving frames or is physically sensing the medium busy at the starting time of its RDG. This is necessary if an HT STA overhears activity in an adjacent BSS - for example it is currently receiving a Data frame addressed to some STA in that BSS and it had previously received an IAC containing a scheduled response.

7.1.5 Response PPDU Contents

When sending a response PPDU, the IAC's Reverse Direction Traffic Identifier (RDTID) constrains what Data MPDUs are eligible to be transmitted.

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.

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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.

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, and is using a MAC-layer protection, it generally protects multiple PPDUs using a single protection exchange.

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. This allows it to respond to the following events:

- Retries of failed transmissions in the current exchange

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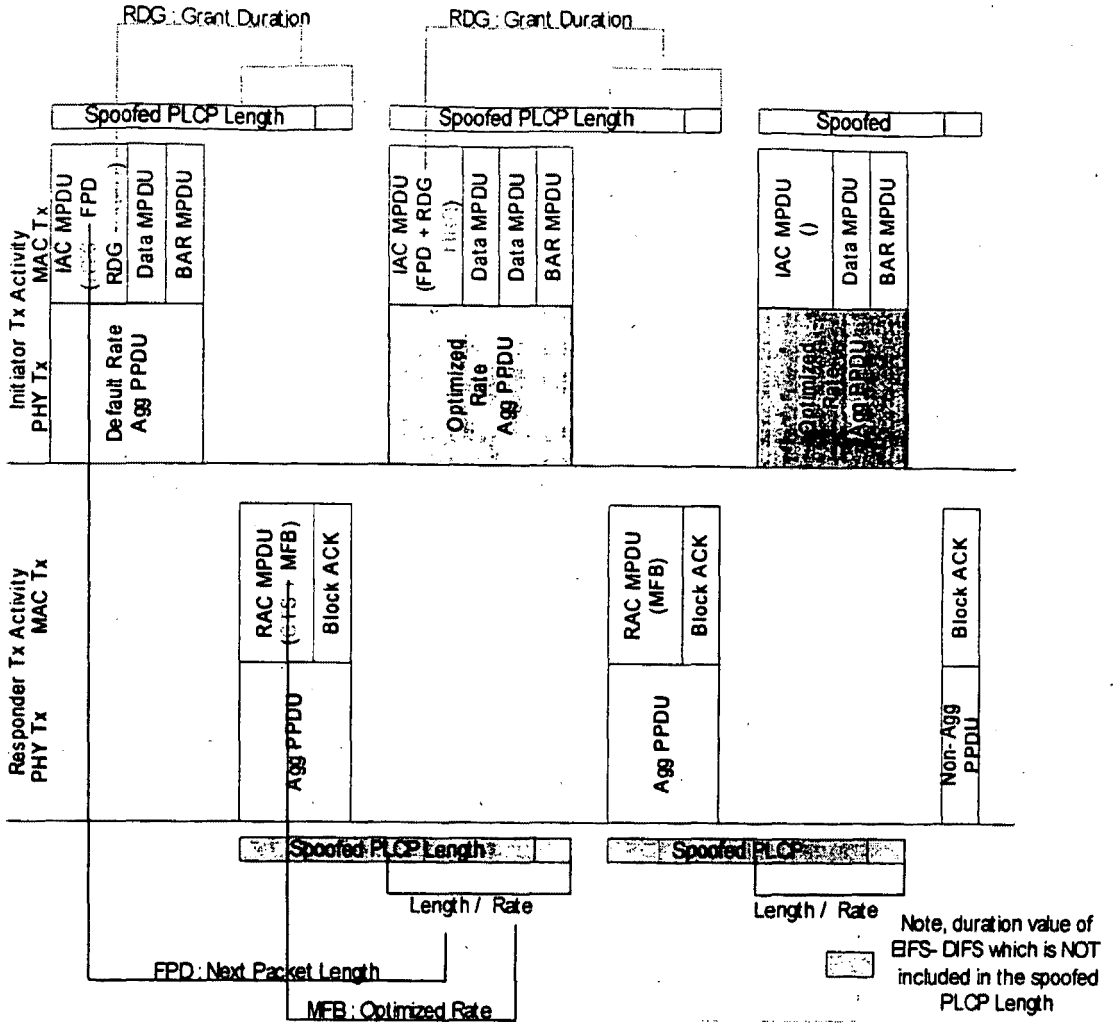


Figure 13 – Basic Operation of Pairwise Spoofing

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 will calculate 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.

7.1.7.4 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.Single Ended Spoofing

Single Ended Spoofing works as follows.

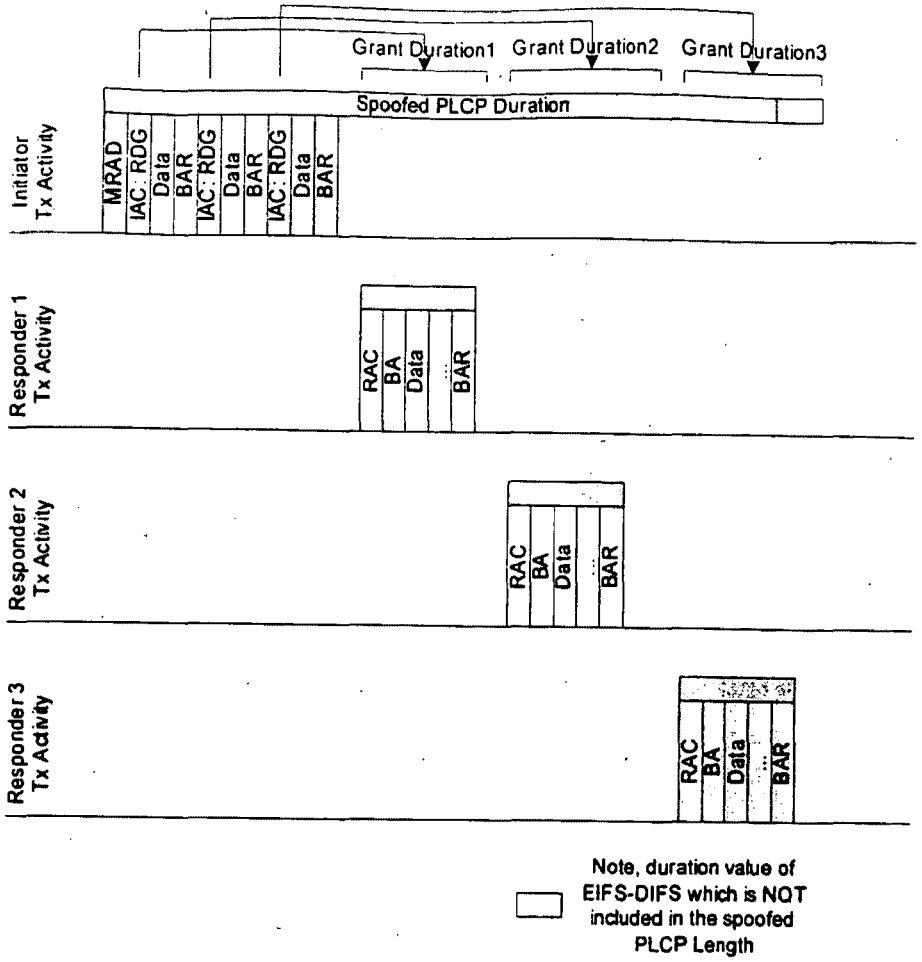


Figure 14 – Basic Operation of Single Ended Spoofing

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.

7.1.8 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

In order to use aggregation, protection or legacy protection is required as defined by the operating mode.

In the LongNAV case, protection is achieved by the exchange of a pair of frames using an appropriate rate such that all devices can receive these frames. These frames may be RTS/CTS if none of the IAC elements (apart from RTS) is required. Otherwise they shall be IAC/RAC.

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After this, there occurs 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 may carry only response MPDUs and training feedback. These response PPDUs do not include any Data or Block ACK Request MPDUs.

The initiator prevents reverse direction data flow by defining an RDG big enough only for the expected response control 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 aggregates and reverse direction Block ACK responses. The responder responds with a non-aggregate PPDU containing a Block ACK. No RAC MPDUs are present in the response PPDUs because none of the logical elements are required to manage the exchange.

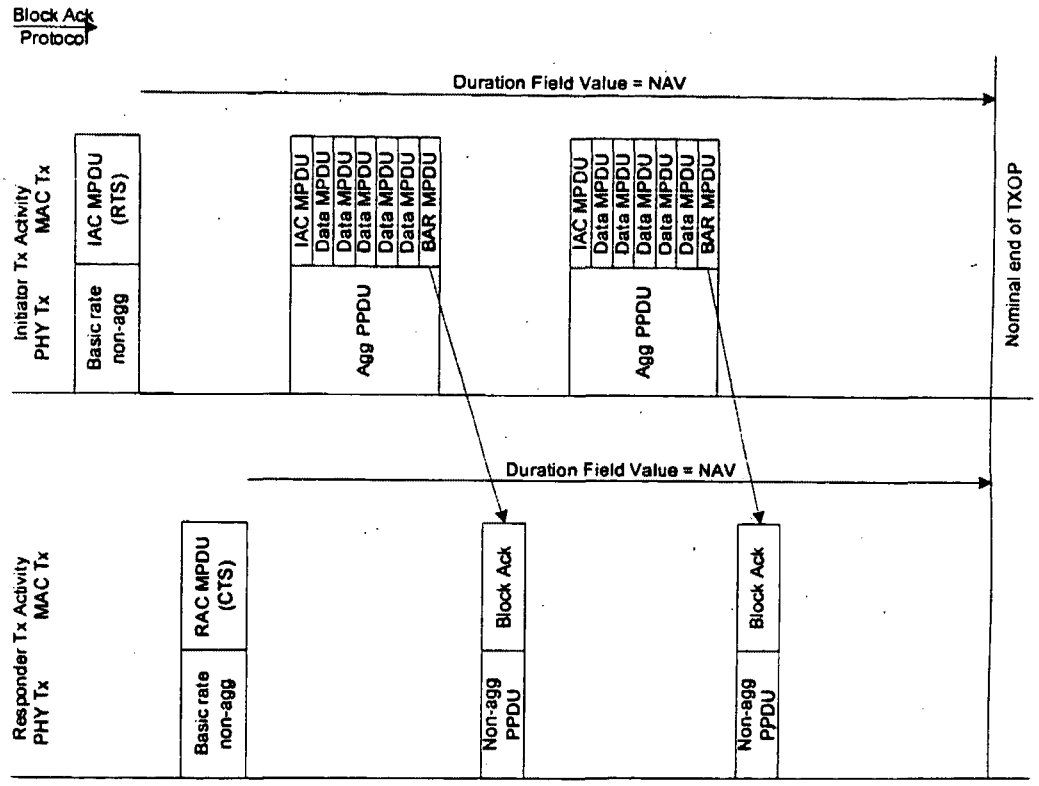


Figure 15 – LongNAV, untrained unidirectional exchange

The responder may want to request some reverse direction, or to send a training response in addition to sending a BA. In this case, it uses an aggregate to collect together this information.

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).

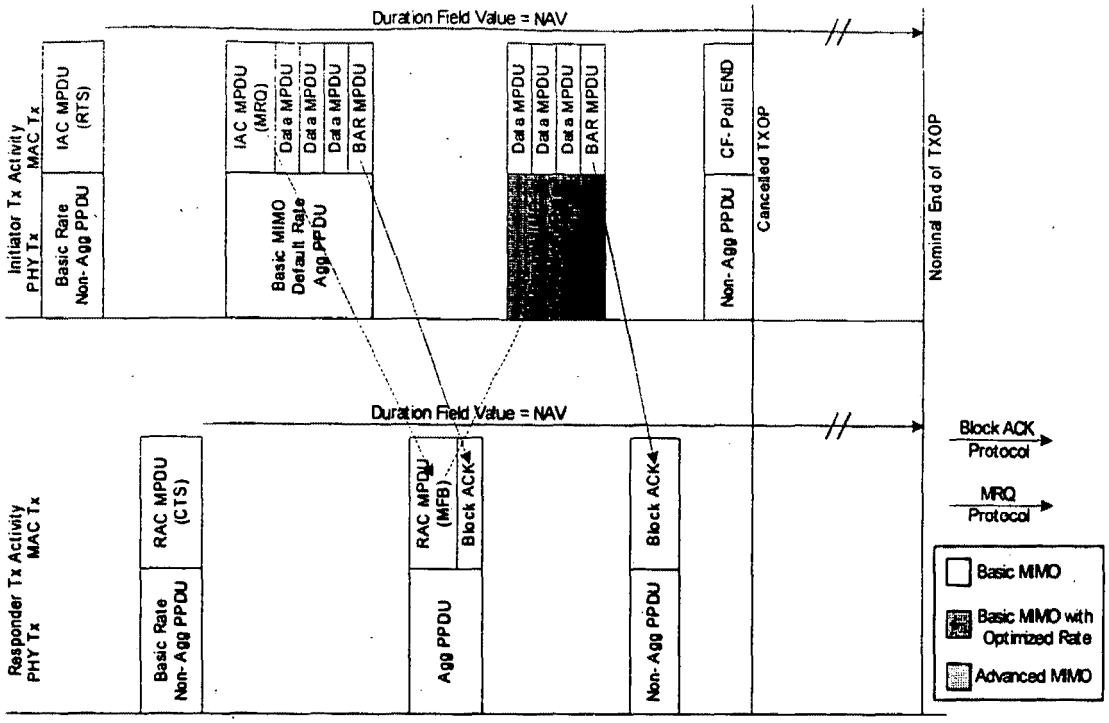


Figure 16 – LongNAV, untrained unidirectional showing aggregate response

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.

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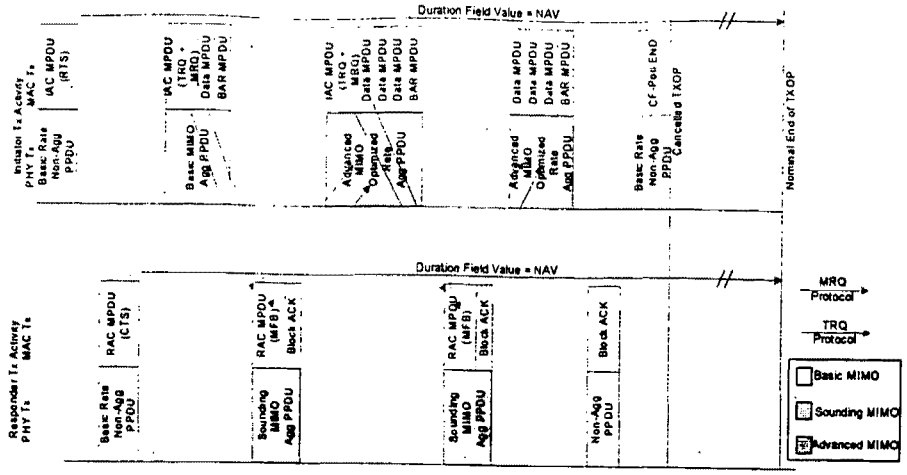


Figure 17 – LongNAV, trained unidirectional showing aggregate response

7.1.9.2 Pairwise Spoofing example

The next set of examples shows uses of Pairwise Spoofing, unidirectional.

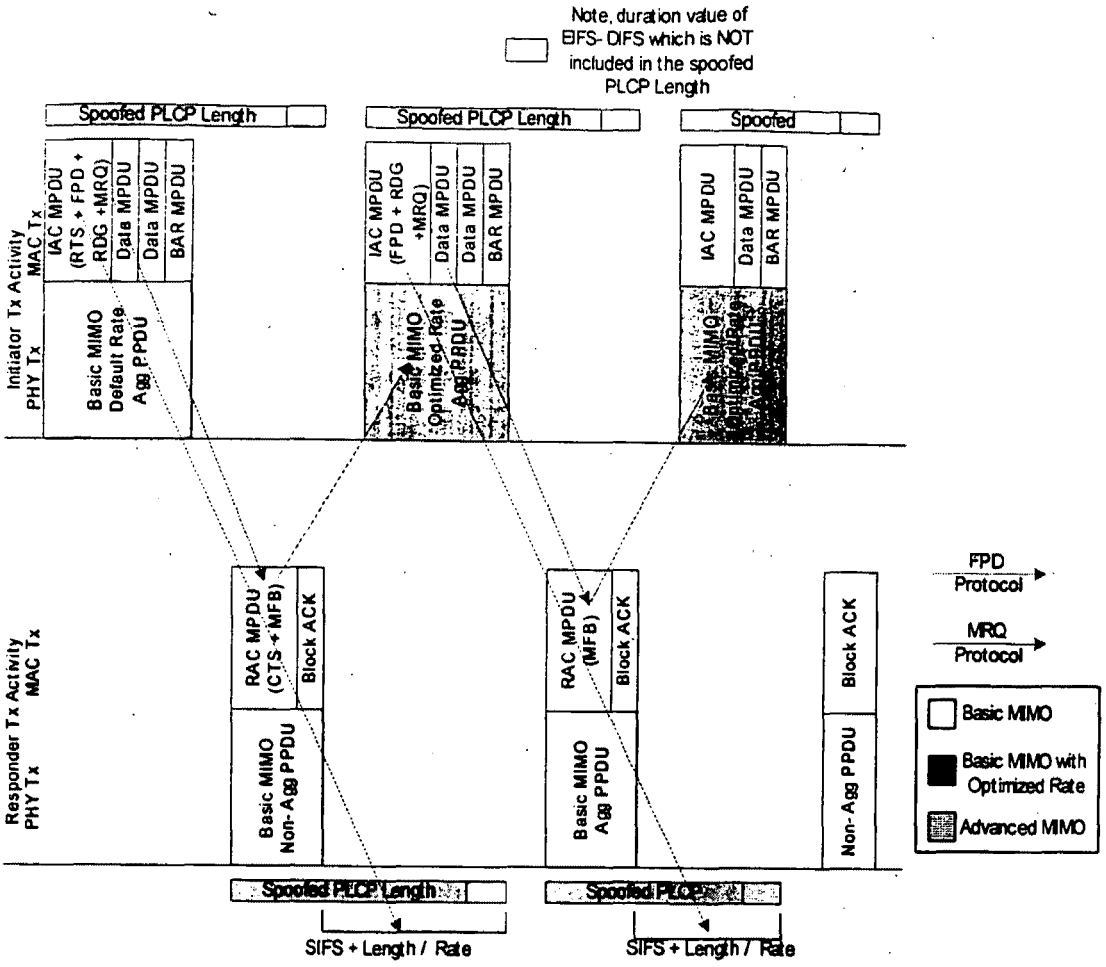


Figure 18 – Pairwise Spoofing, Untrained Unidirectional Exchange

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.

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The following example considers what happens when there is training involved.

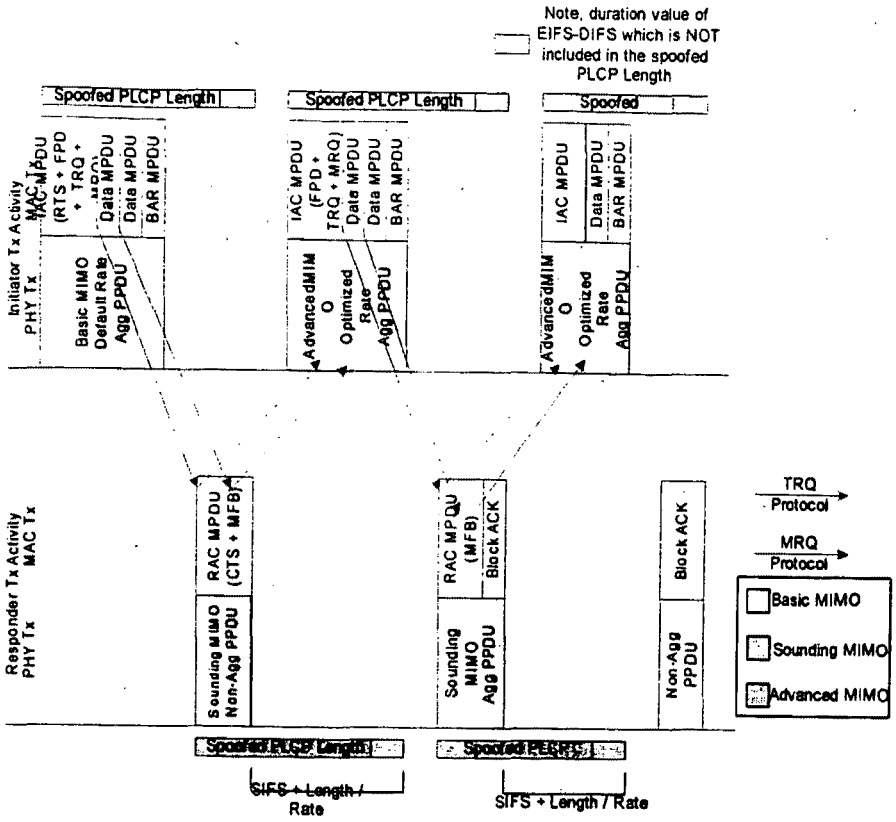


Figure 19 – Pairwise Spoofing, Trained Unidirectional Exchange

In the example shown above, 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

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 reverse direction using an RDR element. This 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.

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In determining an RDR value, a STA shall only consider eligible for transmission 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 duration request. Its next IAC contains an RDG element containing 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 it likes. 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 might have to make to the frame described by the RDG. For example, the PPDU sent next by the responder may include multiple BAR MPDUs.

The initiator can either allow for these responses it may have to make 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 decide not to allow for its own responses. In this case, the responder may send a BAR, but there might be no time to send the BA in the current TXOP. The responder will assume that the BAR was not received and will retry it subsequently.

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7.1.10.3 LongNAV Bi-Directional Example

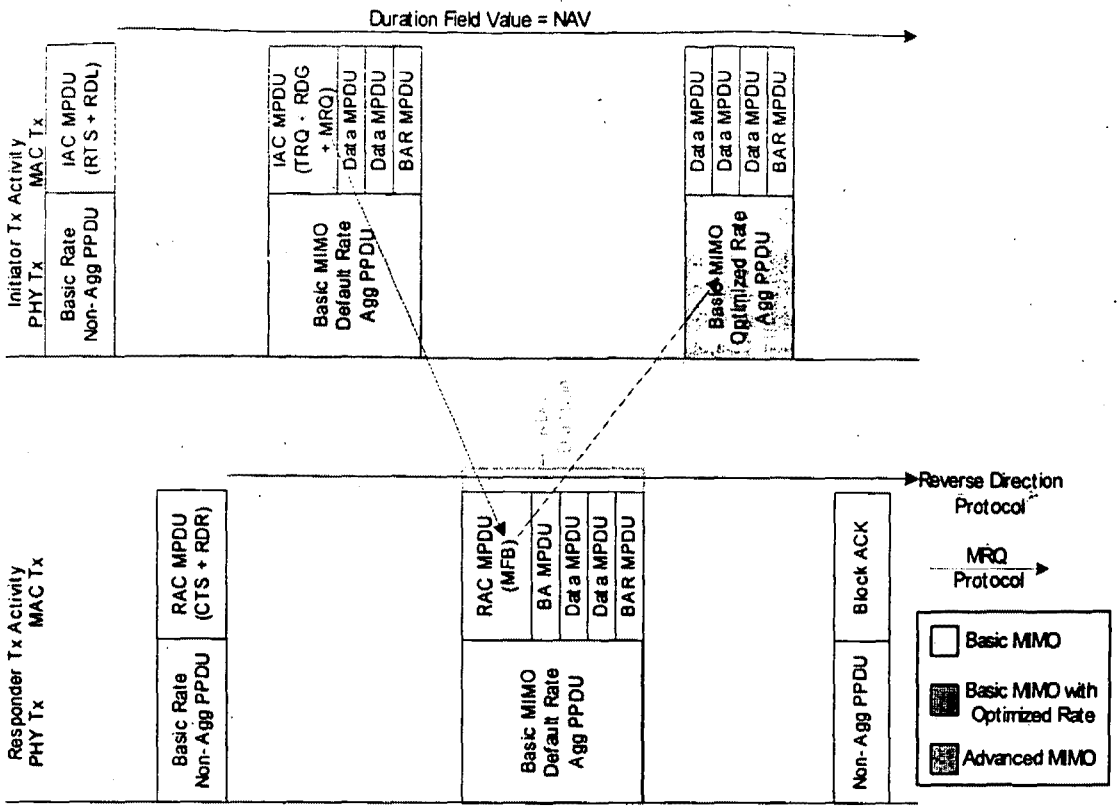


Figure 20 – LongNAV Bi-Directional Example

Initiator sets the granted RDG duration long enough to include any expected response (e.g. RAC + BAs).

The granted RDG duration includes the duration of reverse data plus any expected responses (RAC + BAs). This duration 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.

If no response is necessary, the responder does not need to send a PPDU, and the initiator can continue after a PIFS with no start of frame detected.

There is no need for a responder to send an RAC unless one or more of its logical elements need to be signaled.

7.1.10.4 Pairwise Spoofing Example

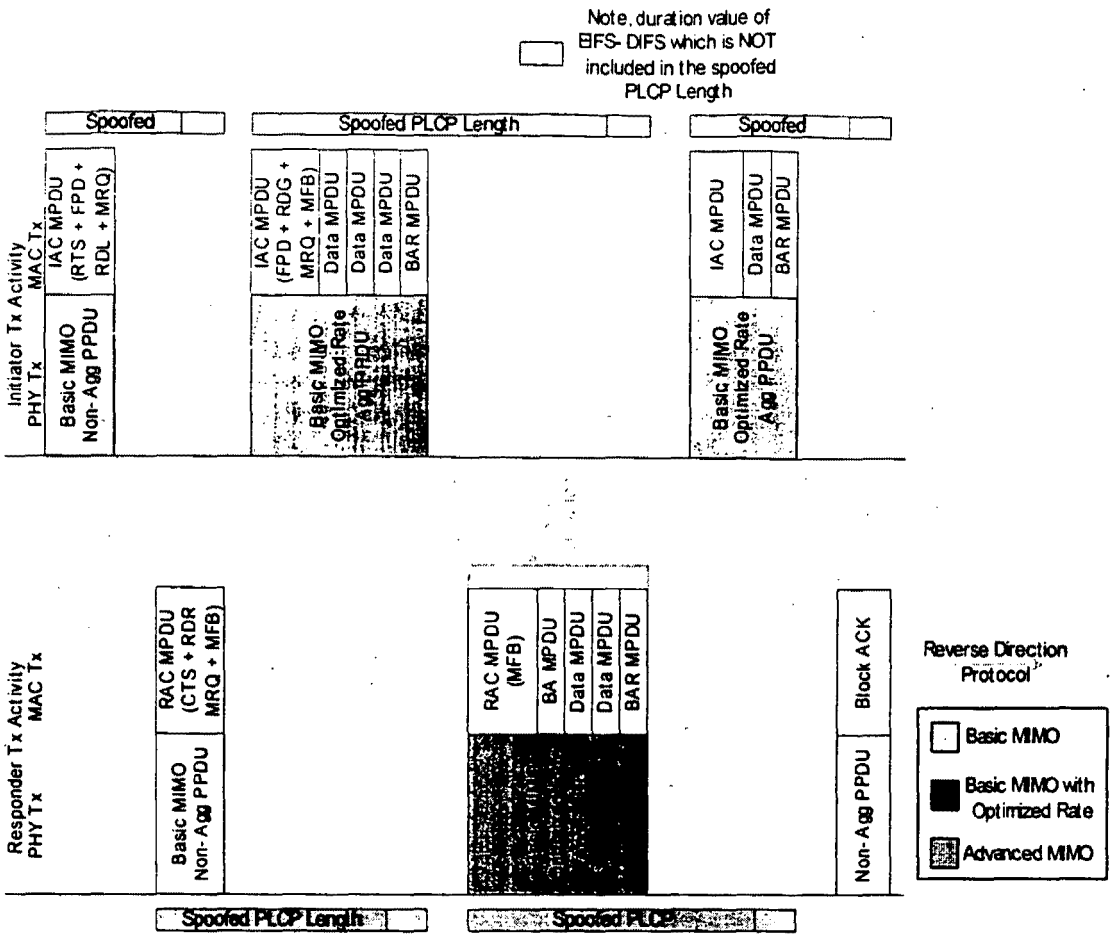


Figure 21 – Pairwise Spoofing, Trained BiDirectional

In the Pairwise Spoofing, Bi-Directional Frame Transfer, the RDG Duration, mentioned in the Long NAV example, will be equivalent to the spoofed duration. The Spoofed NAV and RDG Duration will include the duration of the reverse direction data plus any expected responses (RAC + BAs).

7.1.11 Single receiver aggregation Multiple receiver aggregation (MRA)

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.

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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 22, where the MRA addresses 3 HT clients.

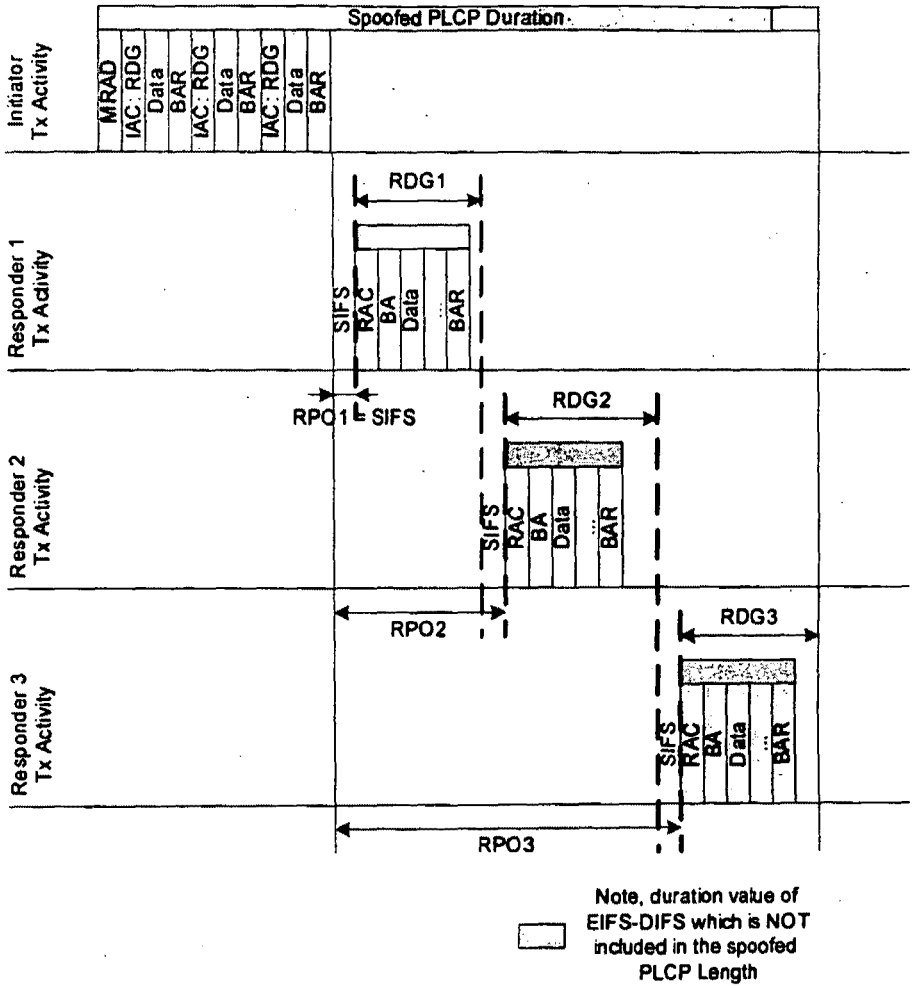


Figure 22 – Example of MRA response scheduling with 3 responders

7.1.11.1.1 Scheduling heuristics for MRA (Informative)

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.

7.1.11.1.2 Mixture of periodic and aperiodic traffic

The HT AP may also mix periodic and aperiodic behavior within the same MRA sequence. It can mix periodic and aperiodic transmissions but it cannot mix periodic and aperiodic RDG to a single HT STA in the same response period because these would require different RDTID values within the same 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 robustly 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.

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7.1.11.4 Interaction of MRA and TRQ+MFB (Informative)

Consider the two possible uses:

1. Periodic
2. Best Effort

In the periodic case, if the shelf-life 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

The examples below for MRMRA frame exchanges are illustrative rather than restrictive.

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.

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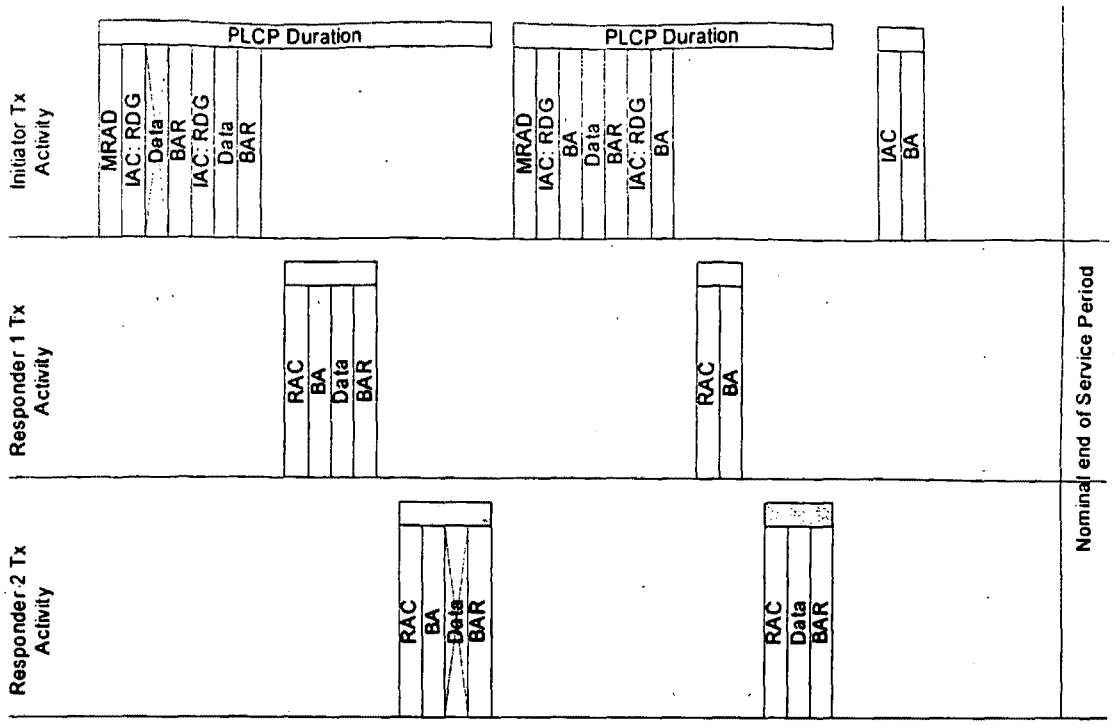


Figure 23 – MRMRA Example for Periodic Traffic

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 for its uplink data (plus RAC, BA, BAR), 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. Because it didn't receive the data properly the BA says this.

The second responder generates a response PPDU containing an RAC (not strictly necessary), BA, Data, BAR. In this case because it received the data correctly the BA indicates this.

The initiator generates a PPDU containing the retried data to responder 1 and grants to both responders. The grant to the first responder is because it has transmitted a BAR and wants the BA. The grant to the second responder is because it did not correctly receive all of the uplink data and is scheduling an opportunity 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 does not contain a MRAD. Strictly, the IAC is not necessary, and the response could be sent in a non-aggregate PPDU.

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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 big 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 does not correspond to a periodic RDR TSID.

The responder can also, at this point, generate an RDR to request additional response duration for its data transmissions to the initiator.

Note, from the receiver's point of view, this sequence is exactly the same as for a LongNAV bidirectional single-receiver sequence – except for the absence of the initial RTS/CTS and timing of the response period.

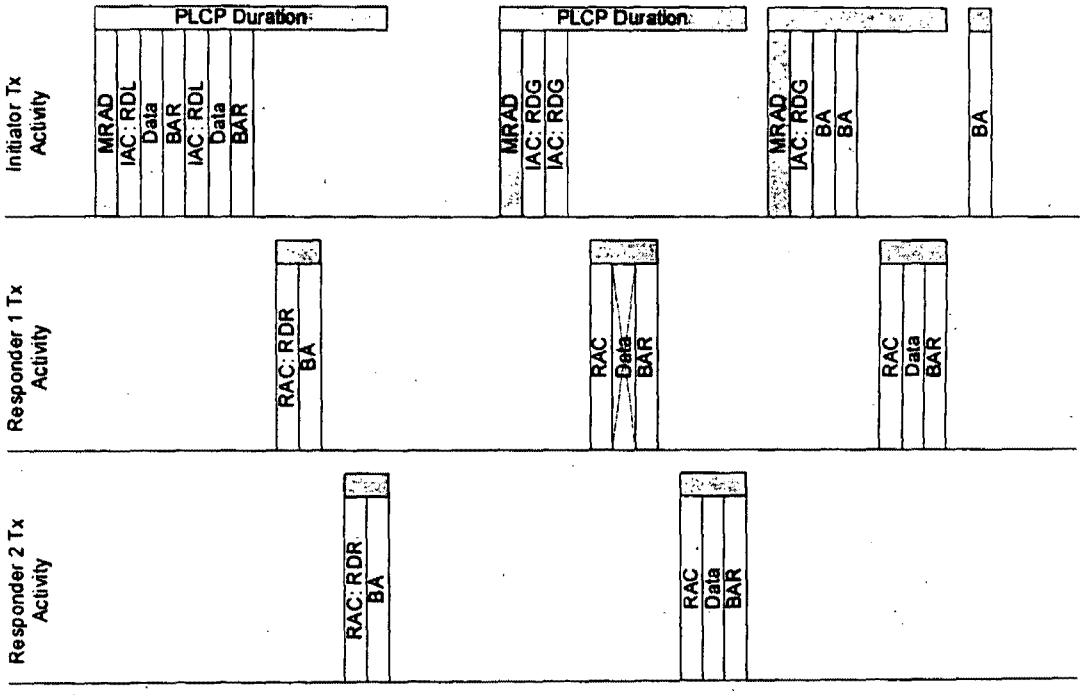


Figure 24 – MRMRA Example for Aperiodic Traffic

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.

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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 to the corresponding MHDR MPDU for MAC header information.

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 are not present outside the boundaries of a frame aggregate.

The following functionalities apply to a transmitting- and receiving STA or AP in an 802.11n network:

- It is optional for a transmitting STA or AP to use MAC Header compression in a frame aggregate.
- It is mandatory for a receiving STA or AP to handle compressed MAC MPDUs in a frame aggregate.

7.2.2.1 Transmitting side

When the transmitting STA or AP uses MAC Header compression it includes a MAC Header (MHDR) MPDU, identified by a Header Identity (HID), in the aggregate.

The transmitting STA or AP includes one or multiple Compressed Header Data (CHDATA) MPDUs, each having the same HID as the corresponding MHDR MPDU.

The transmitting STA or AP 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 or AP 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 or AP determines whether MAC Header compression has been used based on the Type and Subtype definitions in the received MPDUs.

A receiving STA or AP uses 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. When acknowledgements of CHDATA MPDUs are required, the existing Block Acknowledgement scheme is used. Retransmissions of corrupt or non-received CHDATA MPDUs by the transmitting STA or AP are supported by the presence of standard sequence numbers in these MPDUs.

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CHDATA MPDUs for which no corresponding MHDR MPDU is found in the frame aggregate, are discarded.

7.2.3 Ordering constraints for MHDR and CHDATA MPDUs

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 must be preceded by at least one MHDR MPDU for the same HID. No MHDR for a different HID may 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 QoS enhancements

7.4.1 802.11e Requirement

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.

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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 Interactions with 802.11e TSPEC (Informative)

Because our PHY rates cover a much wider range than legacy PHYs (and also potentially very much faster changes too), this increased variability interacts with the TSPEC mechanism that attempts to guarantee some agreed level of service.

In 802.11, providing an application with a guaranteed service level is difficult because:

There is no guarantee that the channel is sufficiently idle to provide this service level (the effect of interference or competing channel access).

If one or both peers of the link (or indeed, anything in its environment) are mobile, the channel between the peers may change so that the desired data rate cannot be achieved.

While the problem is not specific to 802.11n, the problem is worse in 802.11n because the PHY can adapt to the channel capacity quickly and accurately using a training exchange resulting in a very wide range of effective PHY rates that changes rapidly.

802.11e provides a mechanism that allows a traffic specification (TSPEC) to be negotiated between client and AP. The methods described here extend these mechanisms to address these issues.

Two main adaptation methods (and some variants) are described below. These are not mutually exclusive; each may be more appropriate depending on the application. The adaptation method to be used can be negotiated when the TSPEC is created.

Method 1 relies on renegotiation between the MAC and application. Method 2 relies on discarding application packets when the going gets tough. One or both methods may be used, and their use is negotiated when a TSPEC is first created.

7.4.3 TSPEC renegotiation

A QSTA negotiates with a QAP to provide a specific level of service using a TSPEC request (current behavior). Critical to this scheme is that it includes a minimum PHY rate parameter and a data rate. (It may include multiple data rates, such as mean and peak, but this is not important here).

We add two new types of negotiation: upward (an improvement in service) and downward (a reduction in service).

An upward negotiation is initiated by the QAP when one of the following occurs:

- An observation by the QAP that the channel load is less than some threshold. In evaluating the channel load, the QAP should replace the observed load taken by each TSPEC with its maximum committed value.

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- An observation that the actual PHY rate used by a TSPEC is significantly higher than the minimum PHY rate negotiated in the TSPEC. The actual rate can be averaged over some period of time. The QAP can avoid repeated refused renegotiations by recording the "last offered minimum PHY rate" and only attempting a renegotiation if the actual rate is higher than this as well. "Significantly" can mean, for example, a fixed threshold above the current values.
- Deletion of some other TSPEC, thereby making additional capacity available.

A downward negotiation can be triggered by:

- An observation that the actual PHY rate (either instantaneously, or averaged over some period) is less than the minimum PHY rate specified in the TSPEC.
- An observation that the channel free time is not enough to service existing TSPEC commitments. This might arise, for example, if a nearby co-channel BSS starts operation, or due to non-802.11 interference.
- A request to create a new TSPEC or modify an existing TSPEC is received at the QAP from this QSTA, or some other QSTAs.

Renegotiation is started by the QAP, which sends a TSPEC proposal to the QSTA containing the proposed new service parameters and the reason for the renegotiation.

The QSTA can accept the proposal as specified or modify it to some lower level of service (for example, to match a specific application traffic profile). In the case of upward negotiations the QSTA can refuse the suggestion – meaning that it has no use for the additional resources. In the case of downward negotiations, the QSTA can also refuse the suggestion, but only if the reason for the reduction is to admit some other TSPEC. In other cases, the QSTA must either accept the suggestion, or make a reduced suggestion, or delete the TSPEC.

7.4.4 TSPEC Packet Loss Priority (PLP)

The QSTA may negotiate use of packet loss priority (PLP) when a TSPEC is set up, or subsequently.

A QSTA with a PLP-enabled TSPEC adapts, potentially per transmission opportunity (TXOP), to the amount of available time and the channel conditions by discarding "less important" parts of the application traffic (such as the higher-numbered MPEG-4 FGS layers). This is operated at the source end of a TSPEC – either QAP or QSTA.

PLP requires that the application generate separate packets that are marked with a "packet loss priority" value. A zero value of packet loss priority means that the packet is very important (should not be discarded). High values mean that the packet is unimportant (can be discarded).

The TSPEC shall contain a delay bound. The operation of the PLP mechanism ensures that packets are not delayed in the transmitting MAC any longer than this value.

The TSPEC shall be associated with a Block ACK agreement. This is necessary because MSDUs are transmitted out of order with the "most important" ones first.

When a QSTA gets a transmit opportunity, it transmits together all buffered packets of the lowest buffered packet loss priority, gets a selective acknowledgement and performs any necessary

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retries until these are all successfully transmitted, their expiry time is reached or the transmission opportunity ends. This is then repeated until the buffer is empty or the transmission opportunity ends.

The transmitting MAC shall ensure that packets that have been successfully transmitted are delivered to the LLC before their delay bound is reached. This can be achieved by transmitting a Block ACK to move the starting sequence number in order to flush received packets.

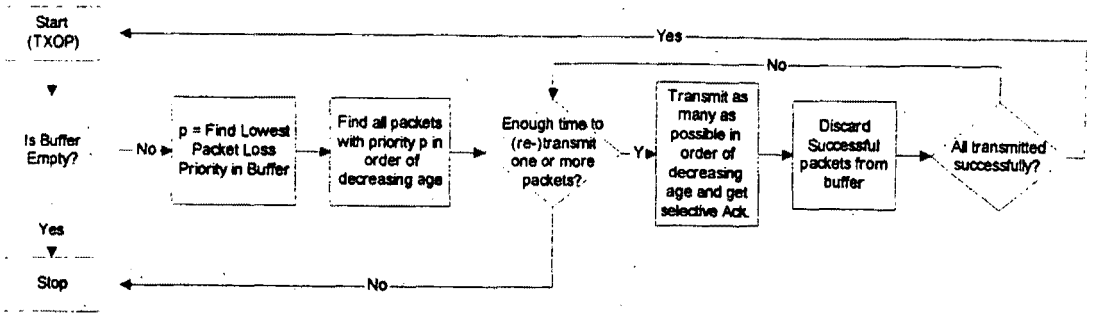


Figure 25 – Flowchart of PLP mechanism

7.5 Scheduling (Informative)

7.5.1 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.

7.5.2 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.

7.5.3 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. [2]

7.5.4 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 [3] From this, it can predict the number of failures in an aggregate, and leave enough room for retransmissions.

---

[2] 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!

[3] How it does this is not relevant here.

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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.

7.5.5 Selecting RDL/RDG values

7.5.5.1 Scheduling decisions for RDL/RDG (Informative)

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.

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.

7.5.5.2 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

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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.

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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 are used to control the format of beacon transmission and what kind of protection must be 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. Note: time divided between contention period for HT and one for 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. 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 necessarily being able to receive legacy MPDUs in it. On detecting what may be a legacy MPDU, the STA should enable itself to receive in that extension channel (not necessarily simultaneous with supporting operation of the BSS in the control channel) in order to determine if a legacy BSS has arrived on the extension channel.

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8.1.3 Infrastructure BSS Operation

8.1.3.1 At the AP

Table 9 – 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 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 normal 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].

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.

In 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 response. 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.

In the 20 MHz-base managed mixed mode, the AP transmits its beacon using the legacy PPDU type. It is sent in the control channel but for the purpose of reliability of reserving the extension channel, implementers may decide to send beacons also in the extension channel. Beacons in the

[4] This will stop other co-channel mixed-capable APs from considering the AP to be a legacy AP.

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extension channel might induce legacy STAs to try association but the HT AP will refuse 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. A 20 MHz HT STA is the one whose permitted width set is limited to 20 MHz.

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.

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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.

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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 26.

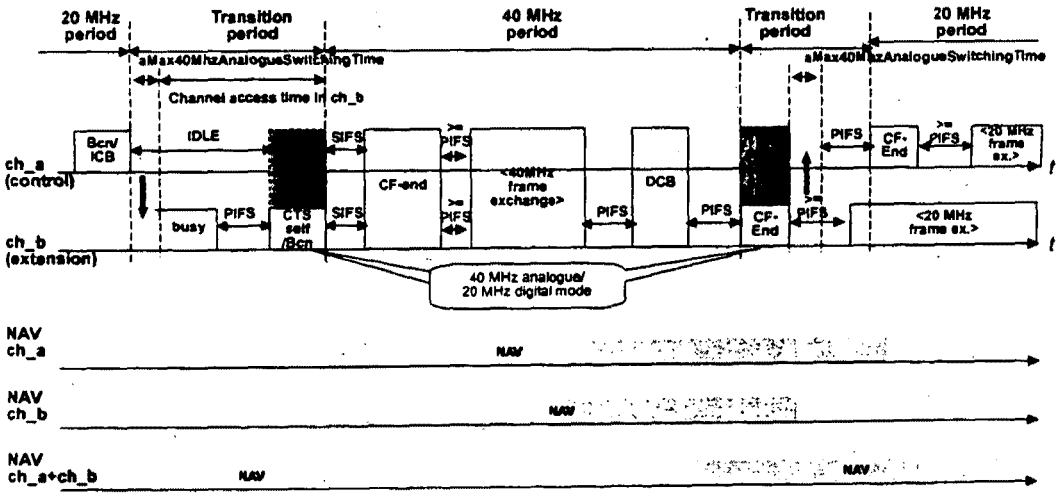


Figure 26 – 20 MHz-Base Managed Mixed Mode

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 CTS-to-self 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 CTS-to-self 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

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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.

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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.

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 IBSS Operation

8.1.4.1 Ad-hoc (IBSS) Operation

8.1.4.1.1 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.

8.1.4.1.2 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 10 – 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

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8.1.4.1.3 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 11 – 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. [6]

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.

[6] 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.

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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 [7]. 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 8.2.3.3) 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.

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.

The purpose of this recommendation is to avoid introducing 20MHz "holes" between adjacent operating 40MHz BSS, thus making them unavailable for 40MHz operation.

[7] Note, the assumption that 802.11h will be used (perhaps in modified form) by TGn.

8.2.3.3 Method to determine Best channel and channel width (Informative)

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 BSS and load information per 20 MHz channel. In each such channel it records its observations of load [8], 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 measurement.

Each HT BSS that permits 40MHz operation will have an entry in each 20-MHz channel it overlaps. The HT BSS load measurement is applied to each such overlapped channel.

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 new 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

8.2.3.3.1 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.

8.2.3.3.2 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.

[8] Load is defined as the percentage of time the channel is busy (averaged over some observation interval).

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 stay-awake time or enable TRMS.

A STA may activate or deactivate TRMS operation at any time.

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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 stay-awake 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.

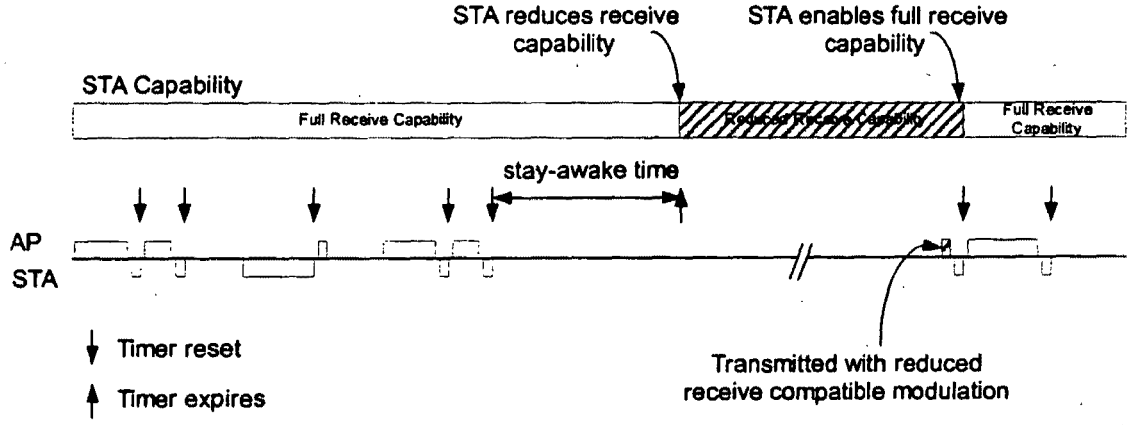


Figure 27 – Data transfer example with timed receive mode switching

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 stay-awake 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 stay-awake 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 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 revers-link data can first be sent in the 4th PPDU. 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. Periodic RDR is there to support applications like VoIP, and I don't expect to see VoIP handsets doing ABF transmissions.
Pairwise Spoofing Untrained IAC/Data/Data/BAR+RAC/BA	This sequence will not work with a MIMO MCS for the first MPDU. 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. The alternative is to add an initial IAC/RAC exchange. This brings the following advantages: • Collisions are detected cheaply • Data is protected from hidden nodes • Data can be trained (fresh MCS and/or/ ABF) 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 Trained forward-direction data	No overhead as the sequence has to be: IAC(TRQ)+RAC(HT-LTFs)+IAC/Data/...

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	The initial IAC can be SISO.
Pairwise Spoofing reversed direction trained data	Same analysis as the LongNAV case. There is no additional overhead.

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9. Background to Protection Mechanisms (Informative)

9.1 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 small. 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.

9.2 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.

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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 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.

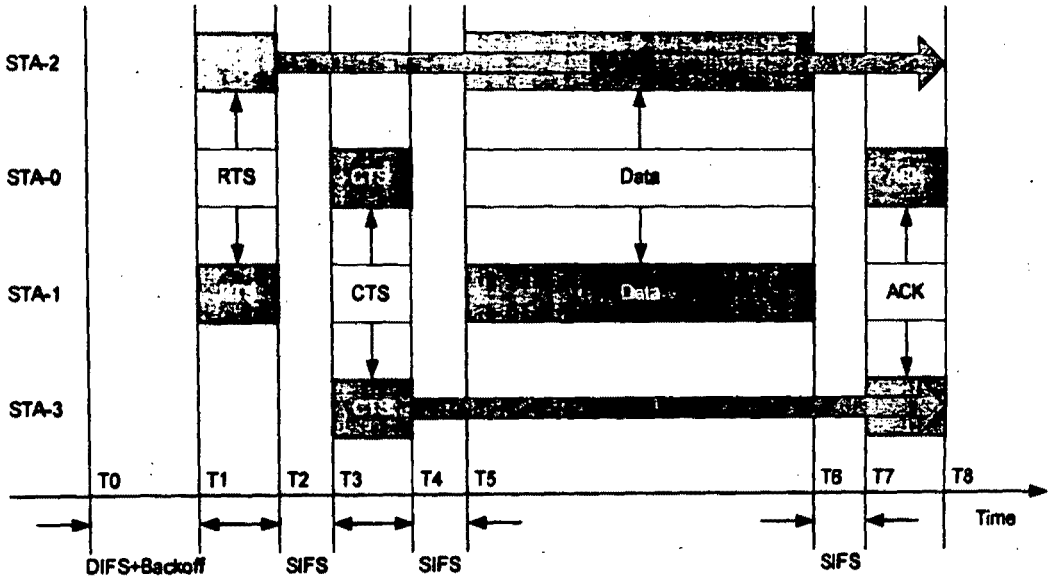


Figure 28 – Standard Virtual Carrier Sense

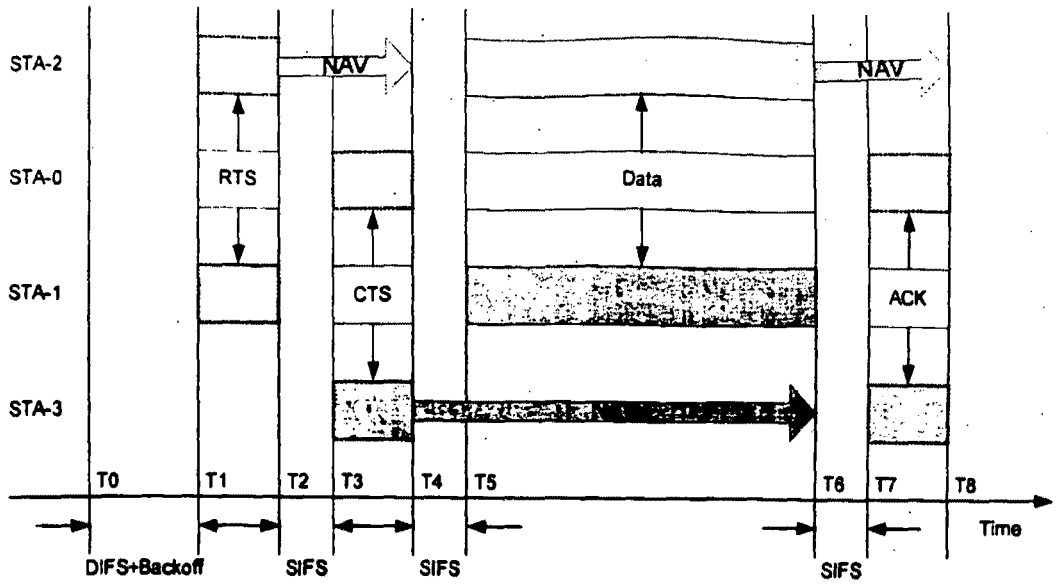


Figure 29 – Pairwise Spoofing Mechanism

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.

9.4 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.

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9.5 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.)

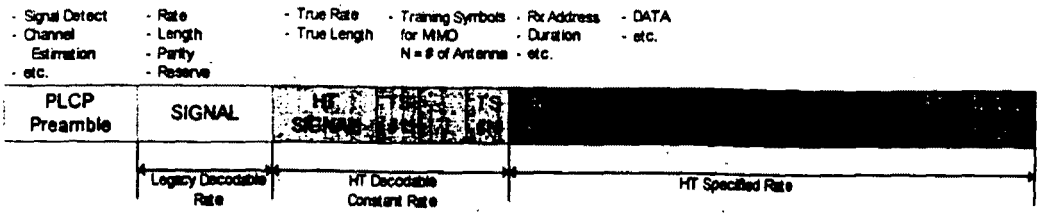


Figure 30 – PPDU Format with Legacy Protection

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.

9.5.1 Interpretation by a Legacy Node

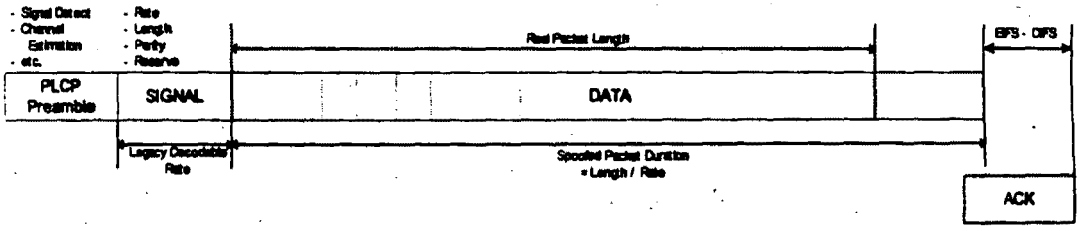


Figure 31 – When Received by a Legacy Node

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.

9.5.2 Interpretation by an HT Node

As seen in Figure 30, 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.

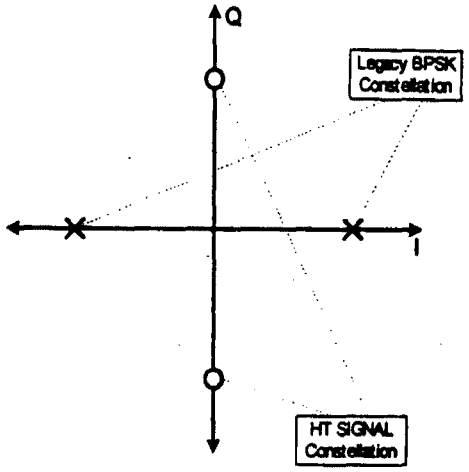


Figure 32 – HT Signal Field BPSK Constellation

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.

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9.5.2.1 MPDU Not Decodable

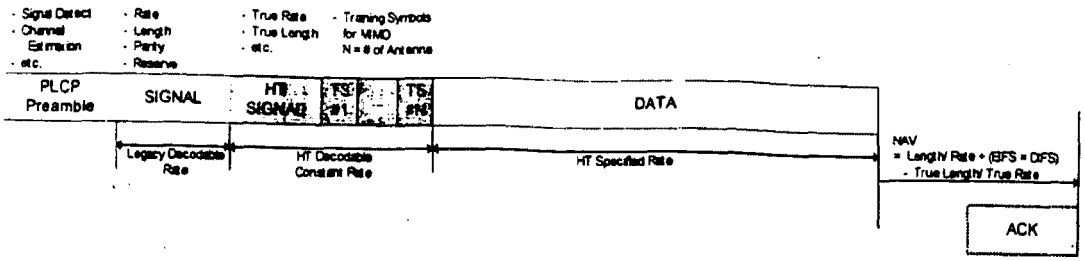


Figure 33 – When Received by an HT Node but MPDU is not Decodable

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 7.1.7.2.2.

9.5.2.2 MPDU Decodable

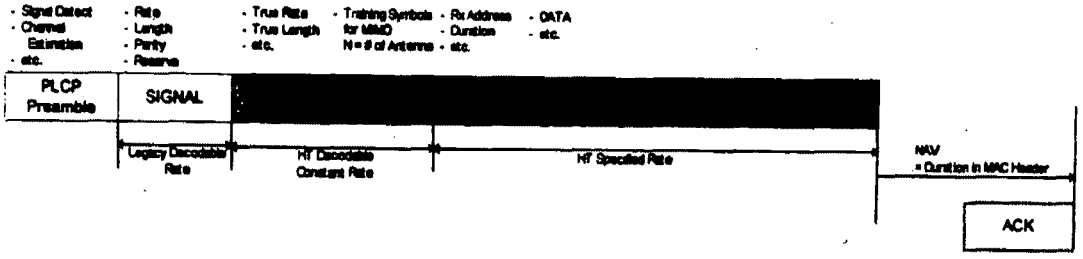


Figure 34 – When Received by an HT Node and the MPDU is Decodable

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.

9.6 Protection mechanisms for MRA

9.6.1 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

9.6.2 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.

9.6.3 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.

9.6.4 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.

Equation Chapter 1 Section 1

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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 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 HT 20 in 20 Legacy upper 20 in 40 Legacy lower 20 in 40 HT upper 20 in 40 HT lower 20 in 40 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 (TXVECTOR)	1 – 264143
MCS	PHY-TXSTART.request (TXVECTOR)	0 – 63
ADV CODING	PHY-TXSTART.request (TXVECTOR)	0, 1, 2
SOUNDING	PHY-TXSTART.request (TXVECTOR)	0, 1
NLTF	PHY-TXSTART.request (TXVECTOR)	2 – 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 12: 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 effects the interpretation of many of the 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 7 of current PHY draft. 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, whereas a value of 2 indicates RS coding option.

1

2 **10.1.1.9 TXVECTOR SOUNDING**

3 In HT format this parameter indicates whether this PPDU is a sounding PPDU. A value of 0
4 indicates that it is not a sounding PPDU. A value of 1 indicates that it is a sounding PPDU. In
5 legacy format this parameter is Null.

6

7 **10.1.1.10 TXVECTOR NLTF**

8 In high-throughout format this parameter specifies the number of long training fields. In legacy
9 format this parameter is Null.

10

11 **10.1.1.11 TXVECTOR AGGREGATE**

12 In high-throughout format this parameter indicates whether the PPDU contains an aggregate
13 PSDU. A value of 0 indicates that the PSDU is not an aggregate and a value of 1 indicates that
14 the PSDU is an aggregate. In legacy format this parameter is Null.

15

16 **10.1.1.12 TXVECTOR SCRAMBLER-INIT**

17 In high-throughout format this is the scrambler initialization field. It is a two bit field. In legacy
18 format this parameter is Null.

19

20 **10.1.1.13 TXVECTOR SHORT-GI**

21 In high-throughout format this parameter indicates whether the data is sent with a short guard
22 interval (0.4 us). A value of zero indicates a standard GI and a value of 1 indicates a short GI. In
23 legacy format this parameter is Null.

24

25 **10.1.1.14 TXVECTOR BEAMFORMED**

26 In high-throughout format this parameter indicates whether a beamforming matrix is applied to
27 the data. A value of zero indicates that no beamforming is applied and a value of 1 indicates that
28 beamforming is applied. In legacy format this parameter is Null.

29

30 **10.1.1.15 TXVECTOR BEAMFORM MATRIX**

31 In high-throughout format this field gives the N_{TX} x N_{SS} x N_{SD} complex matrices which is used
32 to beamform the PPDU. This field is only valid when the BEAMFORMING parameter is one.
33 In legacy format this parameter is Null.

34

10.1.2 RXVECTOR

The RXVECTOR is an array of fields sent from the PHY to the MAC giving information regarding the received PPDU.

Parameter	Associated Primitive	Value
PPDU FORMAT	PHY-RXSTART.indicate (RXVECTOR)	Legacy 20 in 20 HT 20 in 20 Legacy upper 20 in 40 Legacy lower 20 in 40 HT upper 20 in 40 HT lower 20 in 40 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 – 264143
MCS	PHY-RXSTART.indicate (RXVECTOR)	0 – 63
ADV CODING	PHY-RXSTART.indicate (RXVECTOR)	0, 1,2
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 13: Table of parameters for the RX Vector

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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 was 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 7 of current PHY draft. In HT format this parameter indicates the value of the MCS field in the PPDU HT-SIGNAL field. 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 LDPC coding, whereas a value of 2 indicates RS coding option.

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 REUSE L-PREABLE

In high-throughout format this parameter indicates whether the legacy preamble can be reused to estimate the channel of one of the spatial streams. A value of 0 indicates no reuse and a value of 1 indicates reuse. In legacy format this parameter is Null. (Comment: This comes from PHY draft 3.0. Is this still included?)

10.1.2.12 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.

10.1.2.13 RXVECTOR SHORT-GI

In high-throughout format this parameter indicates whether the data was sent with a short guard interval (0.4 us). A value of zero indicates a standard GI and a value of 1 indicates a short GI. In legacy format this parameter is ignored.

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, our proposal introduces two primary techniques:

- Transmission of Multiple Spatial Streams via Multiple Transmit Antennas. Our recommendation is to make 2 antennas mandatory, with the option to scale to 4 antennas.
- 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:

- A reduced guard interval of 400ns, channel dispersion permitting (e.g. TGn channel model B)
- Higher channel coding rate of 7/8
- 256-QAM in certain advanced transmission modes

Due to the susceptibility of a wireless channel to multipath fading, especially with multiple antennas, our proposal has also introduced several 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 (such as LDPC). Such codes have 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.
- Advanced Transmitter beamforming techniques. These include water-filling concepts in the spatial domain, such as unequal power ratios and different choice of modulation-coding schemes on the various spatial streams.

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:

$$\text{Data Rate} = \frac{20M \text{ time samples}}{1 \text{ second}} \cdot \frac{48 \text{ freq tones}}{64 \text{ freq tones}} \cdot \frac{6 \text{ coded bits}}{1 \text{ freq tone}} \cdot \frac{3 \text{ info bits}}{4 \text{ coded bits}} \cdot \frac{64 \text{ freq tones}}{80 \text{ time samples}}$$

$$= 54M \text{ info bits/second}$$

(channel spacing; guard band overhead; constellation size; coding rate; guard interval overhead)

Besides spatial multiplexing, there are 4 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 14.

802.11a/g	Our Proposal	Requirement	Throughput Scaling Factor
Channel BW = 20MHz Number of data subcarriers = 48	Channel BW = 20MHz Number of data subcarriers = 48	Mandatory in device	1x
	Channel BW = 40MHz 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 supported in ABF-MIMO mode	1.16x (128-QAM) 1.33x (256-QAM)
GI = 800ns Tsymbol = 3200ns	GI / Tsymbol = 800ns/3200ns	Mandatory in device	1x
	GI / Tsymbol = 400ns/3200ns	Optional 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	½, 2/3, ¾	Mandatory in device	1x
	7/8 (advanced coding option)	Optional in device	1.167x

Table 14: Options for Throughput Enhancement

Of the options presented in Table 14 for throughput enhancement, our proposal focuses upon using spatial multiplexing (via multiple transmit antennas) and bandwidth expansion (from 20Mhz to 40Mhz) as means for increasing the physical layer data rates. This is because both

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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 optional for the data portion of the PPDU. Using 4 spatial streams in 40MHz, this leads to a maximum PHY data rate of 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 transmit antennas across a 20MHz channel bandwidth. The transmitter datapath is shown in Figure 35.

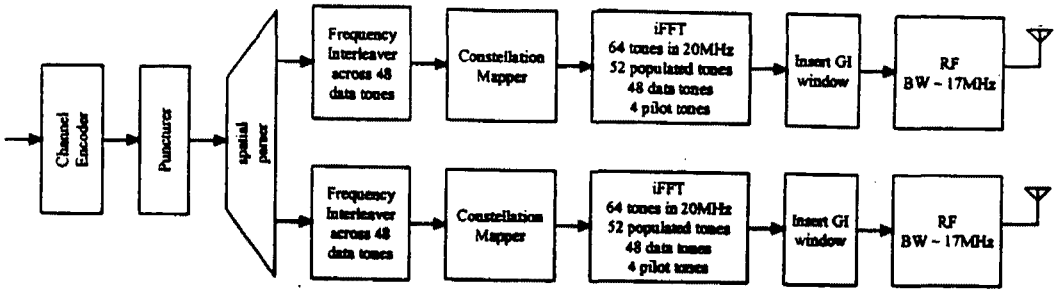


Figure 35: Transmitter Datapath for 2-antenna MIMO in 20MHz

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 36:

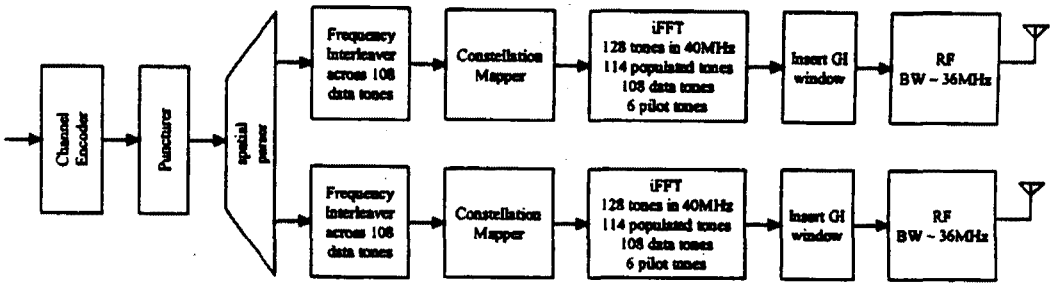
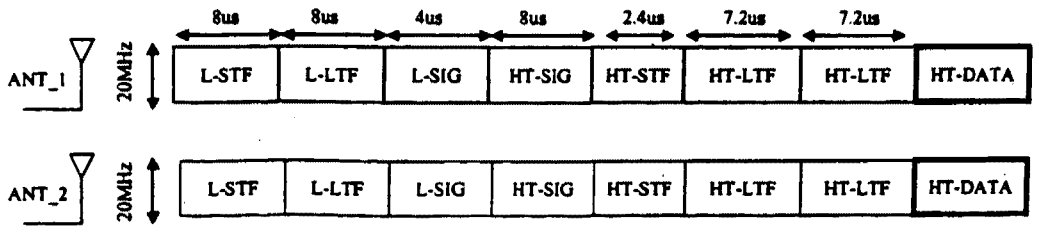


Figure 36: Transmitter datapath for 2-antenna MIMO in 40MHz[9]

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 37:



[9] 40MHz operation by an HT device shall only be permitted in those regulatory domain that allow it.

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Figure 37: 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 38. A 40MHz-capable HT device receiving a 20MHz-only transmission shall indicate to the MAC which sub-channel is currently active.

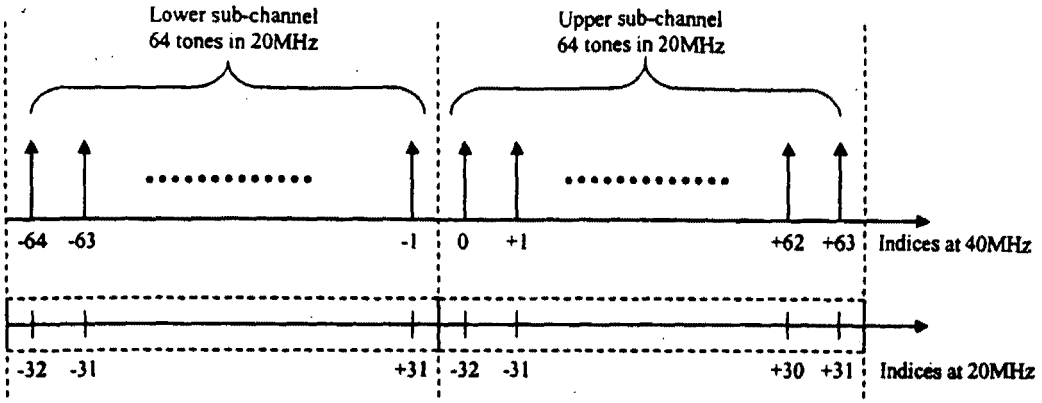


Figure 38: Upper and Lower sub-channel specification in 40MHz

The PPDU format from two transmit antennas, each 40MHz wide, is shown in Figure 39.

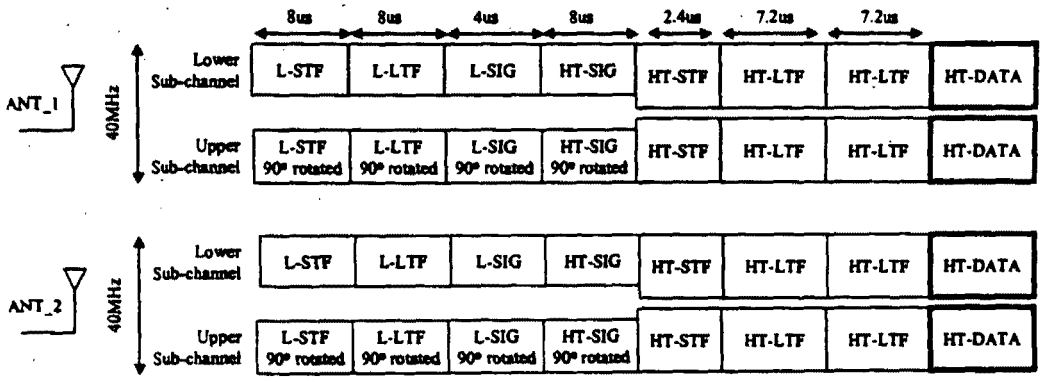


Figure 39: PPDU Format for 2x40 Mandatory Basic MIMO Transmission[10]

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. The optional part of the PPDU, corresponding to the CDD format, is shown in red color in Figure 37 and Figure 39.

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

[10] 40MHz operation by an HT device shall only be permitted in those regulatory domain that allow it.

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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 40:

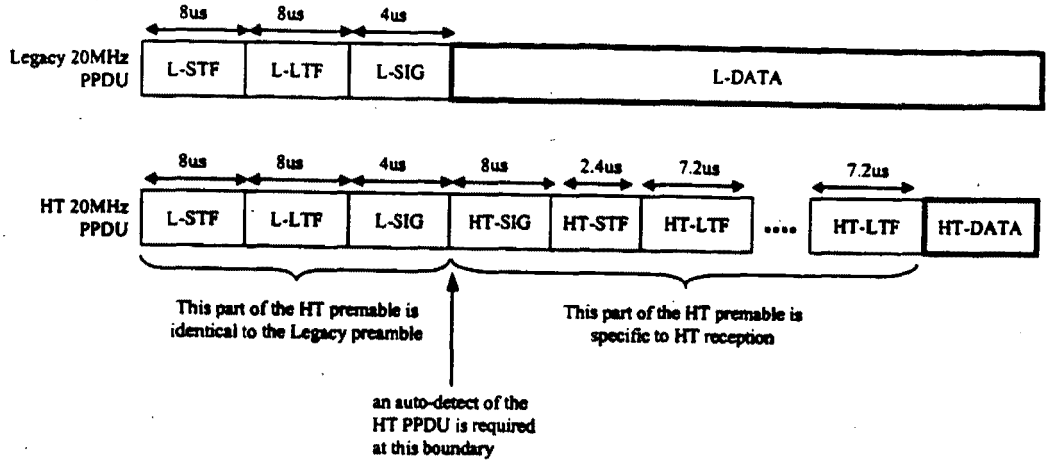


Figure 40: HT Preamble format

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 38 and Figure 39)

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 41.

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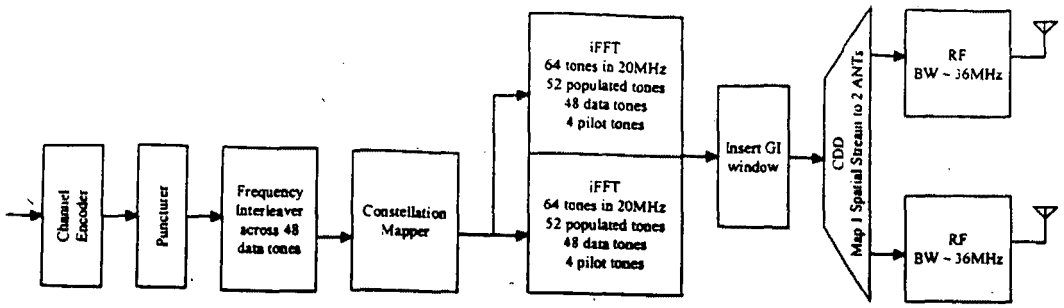


Figure 41: Transmitter configuration for 6Mbps in 40MHz[11]

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 39. The PPDU format for the 6Mbps duplicate mode is shown in Figure 42:

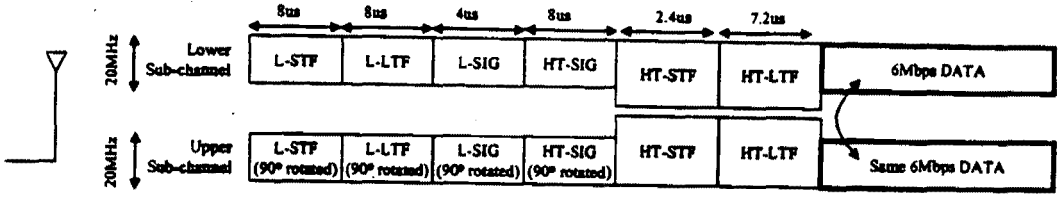


Figure 42: PPDU format for 6Mbps duplicate mode

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 20).

11.1.1.6 Support for Advanced Techniques

All advanced techniques are optional in our proposal.

In our basic mandatory 40MHz MIMO mode, the number of data streams created by the spatial parser in Figure 35 is the same as the number of transmit antennas. And, in this basic configuration, each data stream (henceforth called 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 43. 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

[11] 40MHz operation by an HT device shall only be permitted in those regulatory domain that allow it.

beamforming, only spatial steering is performed. In advanced beamforming, each spatial stream has a unique MCS set and a unique power level. We also support bi-directional beamforming in the ABF-MIMO mode.

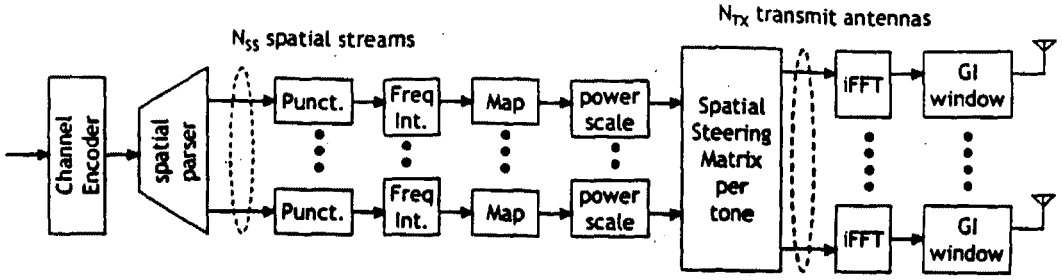


Figure 43: Transmitter Datapath with option to perform spatial shaping

If there is only one spatial stream at the transmitter, we can perform transmit beamforming using CSIT. If SVD of H is used to perform beamforming, that is termed as eigenbeamforming.

We also have the option of introducing advanced coding schemes in our proposal, such as LDPC or concatenated Reed-Solomon/Convolutional encoding. The use of advanced 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 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. • Does not provide any information to help perform spatial shaping • 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 • 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 • Response packet does not contain forward link Channel State Information (CSIT) • 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

11.1.1.8 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)	• Typically, $N_{SS} = N_{TX}$ • Each spatial stream is mapped to one antenna	• No adaptation is performed in the spatial domain • 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 • All spatial streams shall use the same MCS and transmit at same power
Basic-MIMO with TX Beamforming (Optional)	• Typically, $N_{SS} \leq N_{TX}$ • All spatial streams are spatially shaped via a steering matrix • The steering matrix is defined for each tone in the OFDM modulation • All spatial streams have identical MCS and power levels	• CSI is required at the TX • Sounding packet from the recipient to the initiator is required to estimate the CSI at the transmitter • RF calibration is required since reciprocity is used to perform TX beamforming
Advanced MIMO with TX Beamforming (Optional)	• Typically, $N_{SS} \leq N_{TX}$ • All spatial streams are spatially shaped via a steering matrix • The steering matrix is defined for each tone in the OFDM modulation • Power levels for each spatial stream do not have to be identical • MCS for each spatial stream does not have to be identical • Bi-Directional Advanced Beamforming MIMO is supported via UD decomposition	• CSI is required at the TX • Sounding packet from the recipient to the initiator is required to estimate the CSI at the transmitter • RF calibration is required since reciprocity is used to perform TX beamforming

Table 16: 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 20. 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)
Δ_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 17: 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 44:

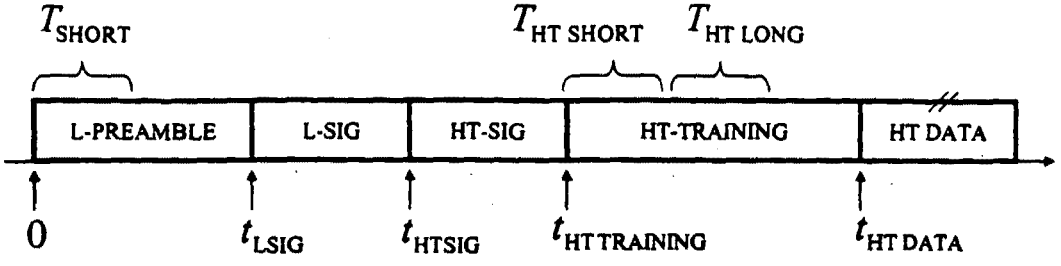


Figure 44: Timing boundaries for subframes in a HT transmission

The signal transmitted on antenna i_{Tx} is given by:

$$\begin{aligned} r_{PACKET}^{(i_{Tx})}(t) = {} & r_{PREAMBLE}^{(i_{Tx})}(t) + r_{LSIG}^{(i_{Tx})}(t - t_{LSIG}) \\ & + r_{HTSIG}^{(i_{Tx})}(t - t_{HTSIG}) \\ & + r_{HT\ TRAINING}^{(i_{Tx})}(t - t_{HT\ TRAINING}) \\ & + r_{DATA}^{(i_{Tx})}(t - t_{DATA}) \end{aligned} \quad (2)$$

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:

$$r_{SUBFRAME}^{(i_{Tx})}(t) = w_{SUBFRAME}(t) \sum_{k=-N_{SR}}^{N_{SR}} C_k \exp\left(j2\pi k \Delta_F t\right) \quad (3)$$

The PHY related parameters are listed in Table 17.

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 45 shows the PPDU format for the basic MIMO mode:

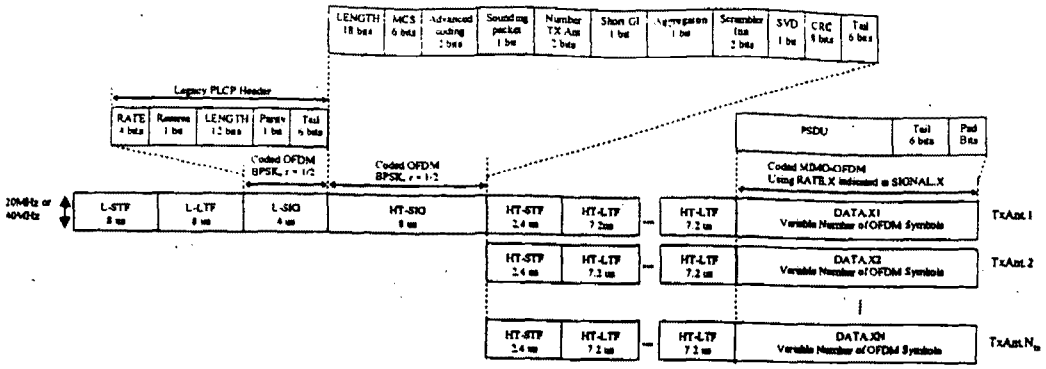


Figure 45: PPDU Format for N_{TX} antennas

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 symbol. 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 ref [2]. The modulation and coding procedure also follows the steps of 17.3.4 in ref [2]. 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 46:

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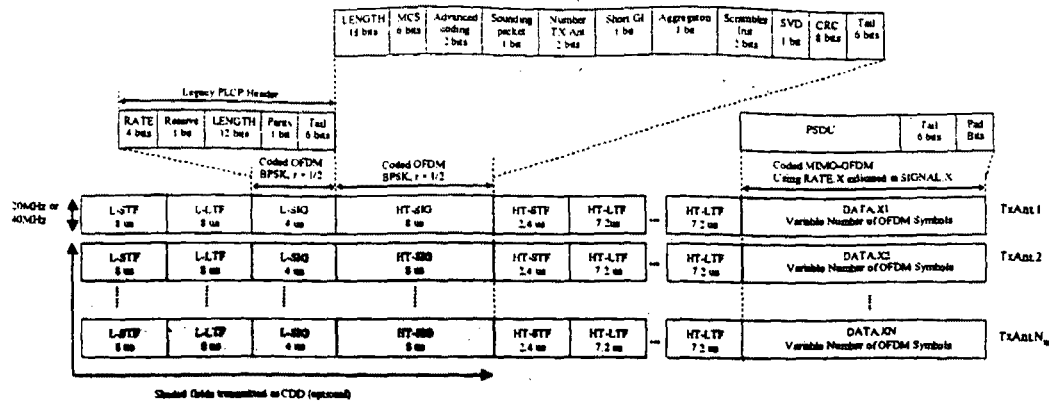


Figure 46: PPDU format leveraging CDD transmission

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 45 and Figure 46, 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:

$$S_{-26,26} = \sqrt{13/6}\{0,0,1+j,0,0,0,-1-j,0,0,0,1+j,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,$$
$$0,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0\} \quad (4)$$

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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:

$$\begin{aligned} S_{-58,58} = \sqrt{13/6}\{&0,0,1+j,0,0,0,-1-j,0,0,0,1+j,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,\\ &0,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,0,0,\\ &0,0,0,0,0,0,0,0,0,0,j-1,0,0,0,-j+1,0,0,0,j-1,0,0,0,-j+1,0,0,0,-j+1,0,0,0,j-1,\\ &0,0,0,0,0,0,0,0,-j+1,0,0,0,-j+1,0,0,0,j-1,0,0,0,j-1,0,0,0,j-1,0,0,0,j-1,0,0\} \end{aligned} \quad (5)$$

The tones in the upper subchannel (see Figure 38) 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. 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:

$$r_{SHORT}^{(i_{TX})}(t) = \begin{cases} \sqrt{N_{TX}}\, w_{TSHORT}(t) \sum_{k=-N_{SR}}^{N_{SR}} S_k \exp\{j2\pi k\Delta_F t\} & i_{Tx} = 1 \\ 0 & otherwise \end{cases} \quad (6)$$

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

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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

$$L_{-26,26} = \{1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,0,$$
$$1,-1,-1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,1,-1,-1,1,-1,1,-1,1,1,1,1\} \quad (8)$$

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:

$$r_{LONG}^{(iTX)}(t) = \begin{cases} \sqrt{N_{TX}}\, w_{T\,LONG}(t) \sum_{k=-N_{SR}}^{N_{SR}} L_k \exp\left(j2\pi k\Delta_F\left(t - T_{GI2}\right)\right) & i_{Tx} = 1 \\ 0 & otherwise \end{cases} \quad (9)$$

where $T_{GI2} = 1.6\mu s$.

If the long training signal is generated in a CDD fashion, we get:

$$r_{LONG}(t) = w_{T\,LONG}(t) \sum_{k=-N_{SR}}^{N_{SR}} L_k \exp\left\{j2\pi k\Delta_F\left(t - (i_{TX}-1)T_{Shift} - T_{GI2}\right)\right\} \quad (10)$$

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:

$$L_{-58,58} = \{1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,0,$$
$$1,-1,-1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,1,-1,-1,1,-1,1,-1,1,1,1,1,1,0,0,0,0,0,0$$
$$0,0,0,0,0,0,0,j,j,-j,-j,j,j,-j,j,-j,j,j,j,j,j,j,j,-j,-j,j,j,-j,j,-j,j,j,j,j,j,0,$$
$$j,-j,-j,j,j,-j,j,-j,j,-j,-j,-j,-j,-j,j,j,-j,-j,j,-j,j,-j,j,j,j\} \quad (11)$$

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

$$r_{PREAMBLE}^{(iTX)}(t) = r_{SHORT}^{(iTX)}(t) + r_{LONG}^{(iTX)}(t - T_{SHORT}) \quad (12)$$

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11.2.1.3.3 HT-Short Training Field

The HT-STF follows the HT signal field (see Figure 45), 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

$$HTS_{-26,26} = \sqrt{13/12}\begin{cases}\{0,0,-1\text{-}j,0,1\text{+}j,0,-1\text{-}j,0,-1\text{-}j,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,\\ 0,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,0,-1\text{-}j,0,1\text{+}j,0,-1\text{-}j,0,0\} & N_{TX}=2\\ \{0,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,-1\text{-}j,0,-1\text{-}j,0,-1\text{-}j,0,-1\text{-}j,0,1\text{+}j,0,-1\text{-}j,0,-1\text{-}j,0,0,\\ 0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,-1\text{-}j,0,-1\text{-}j,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,0\} & N_{TX}=3\\ \{0,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,1\text{+}j,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,1\text{+}j,0,-1\text{-}j,0,0,\\ 0,-1\text{-}j,0,1\text{+}j,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,1\text{+}j,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,0\} & N_{TX}=4\end{cases} \quad (13)$$

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\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,-1\text{-}j,0,-1\text{-}j,0,1\text{+}j,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,1\text{+}j,0,-1\text{-}j,0,\\ 0,0,-1\text{-}j,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,0,0,0,0,0,0,0,\\ 0,0,0,0,0,0,0,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,-1\text{-}j,0, & N_{TX}=2\\ 0,0,-1\text{-}j,0,1\text{+}j,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,1\text{+}j,0,-1\text{-}j,0,-1\text{-}j,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,0\}\\ \{0,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,\\ 0,0,-1\text{-}j,0,-1\text{-}j,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,0,0,0,0,0,0,0,\\ 0,0,0,0,0,0,0,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0, & N_{TX}=3\\ 0,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,-1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,-1\text{-}j,0,-1\text{-}j,0,1\text{+}j,0,0\}\\ \{0,0,-1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,-1\text{-}j,0,-1\text{-}j,0,1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,\\ 0,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{-}j,0,-1\text{-}j,0,-1\text{-}j,0,0,0,0,0,0,0,0,\\ 0,0,0,0,0,0,0,0,1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,-1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0, & N_{TX}=4\\ 0,0,1\text{+}j,0,-1\text{-}j,0,-1\text{-}j,0,-1\text{-}j,0,1\text{-}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,1\text{+}j,0,0\}\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 $1.6\mu s$.

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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 18: 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 $N_{TX} = 2$, 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:

$$HTL_{-26,+26} = \{-1\ -1\ 1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1\ 1$$
$$0\ 1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ 1\}$$ (18)

The tone-interleaving rule across three antennas in 20MHz is grouped into 3 sets:

$$set\_1 = [-26:3:-2], [2:3:26]$$
$$set\_2 = [-25:3:-1], [3:3:24]$$
$$set\_3 = [-24:3:-3], [1:3:25]$$ (19)

In 20MHz, for $N_{TX}=4$, sequence 4 is:

$$HTL_{-26,+26} = \{-1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ -1\ 1$$
$$0\ 1\ 1\ -1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ -1\ 1\ 1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ 1\ -1\ 1\ 1\ 1\ -1\ 1\}$$ (20)

The tone-interleaving rule across four antennas in 20MHz is grouped into 4 sets:

$$set\_1 = [-26:4:-2], [3:4:23]$$
$$set\_2 = [-25:4:-1], [4:4:24]$$
$$set\_3 = [-24:4:-4], [1:4:25]$$
$$set\_4 = [-23:4:-3], [2:4:26]$$ (21)

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.

$$HTL_{-58,+58} = \{-1\ 1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ 1\ -1\ 1\ -1$$
$$1\ 1\ -1\ -1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ 1\ -1\ -1\ -1\ 1\ 1\ -1\ -1\ 1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ 1\ 1$$
$$0\ 0\ 0\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ -1\ 1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ 1\ -1$$
$$-1\ 1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ 1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ -1\ 1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ 1\ 1\ 1\}$$ (22)

In 40MHz, for $N_{TX}=2$, sequence 7 is:

$$HTL_{-58,+58} = \{-1\ 1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ 1\ 1\ 1\ -1$$
$$-1\ 1\ 1\ -1\ -1\ 1\ 1\ 1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ 1\ 1\ 1\ 1\ -1\ -1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ -1$$
$$0\ 0\ 0\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ -1\ 1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ 1\ -1$$
$$1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ 1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ 1\ 1\ 1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ 1\ 1\}$$ (23)

The tone-interleaving rule across two antennas in 40MHz is grouped into 2 sets:

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$$set\_1 = [-58:2:2], [2:2:58]$$
$$set\_2 = [-57:2:-3], [3:2:57] \quad (24)$$

The tone-interleaving pattern in space and time for the HT long training fields is shown in Figure 47 for 2 antennas (2 spatial streams):

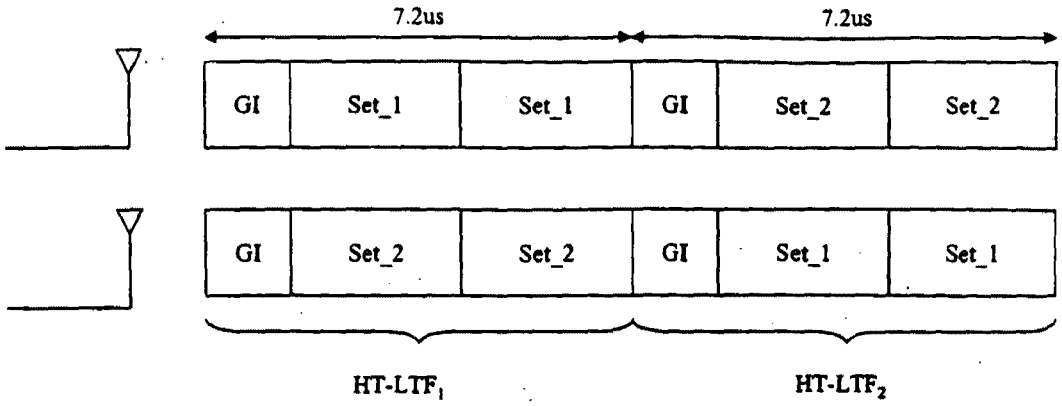


Figure 47: HT-LTF pattern for 2 antennas (2 spatial streams)

In 40MHz, for $N_{TX} = 3$, sequence 8 is:

$$HTL_{-58,+58} = \{-1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1$$
$$1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 0 \quad (25)$$
$$0\ 0\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1$$
$$-1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ \}$$

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 48 for 3 antennas (3 spatial streams):

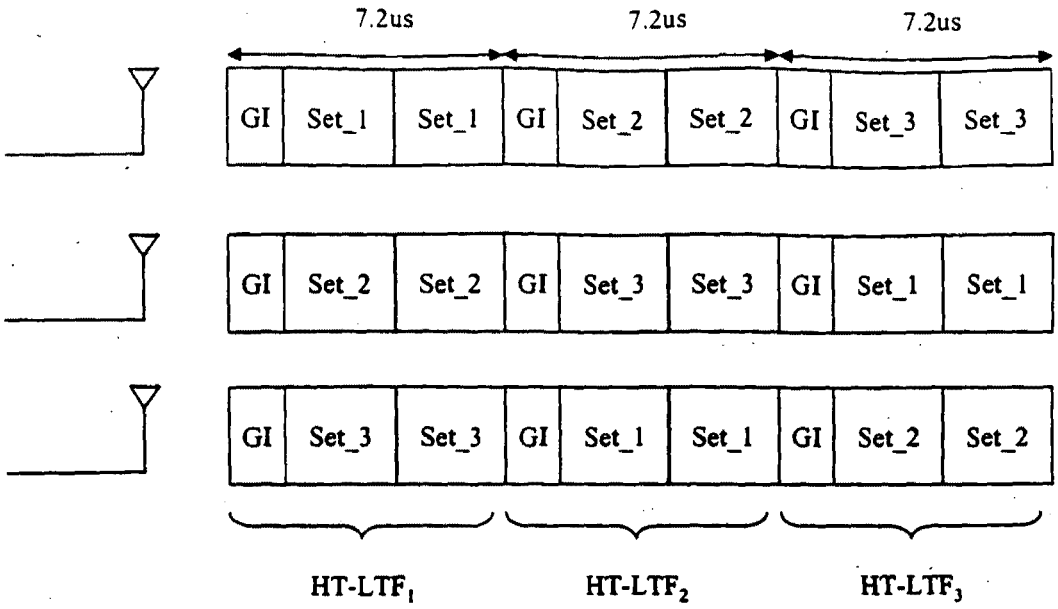


Figure 48: HT-LTF pattern for 3 antennas (3 spatial streams)

In 40MHz, for $N_{TX} = 4$, sequence 9 is:

$$\begin{aligned} HTL_{-58,+58} = \{&-1\ 1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ 1\ 1\ -1\ \ -1\ -1\ -1\ 1\ 1\ -1\ -1\ -1\ 1\ -1\ 1\ -1 \\ &1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ \ -1\ -1\ 1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ 1\ -1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ 1\ 0 \\ &0\ 0\ -1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ 1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ -1 \\ &-1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ 1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ 1\ 1\} \end{aligned} \quad (27)$$

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 49 for 4 antennas (4 spatial streams):

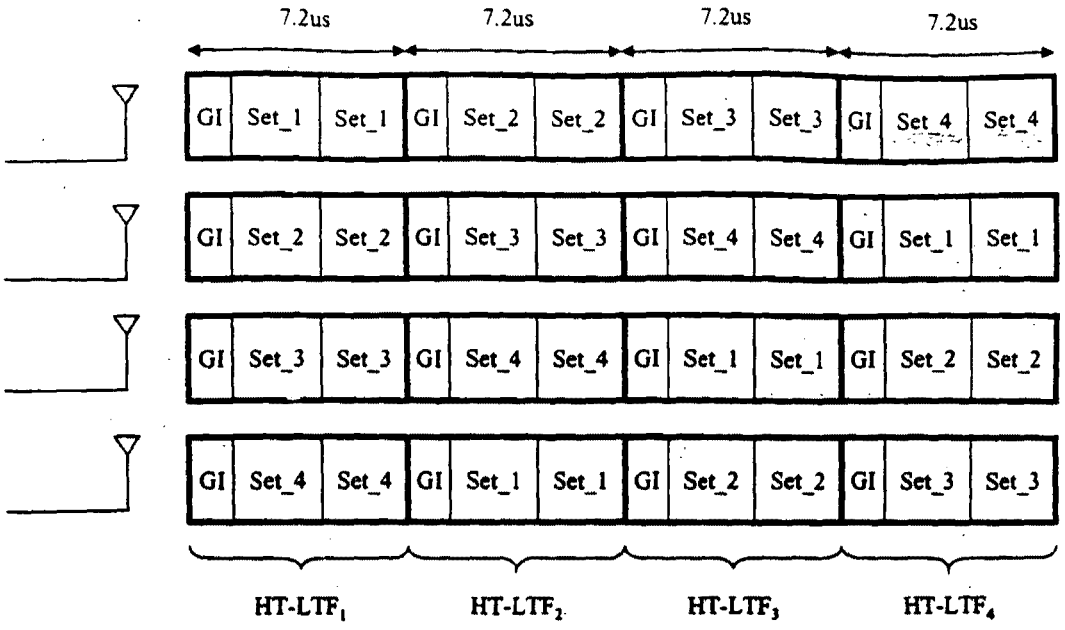


Figure 49: HT-LTF pattern for 4 antennas (4 spatial streams)

The HT long training signal is generated similarly to the HT short training signal.

$$r^{(i_{Tx})}_{HT\,LONG}(t) = w_{T\,HT\,LONG}(t)\sqrt{N_{TX}} \sum_{k\in set\_(1+[(i_{TX}-1)+(n-1)] \bmod N_{TX})} HTL_k \exp\left\{j2\pi k\Delta_F\left(t - T_{GI} - (n-1)T_{HT\,LONG}\right)\right\}$$
$$for \quad (n-1)T_{HT\,LONG} \le t < nT_{HT\,LONG} \quad and \quad n = 1,\mathrm{L}\ , N_{TX} \qquad (29)$$
$$for \quad i_{TX} \in \{1,\mathrm{K}\ , N_{TX}\}$$

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:

$$r^{(i_{Tx})}_{HT\,TRAINING}(t) = r^{(i_{Tx})}_{HT\,SHORT}(t) + r^{(i_{Tx})}_{HT\,LONG}\left(t - T_{HT\,SHORT}\right) \qquad (30)$$

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-LTF is 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 N_{SS}. And, as mentioned above, in addition to tone-interleaving, the HT-LTF also undergoes the same spatial steering as the HT-DATA fields.

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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 50.

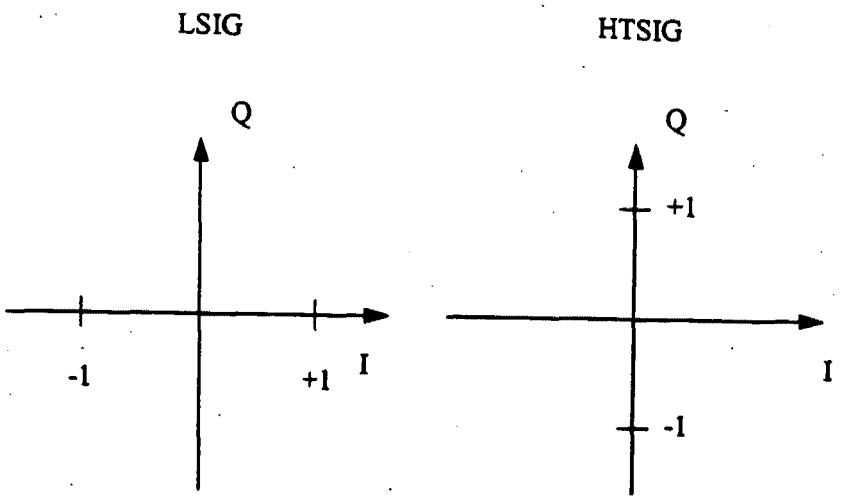


Figure 50: Constellation specification for LSIG and HTSIG

11.2.1.4.1 LSIG

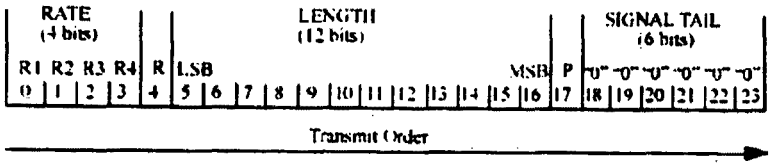


Figure 51: SIGNAL field bit assignment

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 ref [2]. 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 LSIG 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 20MHz and 40Mhz respectively. Then, for transmission over a single antenna, we have,

$$r_{LSIG}^{(i_{Tx})}(t)=\begin{cases}\sqrt{N_{Tx}}\,w_{SYM}(t)\sum_{k=-N_{SR}}^{N_{SR}} LSIG_k \exp\{j2\pi k\Delta_F(t-T_{GI})\} & i_{Tx}=1\\ 0 & otherwise\end{cases} \quad (31)$$

Similarly, if the legacy training fields are transmitted across multiple transmit antennas using CDD, we have

$$r_{LSIG}^{(i_{Tx})}=w_{SYM}(t)\sum_{k=-N_{SR}}^{N_{SR}} LSIG_k \exp\{j2\pi k\Delta_F(t-T_{GI}-(i_{Tx}-1)T_S)\} \quad (32)$$

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 ref [2]. 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 19: 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 52 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. If CDD is used to transmit the legacy signal fields, then

$$r^{(i_{Tx})}_{HTSIG}(t) = \sum_{n=1}^{2} \left[w_{SYM}(t) \sum_{k=-N_{SR}}^{N_{SR}} HTSIG^{n}_{k} \exp\left\{ j2\pi k\Delta_F \left(t - T_{GI} - (n-1)T_{SYM} - (i_{Tx}-1)T_S \right) \right\} \right] \quad (34)$$

where $T_{SYM} = 4\mu s$ is the OFDM symbol duration.

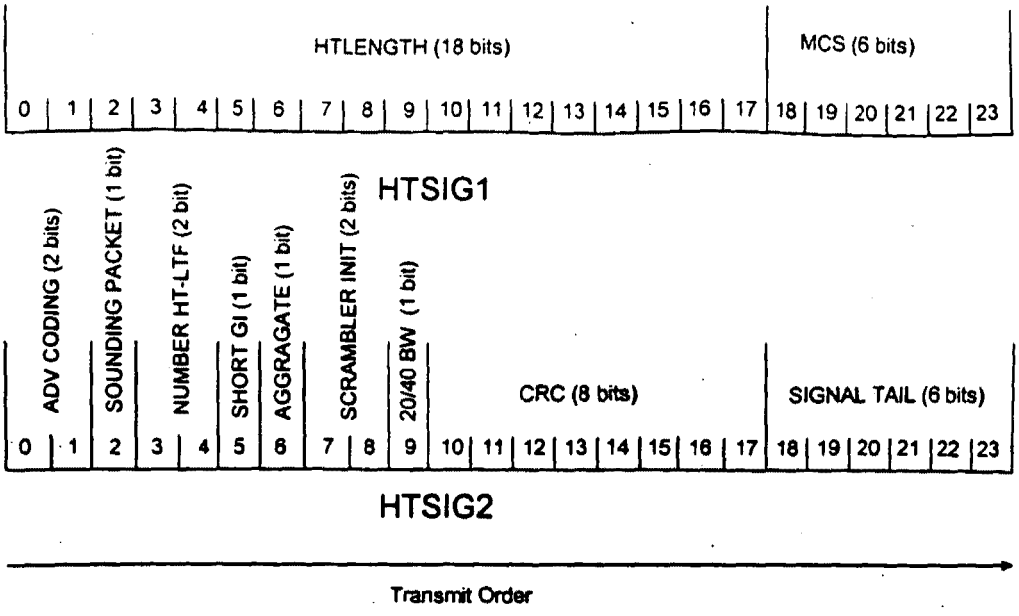


Figure 52: HT SIGNAL FIELD (HTSIG1 and HTSIG2) bit assignment

11.2.1.4.2.1 HTLENGTH field

The HTLENGTH field shall be an unsigned 18-bit integer that indicated 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 20.

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 20: MCS field content for the basic mode

MCS indices from 33 to 63 (31 in number) are reserved for the Advanced MIMO Mode.

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11.2.1.4.2.3 ADVCODING

ADVCODING is a 2-bit field signaling that advanced coding is used.

Bit 0,1 HTSIG2	Action
0	No ADVCODING
1	LDPC
2	RS
3	NOT USED

Table 21: ADVCODING Field Content

11.2.1.4.2.4 SOUNDING PACKET

This bit indicates that MIMO training is per antenna and ALL antennas are excited. If 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.

11.2.1.4.2.9 20/40 BW

This bit indicates whether the current PPDU is signaled in 20MHz or 40MHz. 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 53.

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

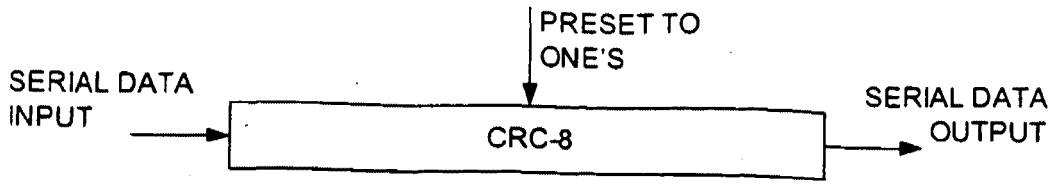
1101 0001 1101 1101 0, 0111 1011 0100 1011 1010 0000, 0010 1101 10

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

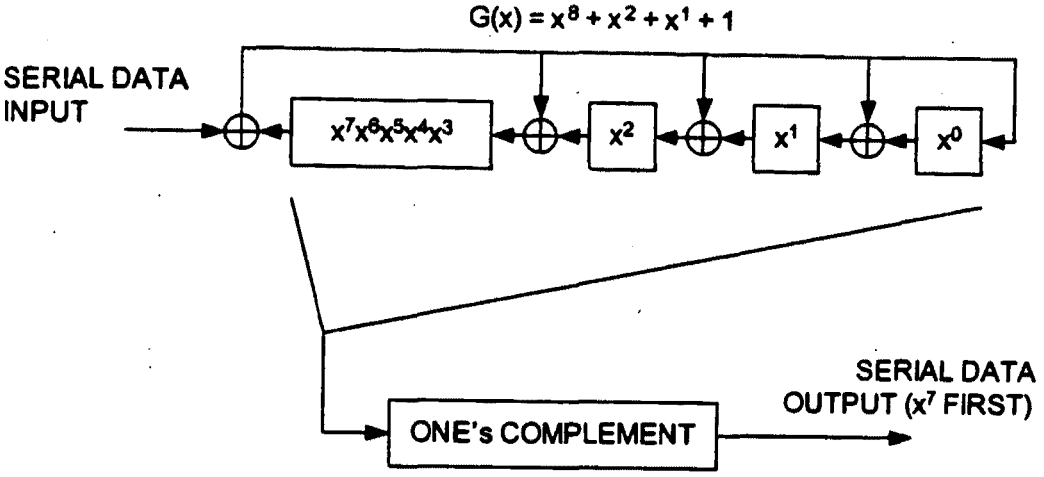


Figure 53: Generation of CRC bits

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 contains no 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 11.2.1.5.31.2. The PPDU is de-multiplexed across several spatial streams, which are created after the parser. Figure 35. 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 [2].

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 INITSCRAMBLER 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 35. 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 ref [2]. (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 ref [2]. For a code rate of 7/8, the puncturing pattern is illustrated in Figure 54.

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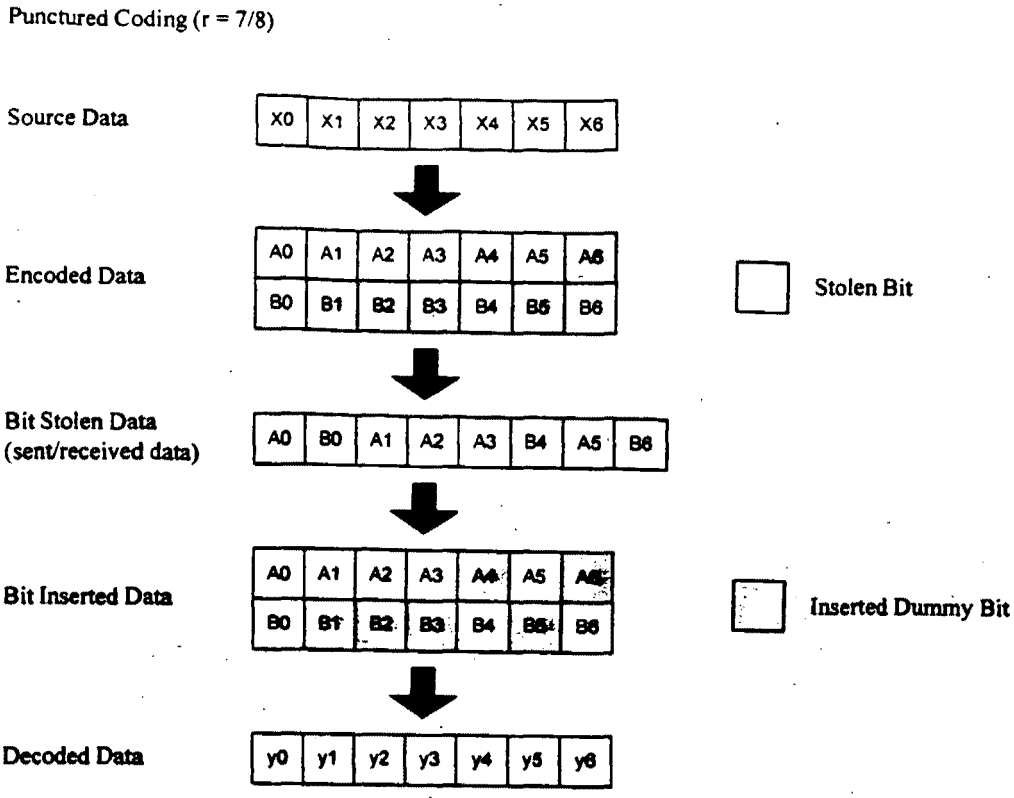


Figure 54: Puncturing pattern for code rate = 7/8

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.

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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 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.

The basic interleaver array has N_{row} rows and N_{column} columns. These parameters are specified in

Table 22 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 22: Interleaver Parameters

	N_{column}	N_{row}
20 MHz channels	16	$3\,N_{BPSC}$
40 MHz channels	18	$6\,N_{BPSC}$

The interleaver is defined by a two-step permutation. The first permutation ensures that adjacent coded bits are mapped onto nonadjacent subcarriers. The first permutation is modified from the 802.11a interleaver such that the column indexes in the array are rotated for each spatial stream. 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 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; and j shall be the index after the second permutation, just prior to modulation mapping.

The first permutation is defined by the rule

$$i = N_{row} \times \left(\left(\left(k \bmod N_{column} \right) + i_{SS} \right) \bmod N_{column} \right) + \mathrm{floor}\left(k / N_{column} \right) \qquad k = 0,1,\mathrm{K}\,, N_{CBPS} - 1 \qquad (37)$$

where $i_{SS} = 0,1,\mathrm{K}\,, N_{SS} - 1$ is the index of the spatial stream on which this interleaver is operating. The insertion of i_{SS} is a modification of the 802.11a interleaver. This results in a "column offset" in the de-interleaving process. That is, bits are read in by rows and out by columns, but starting with column i_{SS} in a column-cyclic fashion.

The second permutation is defined by the rule

$$j = s \times \mathrm{floor}\left(i / s \right) + \left(i + N_{CBPS} - \mathrm{floor}\left(N_{column} \times i / N_{CBPS} \right) \right) \bmod s \qquad i = 0,1,\mathrm{K}\,, N_{CBPS} - 1 \qquad (38)$$

where s is determined according to

$$s = \max(N_{BPSC} / 2,1) \quad (39)$$

The deinterleaver, which performs the inverse relation, is also defined by two permutations.

Here the index of the original received bit before the first permutation shall be denoted by j; i shall be the index after the first and before the second permutation; and k shall be the index after the second permutation.

The first permutation is defined by the rule

$$i = s \times \text{floor}(j/s) + (j + \text{floor}(N_{column} \times j / N_{NCBPS})) \bmod s \qquad j = 0,1,\text{K}\,, N_{CBPS} - 1 \quad (40)$$

where s is as defined in Equation (39)

This permutation is the inverse of the permutation described in Equation (38)

The second permutation is defined by the rule

$$k = N_{column}(i \bmod N_{row}) + (\text{floor}(i / N_{row}) - i_{ss} + N_{column}) \bmod N_{column} \quad i = 0,1,\text{K}\,, N_{CBPS} - 1 \quad (41)$$

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 ref [2].

There is one exception as described in clause 11.2.1.4. The mapping of the HTSIG field shall be 90 degrees rotated.

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 ref [2]).

Construction of the OFDM data symbol in 40MHz begins with bonding two adjacent 20MHz OFDM symbols, as shown in Figure 55. 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:

$$
\begin{aligned}
&\textit{Nulled Tones} = \{-64\text{K}-59,-1,0,+1,+59\text{K}+63\} \\
&\textit{Populated Tones} = \{-58\text{K}-2,+2\text{K}+58\} \\
&\textit{Pilot Tones} = \{-53,-25,-11,+11,+25,+53\} \\
&\textit{Data Tones} = \{\textit{Populated Tones}\}-\{\textit{Pilot Tones}\}
\end{aligned}
\tag{42}
$$

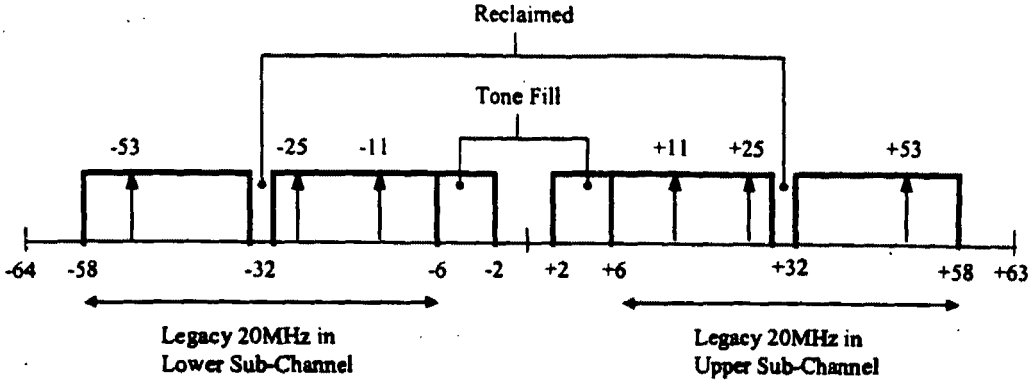


Figure 55: Tone Format for Fat Channel at 40MHz

The mapping of the input of the 40MHz channel to a 128-point IFFT is illustrated in Figure 56.

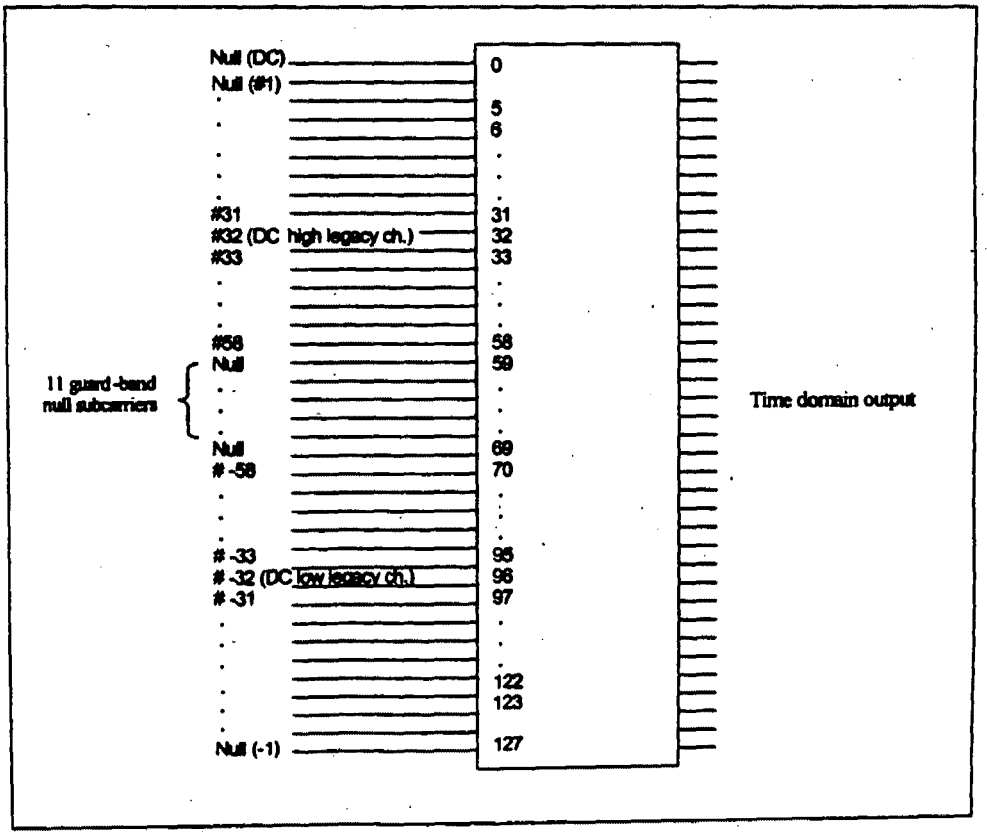


Figure 56 Inputs and Outputs of IFFT for a 40 MHz channel

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 ref [2], 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

$$r_{DATA,n}^{iTX}(t) = w_{SYM}(t)\left(\sum_{k=0}^{N_{SD}-1} d_{k,n}^{(iTX)} \exp\left(j2\pi M(k)\Delta_F(t-T_{GI})\right) + p_{n+3}\sum_{k=-N_{SR}}^{N_{SR}} P_k^{(iTX)} \exp\left(j2\pi k\Delta_F(t-T_{GI})\right)\right) \quad (43)$$

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 ref [2]. $M(k)$ in the 40MHz mode is defined as

$$M(k) = \begin{cases} k-58 & 0 \le k \le 4 \\ k-57 & 5 \le k \le 31 \\ k-56 & 32 \le k \le 44 \\ k-55 & 45 \le k \le 53 \\ k-52 & 54 \le k \le 62 \\ k-51 & 63 \le k \le 75 \\ k-50 & 76 \le k \le 102 \\ k-49 & 103 \le k \le 107 \end{cases} \quad (44)$$

The contribution of pilot subcarriers in the 20MHz mode is given by (24) in clause 17.3.5.9 in ref [2]. The subcarrier frequency locations in the 20MHz mode is shown in Figure 117 in clause 17.3.5.9 in ref [2]. The subcarrier frequency locations in the 40MHz mode is shown in Figure 55.

The iFFT mapping for the 6Mbps duplicate mode in 40MHz differs slightly from the mapping shown in (43):

$$r_{DATA,n}^{(i)}(t) = w_{SYM}(t)\left(\sum_{k=0}^{N_{SD}-1} d_{k,n}\exp\left(j2\pi\left(M(k)-32\right)\Delta_F(t-T_{GI})\right) + j\sum_{k=0}^{N_{SD}-1} d_{k,n}\exp\left(j2\pi\left(M(k)+32\right)\Delta_F(t-T_{GI})\right) + p_{n+1}\sum_{k=-N_{SR}}^{N_{SR}} P_k\exp\left(j2\pi(k-32)\Delta_F(t-T_{GI})\right) + jp_{n+1}\sum_{k=-N_{SR}}^{N_{SR}} P_k\exp\left(j2\pi(k+32)\Delta_F(t-T_{GI})\right)\right) \quad (45)$$

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

$$r_{DATA}^{(i_{Tx})}(t) = \sum_{n=0}^{N_{SYM}-1} r_{DATA,n}^{(i_{Tx})}(t - nT_{SYM}) \quad (46)$$

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 allocated to subcarriers -21, -7, +7, and +21 in the 20MHz mode, and to subcarriers -53, -25, -11, +11, +25 and +53 in the 40MHz mode.

11.2.1.5.10.1 Legacy pilot subcarriers

Legacy pilots are defined as 802.11a. Refer to clause 17.3.5.8 in ref [2].

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 the inverse Fourier transform of the sequence $P_k^{(i_{Tx})}$, which is defined as:

$$\begin{aligned} P_{-26,26}^{(i_{Tx})} = \{&0,0,0,0,0,P_{-21}^{(i_{Tx})},0,0,0,0,0,0,0,0,0,0,0,0,0,0,P_{-7}^{(i_{Tx})},0,0,0,0,0,0,0,\\ &0,0,0,0,0,0,P_{7}^{(i_{Tx})},0,0,0,0,0,0,0,0,0,0,0,0,0,-P_{21}^{(i_{Tx})},0,0,0,0,0\} \end{aligned} \quad (47)$$

where the non-zero elements of $P_k^{(i_{Tx})}$ are generated by the following rule:

$$P_k^{(i_{Tx})} = \exp\left\{\frac{j\pi}{2}(i_{Tx}-1)m\right\}, \quad m = \frac{1}{2}\left(\frac{k}{7}+3\right) \quad (48)$$

In the 40MHz mode, $P_k^{(i_{Tx})}$ is given by

$$\begin{aligned} P_{-58,58}^{(i_{Tx})} = \{&0,0,0,0,0,P_{-53}^{(i_{Tx})},0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,P_{-25}^{(i_{Tx})},0,0,\\ &0,0,0,0,0,0,0,0,0,0,0,-P_{-11}^{(i_{Tx})},0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,P_{11}^{(i_{Tx})},0,0,0,0,\\ &0,0,0,0,0,0,0,0,0,0,-P_{25}^{(i_{Tx})},0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,\\ &0,0,P_{53}^{(i_{Tx})},0,0,0,0,0\} \end{aligned} \quad (49)$$

where the non-zero element of $P_k^{(i_{Tx})}$ are generated by the following rule:

$$P_k^{(i_{Tx})} = \exp\left\{\frac{j\pi}{2}(i_{Tx}-1)m\right\}, \quad m = \begin{cases} \frac{(k+11)}{14}+3, & k = -53,-25,-11 \\ \frac{(k+3)}{14}+3, & k = 11,\ 25,\ 53 \end{cases} \quad (50)$$

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 ref [2]. The example in clause 17.3.2.5 in ref [2] 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

$$w_T[n] = w_T(nT_s) = \begin{Bmatrix} 1 & 1 \le n \le 159 \\ 0.5 & 0,160 \\ 0 & otherwise \end{Bmatrix} \quad (51)$$

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 ref [2]. 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 [2]) 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 [2]. 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.

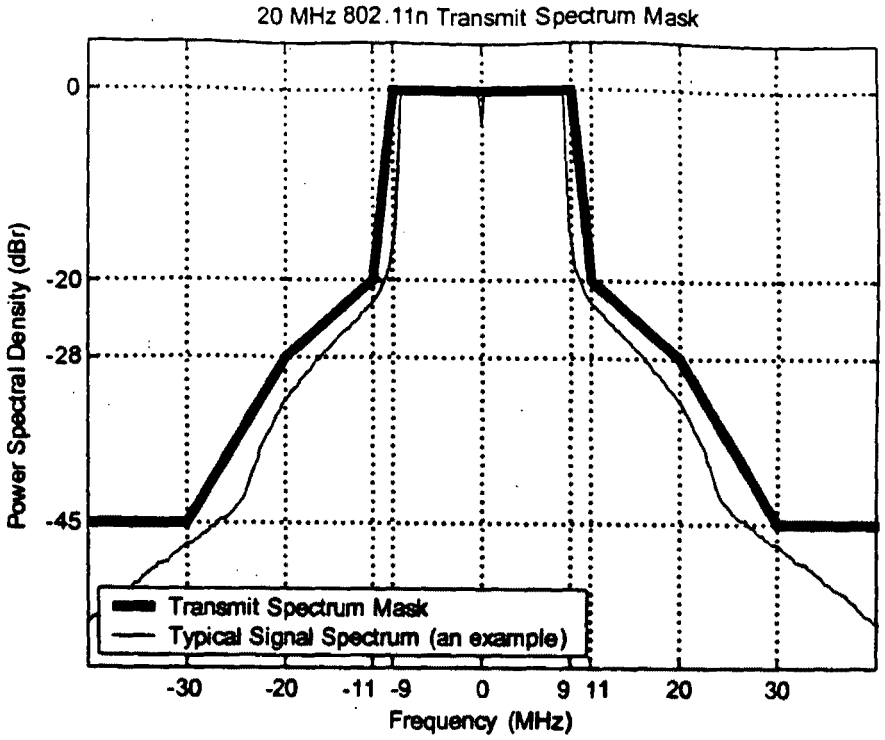


Figure 57: Transmit Spectrum Mask for 20MHz channelization

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.

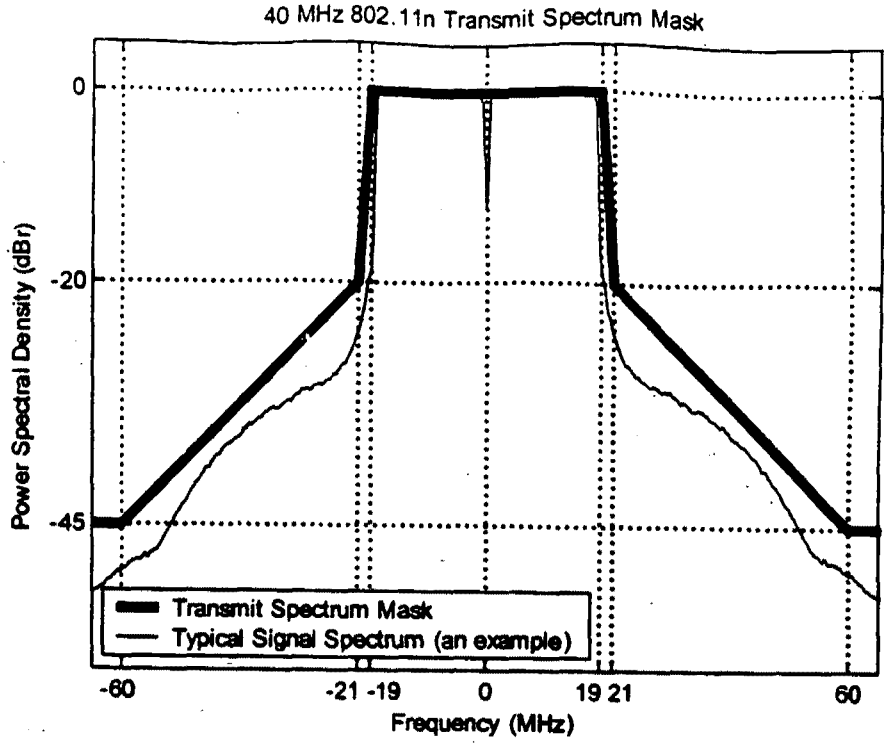


Figure 58: Transmit spectrum mask for 40MHz channelization

A HT device transmitting a 20MHz signal in a 40MHz BSS shall conform to the spectral mask shown in Figure 58.

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,

$$y_{N_{TX}\times 1} = V_{N_{TX}\times N_{SS}} \cdot x_{N_{SS}\times 1} \quad (52)$$

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,

$$H = UDV^H \quad (53)$$

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,

$$H_U = H_D^H \quad (54)$$

11.2.2.3.4 Calibration Calculation (Informative)

Calculation of beamforming matrices using implicit feedback relies on channel reciprocity (the downlink channel is the transpose of the uplink channel, and visa versa). This property is true for the actual wireless channel; however, the composite channel includes not only the actual wireless channel but also the complex gains of the transmitter and receiver amplifiers. The calibration process is used to calibrate for the gains of the transmitter and receiver paths in both STAs

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 59:

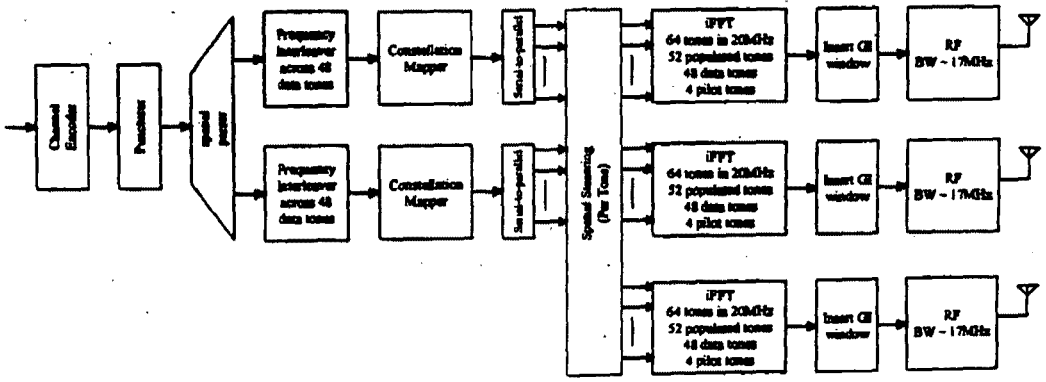


Figure 59: Transmitter architecture for TX Beamforming for N_{ss}=2,and N_{TX} = 3

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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 20.

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 stream 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,

$$p_1^2 + p_2^2 + \mathrm{K} + p_{N_{SS}}^2 = N_{SS} \quad (55)$$

After the scaling of power ratios, the beamforming matrix, V, is applied. The operation of power scaling and beamforming is represented as,

$$\vec{y} = V \cdot P \cdot \vec{x} \quad (56)$$

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 23.

Table 23: 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

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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 60:

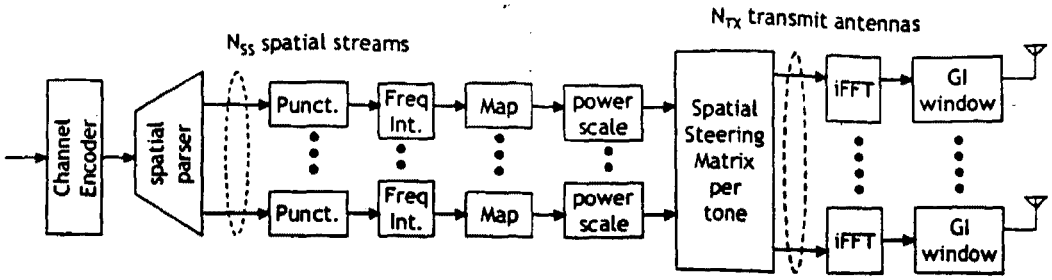


Figure 60: Transmit Datapath Architecture for ABF-MIMO mode

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 24. The constellation mapping for 256QAM is as follows.

Table 24: 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 60 (which is different from basic BF-MIMO, as shown in Figure 59). 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 Options for Advanced Coding

Our proposal introduces two flavors of advanced coding: (i) LDPC (low density parity check) coding, and (ii) Concatenated coding using an outer Reed-Solomon (RS) code and the 802.11a convolutional code as the inner code.

11.2.4.1 Low Density Parity Check Codes

There has is great interest in employing a Low Density Parity Check (LDPC) code in the 802.11n standard. It has been shown that LDPC codes, like turbo codes, can provide near Shannon capacity performance. Our proposal has chosen to endorse LDPC due to (a) their ability to provide good performance at high code rates (thus enhancing throughput), and (b) more flexibility in decoder design options.

At the time of submission of this proposal, there are several companies working towards convergence of a precise LDPC code definition within 802.11 task group N. It is expected that this convergence process will continue over the next few months, and the authors of this proposal expect to endorse the outcome of this convergence process. Accordingly, this proposal shall not initially endorse a particular LDPC code. Rather, we shall discuss only overview material on LDPC with indication on how the LDPC can be integrated into the 802.11n standard. Simulation results are presented for a "placeholder" rate 7/8 LDPC code.

11.2.4.1.1 LDPC Overview

LDPC codes are block codes that are specified by the parity check matrix of size $M \times N$ defines an LDPC block code (N,K), where K is the information block size, N is the length of the codeword, and M is the number of parity check bits, $M = N-K$. The general characteristic of an LDPC parity check matrix is low density of non-zero elements (1's in this case), which allows utilization of efficient decoding algorithms. This particular parity check matrix is designed in a way that enables simple encoding as well. It can be represented in the following form:

$$\mathbf{H} = \left[\mathbf{H}^d \mid \mathbf{H}^p\right] \tag{57}$$

$\mathbf{H}^d$ is an $M \times K$ matrix and corresponds to the "data" bits of the codeword. The design of this matrix ensures high coding gain. $\mathbf{H}^p$ is an $M \times M$ "dual diagonal" matrix and corresponds to the "parity" bits of the codeword. These codes are systematic block codes. Codewords have the structure

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$$\mathbf{c} = \begin{bmatrix} \mathbf{d} \\ \mathbf{p} \end{bmatrix} \tag{58}$$

where $\mathbf{d} = [d_0 \mathrm{L}\ d_{K-1}]^T$ is the block of (uncoded) data bits and $\mathbf{p} = [p_0 \mathrm{L}\ p_{M-1}]^T$ are the parity bits. A codeword is any binary N-vector $\mathbf{c}$ that satisfies

$$\mathbf{Hc} = \mathbf{H}^d\mathbf{d} + \mathbf{H}^p\mathbf{p} = \mathbf{0}. \tag{59}$$

Thus, a given the data block $\mathbf{d}$ is encoded by solving binary equation $\mathbf{H}^p\mathbf{p} = \mathbf{H}^d\mathbf{d}$ for the parity bits $\mathbf{p}$. In principle, this involves inverting the $M \times M$ matrix $\mathbf{H}^p$.

While $\mathbf{H}^p$ itself may be a "low density" parity matrix (meaning it is mostly of zeros), this property is not generally also true for its inverse. Thus, additional "dual diagonal" structure is imposed in order to in order ensure an efficient encoder. This structure is

$$\mathbf{H}^p = \begin{bmatrix} 1 & 0 & 0 & 0 & \ldots & 0 & 0 \\ 1 & 1 & 0 & 0 & \ldots & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & \ldots & 0 \\ & & & \ldots & & & \\ & & & \ldots & & & \\ 0 & \ldots & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & \ldots & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & \ldots & 0 & 1 & 1 \end{bmatrix} \tag{60}$$

It should be clear that $\mathbf{H}^p\mathbf{p}$ is a differential encoding of the parity bits, and hence, the inverse operation is a very simple differential decoder.

11.2.4.1.2 Recommended Code Parameters

This proposal recommends that the mother LDPC code have rate 7/8. This rate will then match the highest rate available from the convolutional code.

Lower code rates can be obtained by "shortening." In this method, a data block of $\mathbf{d}'$ of length $K' < K$ is encoded by first padding $K - K'$ zeros to produce a new data vector $\mathbf{d} = [\mathbf{0}|\mathbf{d}']$. $\mathbf{d}$ is then encoded using the rate 7/8 mother code to produce the codeword $\mathbf{c} = [\mathbf{0}|\mathbf{d}'|\mathbf{p}]$, however, only $\mathbf{c}' = [\mathbf{d}'|\mathbf{p}]$ is transmitted. Thus, the shortened code rate is $K'/(N - K')$.

This proposal requires that the LDPC design should, by shortening or other methods, provide code rates 1/2, 2/3 and 3/4 in order to match the code rates of provided by punctured convolutional codes.

Selection of the LDPC block size presents trade-off between performance, decoder complexity and decoding time. The last codeword of the PSDU is particularly time critical as it must be decoded within a fraction of a SIFS period. Our studies on decoder complexity have shown that N = 2000 bits is sufficiently long to provide good performance with limited decoder complexity.

Furthermore, the last block decoding problem can be mitigated shortening the last codeword more than the others. This produces a more powerful lower rate code which then requires fewer iterations to decode. Since the vast majority of 802.11n PSDUs should exceed several multiples of 2000 bits, these PSDUs will be encoded using several LDPC codewords. Thus, shorting of the last codeword simultaneously solves the rate matching problem and the SIFS decoding time problem.

11.2.4.1.3 LDPC Implementation in MIMO Architecture

LDPC codes are self interleaved codes, and hence, they do not need a frequency interleaver. Figure 61 shows the MIMO coding architecture to be employed with LDPC. The differences between this architecture and the architecture of Figure 35 are that with LDPC we achieve lower code rates via shortening of the mother rate 7/8 code (rather than puncturing a rate 1/2 convolutional code), and there are no per spatial stream frequency interleavers. The parser is identical to the one described in 11.2.1.5.7.1.

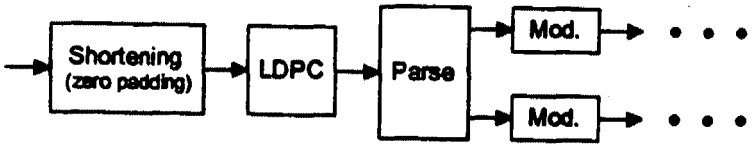


Figure 61: LDPC inclusion in the transmit datapath architecture

11.2.4.2 Reed-Solomon Codes

We propose the use of an outer RS encoder in the system as follows:

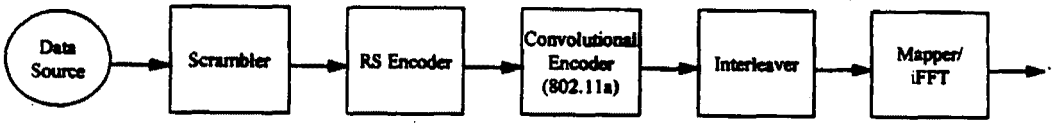


Figure 62: Concatenated RS and Convolutional encoding

We propose to use a (220,200) 20 byte-error correcting RS encoding over GF(256) using the following generator polynomial: $x^8+x^4+x^3+x^2+1$. This is the same generator polynomial used in the ATSC HDTV standard. This code will correct upto 10 byte errors per 220 byte codeword. There is no additional interleaver between the RS encoder and the convolutional encoder. After scrambling, the data bits are grouped into 200 byte groups that are then encoded into 220 bytes in a systematic fashion by the RS encoder.

The proposal does not restrict the packet size to be an integral multiple of 200 bytes. The RS encoder begins encoding data in blocks of 200 bytes and any leftover bytes (< 200) are encoded as a shortened RS codeword with the same number of parity bytes (20). This scheme does not need any other mechanism to inform the receiver as to the number of codewords in a packet. For packet sizes less than 200 bytes, 20 bytes of parity are always appended. In many cases, the

number of RS parity bytes is less than the number of pad-bits that are needed to transmit an integer number of OFDM symbols per antenna, and in those cases the overhead due to the RS encoding will be zero. For example, in a 2 x 2 rate ¾ 64QAM system in 40 MHz, a 100-byte data packet requires 166 bits as pad-bits. Hence 20 bytes of parity can be accommodated with no extra overhead.

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TGn Sync Proposal

Date: Aug 13, 2004

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TGn Sync Proposal Team - Background

- Team operated as a technical group to help motivate a ***rapid introduction*** of the 802.11n standard
- Participating companies from a ***broad range of markets***
  - PC
  - Enterprise
  - Consumer Electronics
  - Semiconductor
  - Handset
  - Public Access
- Solution incorporates a ***worldwide perspective*** of perceived market demand and regulatory concerns
  - Team has representation from the US, Europe and the Pacific Rim

Proposal Overview

- High throughput and minimal design complexity
  - Superior robustness for a broad range of applications
  - Low cost, low power consumption
- Scalable architecture
- Seamless interoperability with 802.11 legacy devices
- Flexible architecture offering regulatory compliance in all major regulatory domains while preserving interoperability

PHY Summary of TGn Sync Proposal

- Basic configuration delivers 243 Mbps using only two antennas
  - Follows historical trend of 5x for 802.11 (.11 → .11b → .11a/g)
- Higher optional PHY data rate rates (>600 Mbps) for future generation devices
- MIMO evolution of 802.11 OFDM PHY with spatial division multiplexing of spatial streams
- Multiple antennas (2 mandatory, greater than 2 optional)
- Preamble designed for seamless interoperability with legacy 802.11a/g
- Wider bandwidth options with fully interoperable 20 MHz and 40 MHz* channel capability
- Support for licensed 10 MHz modes
- Optional enhancements
  - Advanced FEC coding techniques (RS, LDPC)
  - Transmit beamforming with negligible additional cost in receiving client device
  - 1/2 guard interval
  - Rate 7/8 coding

*Not required in regulatory domains where prohibited.

MAC Summary of TGn Sync Proposal

- Supports .11e
- Frame aggregation, single and multiple* destinations
- Bi-directional data flow
- Feedback mechanisms that enhance rate adaptation
- Protection mechanisms for seamless interoperability and coexistence with legacy devices
- Channel management (including receiver assisted channel training protocol)
- Power management

* Optional

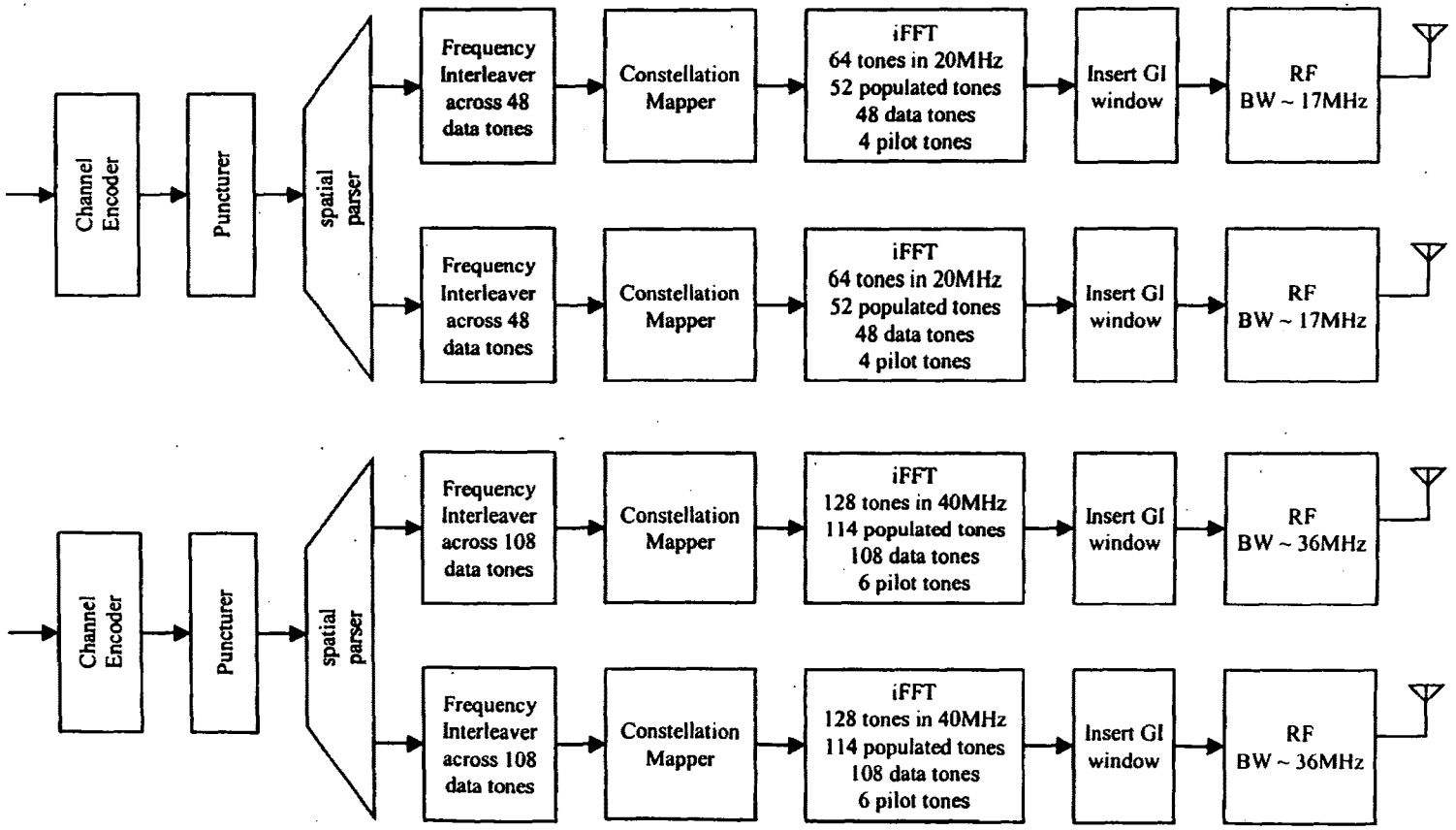
PHY

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Basic Tx Data Path

- FEC coding
  - Conventional K = 7 convolutional code
    - Rates: 1/2, 2/3 and 3/4
    - Supports legacy operation
  - Optional LDPC/RS
  - Optional rate 7/8 code
- Spatial stream parsing
- Frequency interleaving
  - Block interleaver w/ QAM bit rotation (like 11a)
  - 20 MHz ⇒ 16 columns ⇒ freq. sep. = 3 subcarriers
  - 40 MHz ⇒ 18 columns ⇒ freq. sep. = 6 subcarriers
- QAM modulation
  - BPSK, QPSK, 16 QAM and 64 QAM
- Optional 1/2 guard interval

Basic Tx Data Path



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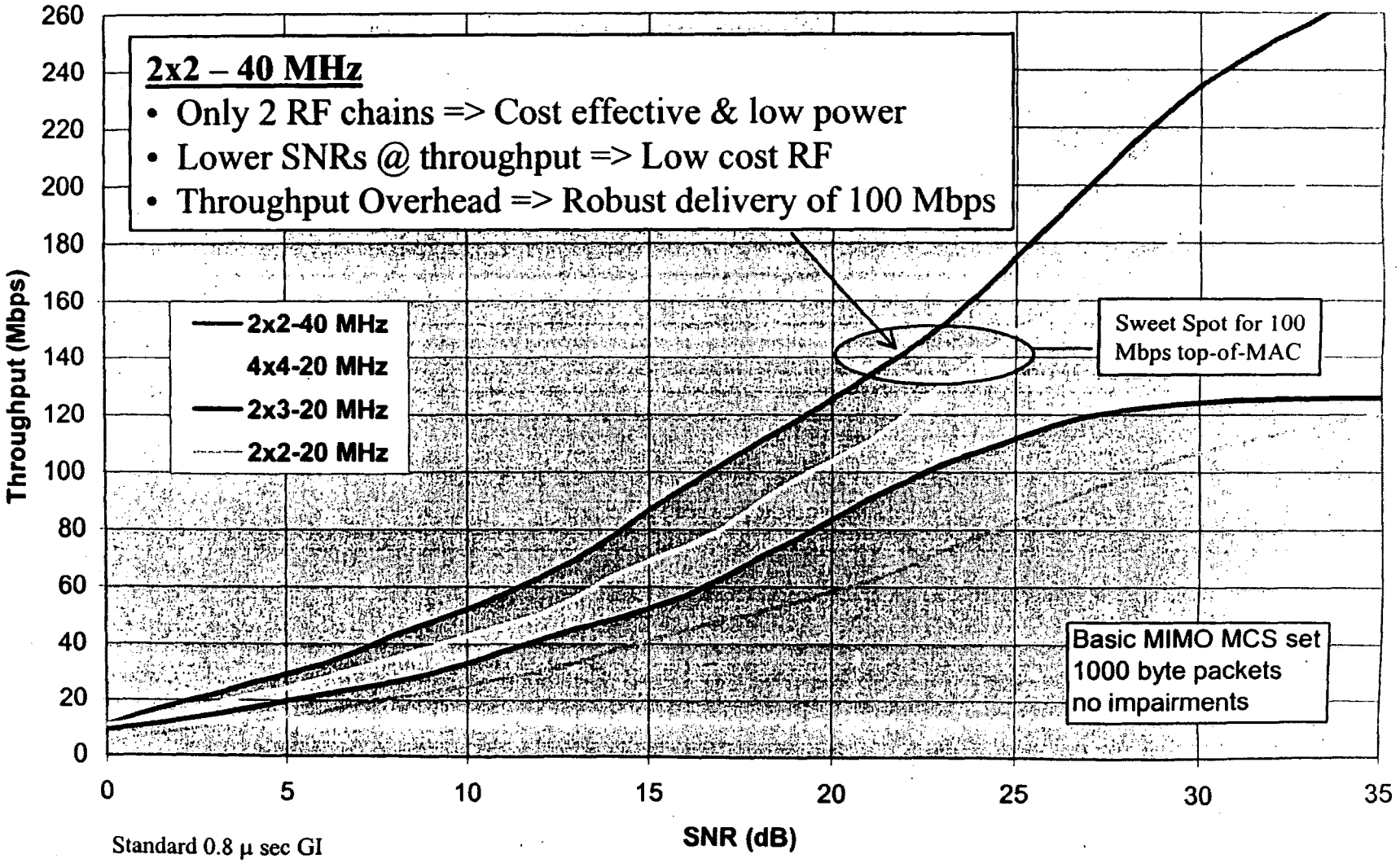
Basic MCS Set

Modulation	Code Rate	Data Rates* 20 MHz (Mbps) (1,2,3,4 spatial streams)	Data Rates* 40 MHz (Mbps) (1,2,3,4 spatial streams)
BPSK	1/2	6, 12, 18, 24	13.5, 27, 45.5, 54
QPSK	1/2	12, 24, 36, 48	27, 54, 81, 108
QPSK	3/4	18, 35, 54, 72	40.5, 81, 121.5, 162
16 QAM	1/2	24, 48, 72, 96	54, 108, 162, 216
16 QAM	3/4	36, 72, 108, 144	81, 162, 243, 324
64 QAM	2/3	48, 96, 144, 192	108, 216, 324, 432
64 QAM	3/4	54, 108, 162, 216	121.5, 243, 364.5, 486
64 QAM	7/8	63, 126, 189, 252	141.75, 283.5, 425.25, 567
+ Duplicate Format, BPSK R = ½ provides 6 Mbps for 40 MHz channels			

*** Optional short GI (0.4 μsec) increases rates by 11.1% for maximum data rate of 640 Mbps**

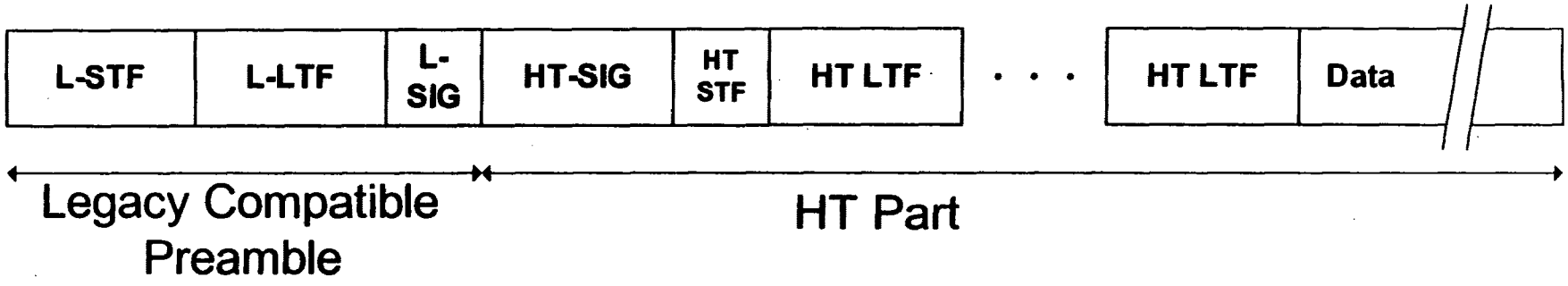
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Throughput Comparison Model D NLOS



Standard 0.8 μ sec GI

PPDU Format



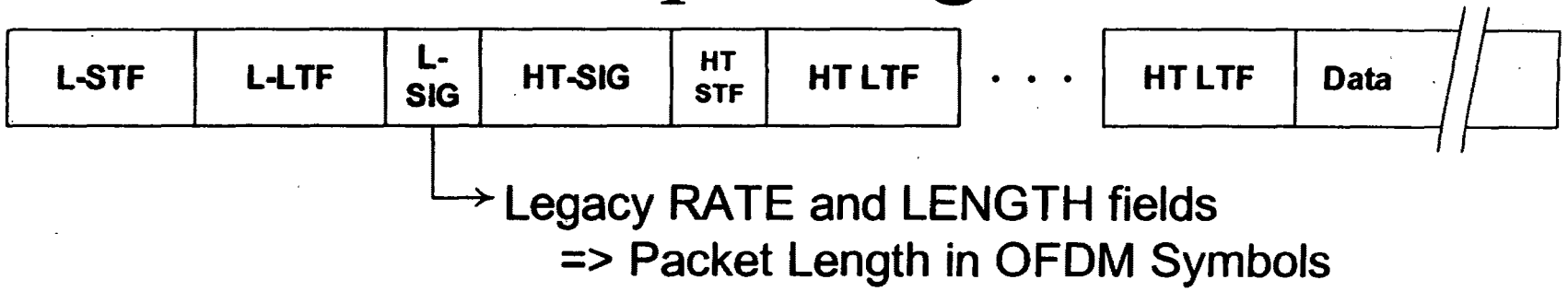
Legend

L- Legacy, HT- High Throughput
STF = Short Training Field
LTF = Long Training Field
SIG = Signal Field

Legacy Compatible

Can be decoded by ***any*** legacy 802.11a or g compliant device for interoperability

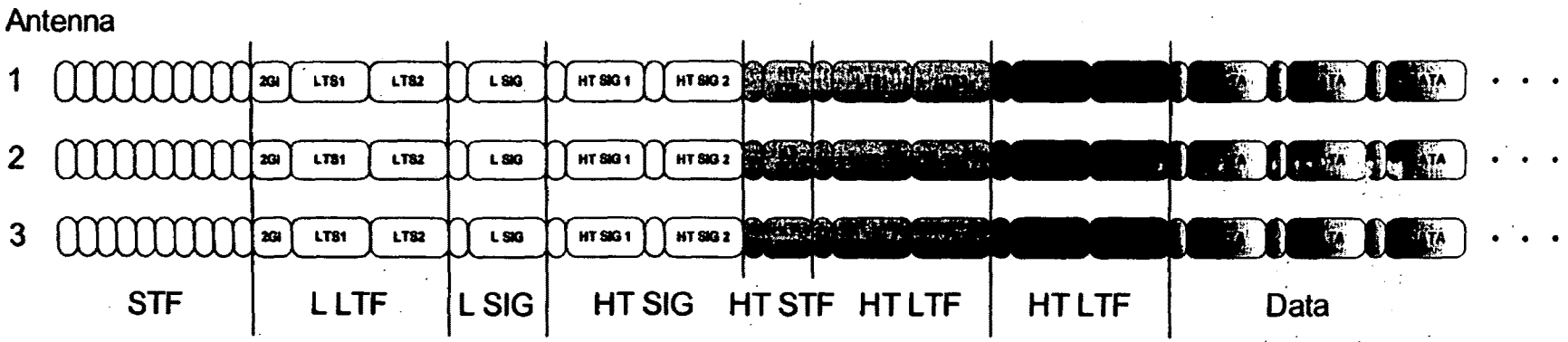
Spoofing



- RATE and LENGTH
  ⇒ PPDU length in OFDM symbols
- Spoofing
  - Spoofing means that the legacy RATE and LENGTH fields are falsely encoded in order to determine a specified length
  - L-SIG RATE = 6 Mbps ⇒ spoofing duration up to ~3 msec

Training Fields

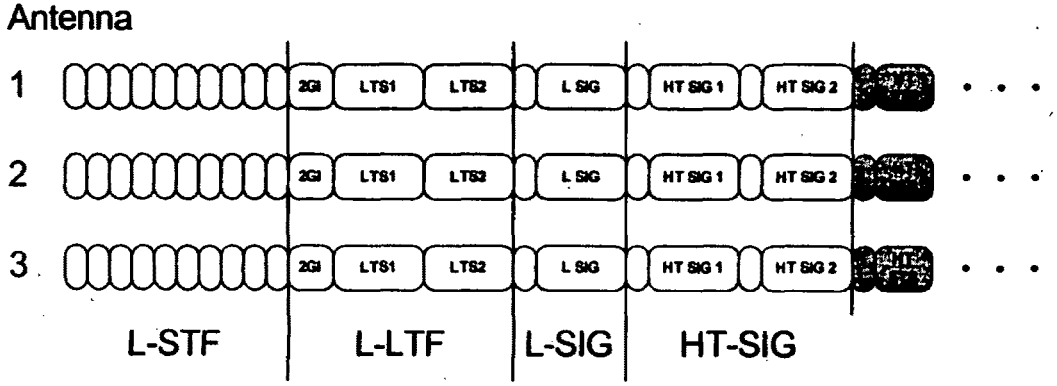
- Design priorities
  - Backward compatibility with 802.11a/g
  - Robust performance
  - Cost effective implementation
  - Low overhead



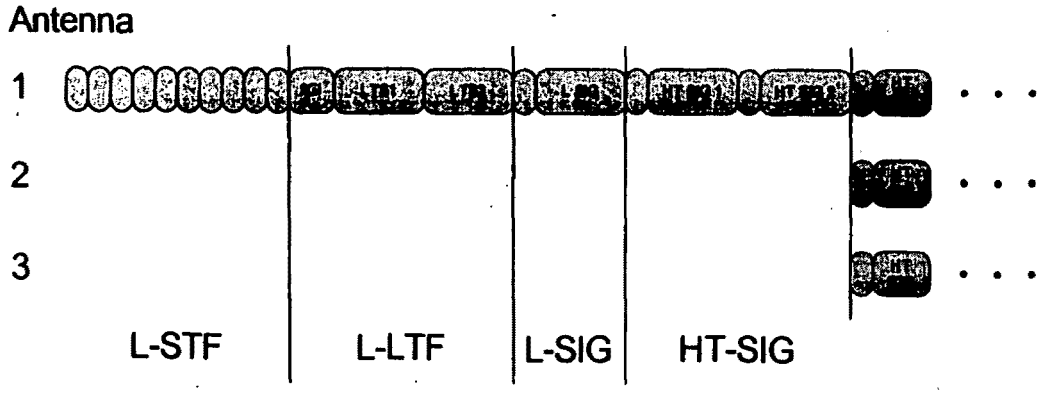
These space-time diagrams apply to both 20 and 40 MHz channels

Legacy Compatible Preamble

CDD



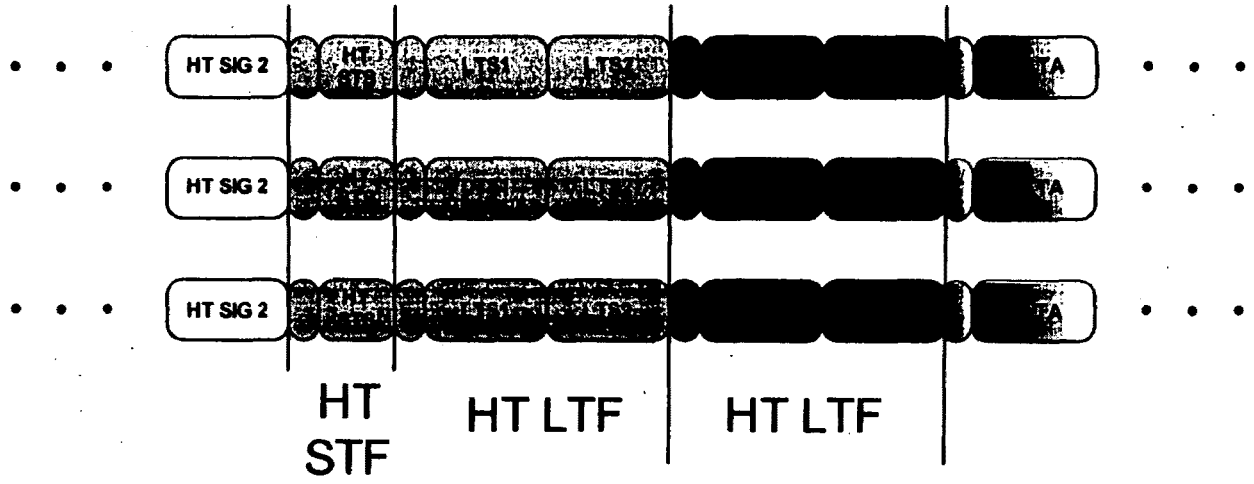
or single antenna



The L-STF, L-LTF, L-SIG and HT-SIG are transmitted as a single spatial stream. This may be either transmitted on all Tx antennas via a method such as Cyclic Delay Diversity (CDD), or on a single antenna. These are implementation options.

Requirement: These fields must be transmitted in an omni-directional mode that can be demodulated by legacy receivers.

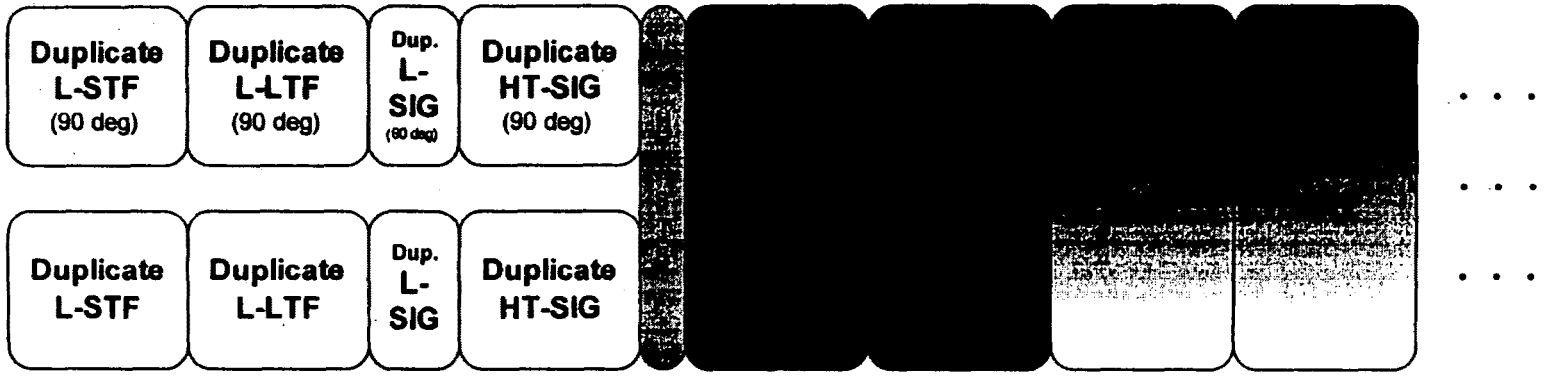
HT Training Fields



- HT-STF
  - Used for 2nd AGC
- HT-LTF
  - Used for MIMO channel estimation
  - Additional frequency or time alignment
- Tone interleaving of spatial streams

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40 MHz PPDU Format



- Duplicate format preamble
  - Provides interoperability with 20 MHz legacy STAs
  - Data, pilot and training tones in each 20 MHz subchannel are identical to corresponding 20 MHz format
  - 90 deg phase shift on upper sub-channel controls PAPR
- HT part
  - 108 data tones + 6 pilots
  - 3 center nulls (not shown)

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40/20 MHz Interoperability

- **20 MHz PPDU ⇒ 40 MHz receiver**
  - Combine modulation symbols from upper & lower sub-channels
  - 20 MHz PPDU in lower sub-channel
    - Zero combining weights in upper subchannel
    - No loss in performance relative to a 20 MHz receiver
  - Use differential sub-channel energy to detect 20 vs. 40 MHz signals
- **40 MHz PPDU ⇒ 20 MHz receiver**
  - One sub-channel is sufficient to decode the L-SIG
  - Detects only half of the 40 MHz signal
    ⇒ 3 dB performance penalty for 20 MHz clients
- See MAC slides for additional information on 40/20 inter-op

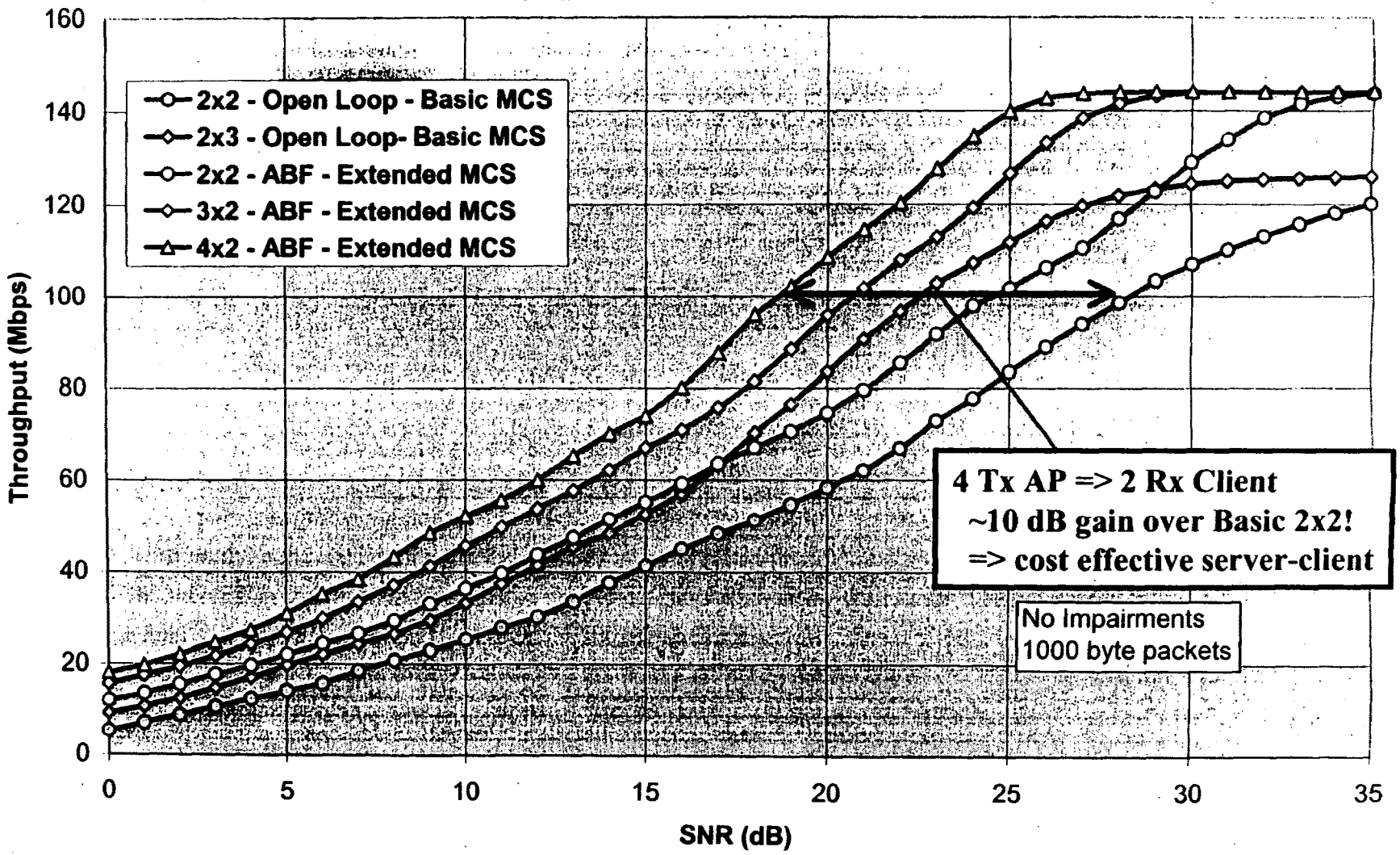
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Transmit Beamforming

- Basic Beamforming
  - Cost, complexity, and power consumption contained in the AP
    - Enterprise AP, media server AP, set-top box, or desktop PC
  - Very low overhead for BF receive only client
    - Low client cost, essentially zero overhead
    - Low power consumption – battery operated
  - Basic MCS set
  - Channel sounding PPDU provides capability to estimate the channel from all Tx antennas
  - Receiver does not need to know the beamforming specifics at the transmitter
  - Simple packet exchange for calibration
- Optional Advanced Beamforming (ABF)
  - Extended MCS Set
    - Provides independent modulation/coding across spatial streams
  - Support for unequal spatial stream power loading
  - Support for bi-directional beamforming

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ABF Throughput Comparison 20MHz, Model D NLOS

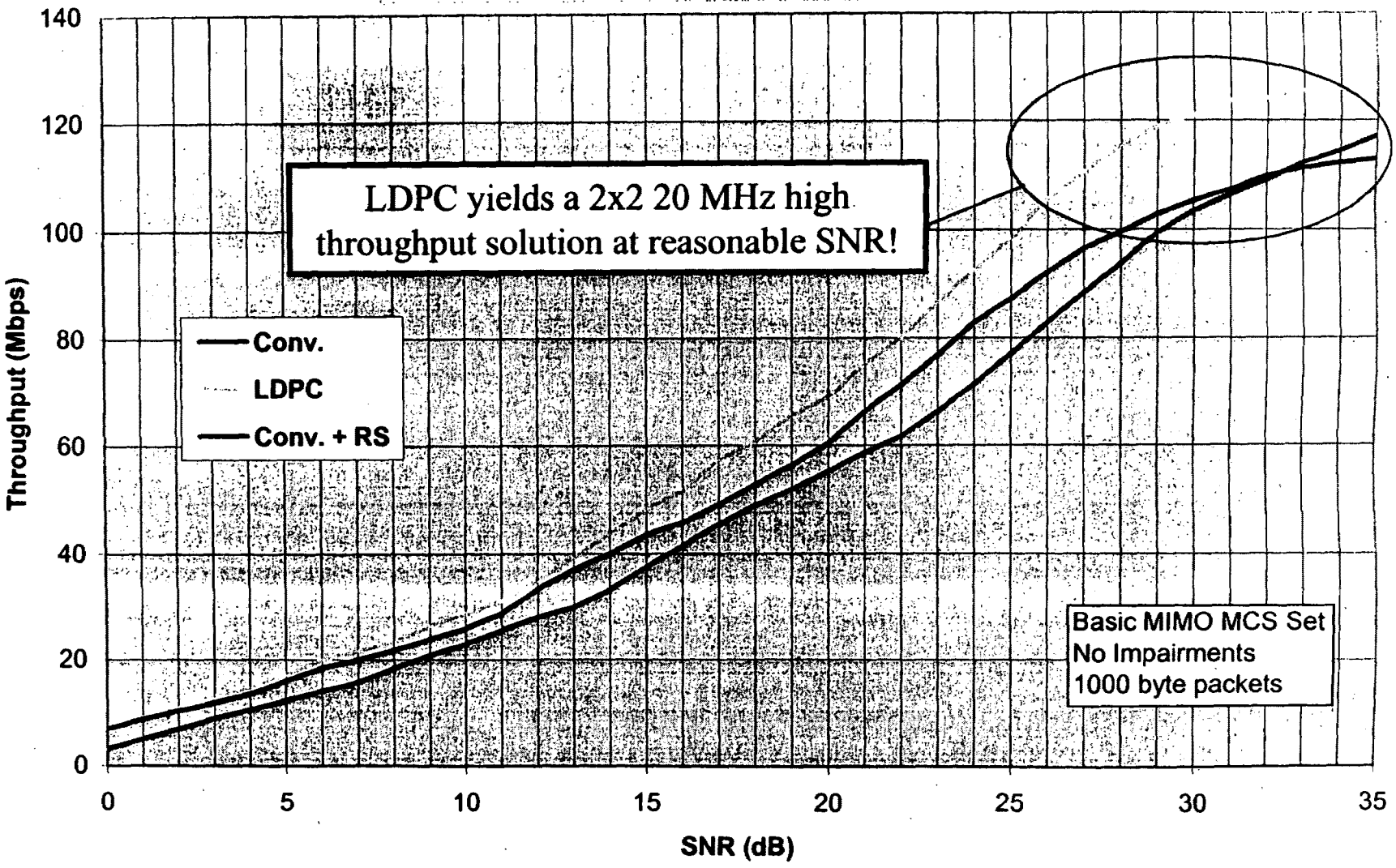


Optional Advanced Coding Modes

- Low Density Parity Check (LDPC)
  - Superior performance at high code rates (7/8)
- Reed-Solomon (RS)
  - Outer code concatenated with inner convolutional code
  - Very low cost, mature technology

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Adv. Coding Throughput Comparison
2x2, 20MHz, Model D NLOS

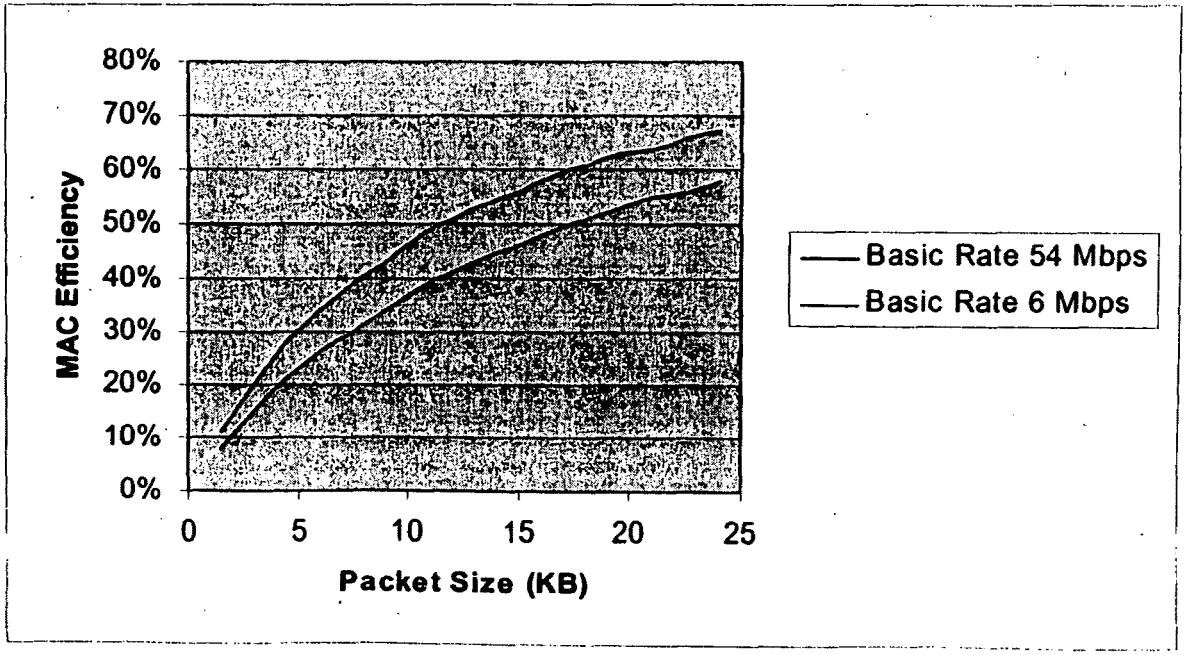


MAC

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MAC Challenges in HT Environment

- HT requires an improvement in MAC Efficiency
- HT requires effective Rate Adaptation
- HT requires Legacy Protection



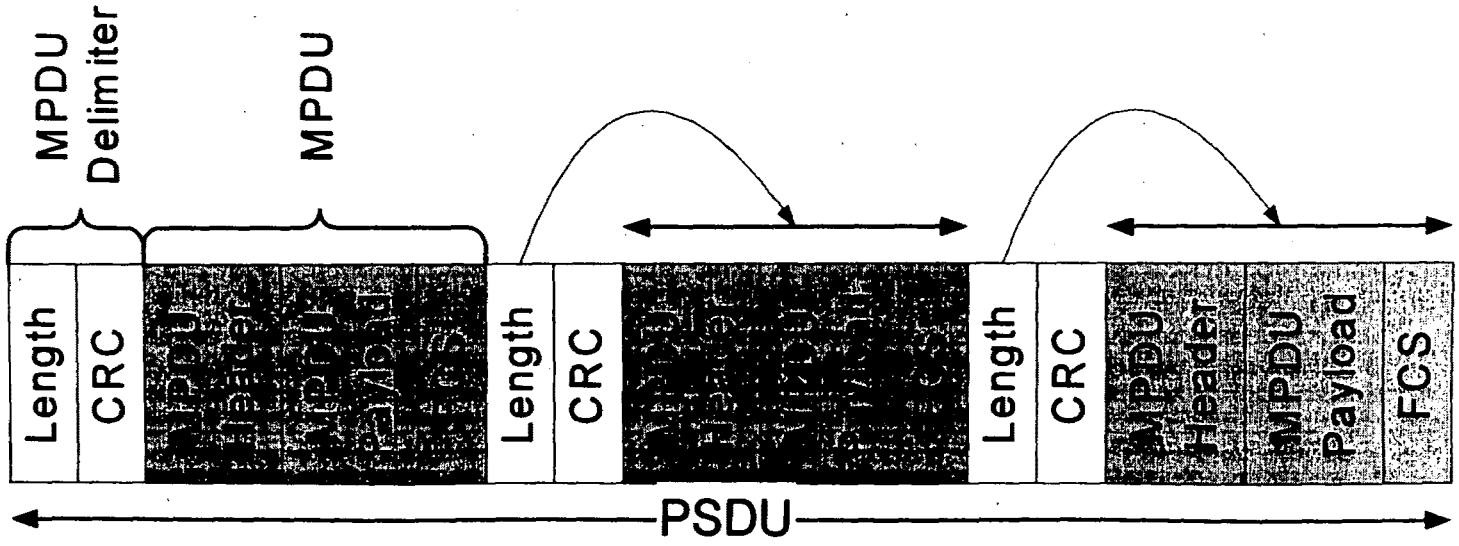
New MAC Features

- Aggregation Format
- Aggregation Exchanges
  - Protocol for training
  - Protocol for reverse direction data
  - Single and multiple responder
- Header Compression
- Protection Mechanisms
- Coexistence & Channel Management
- MIMO Power Management

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Aggregation Framing

- Robust Structure
- Aggregation Framing is a purely-MAC function (PHY has no knowledge of MPDU boundaries)



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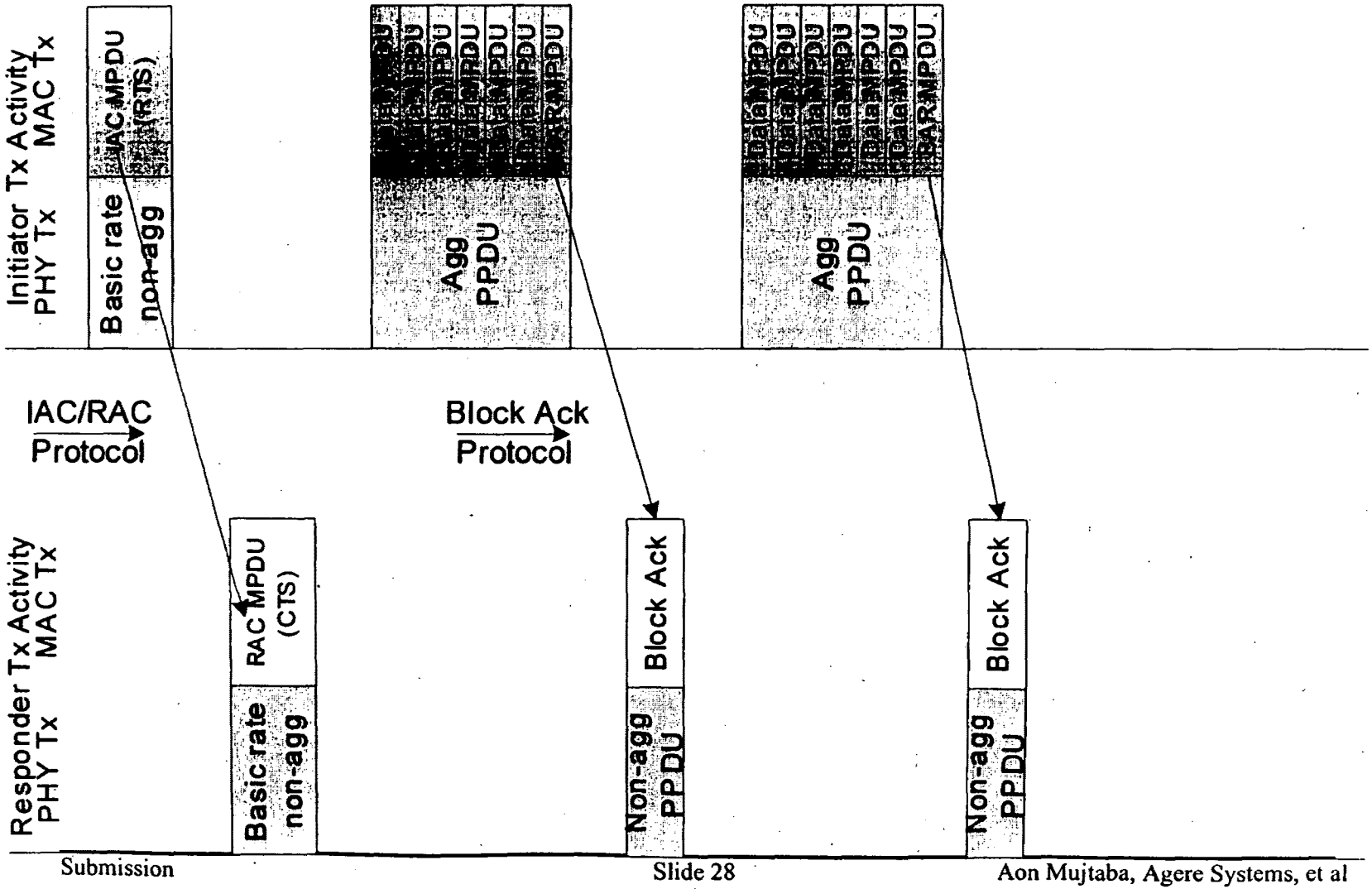
Aggregate Exchange Sequences

- MPDU or frame exchange sequences now extended to aggregate exchange sequences in which groups of frames are exchanged "at a time"
  - Allows effective use of Aggregate Feature
  - Allows control, data and acknowledgement to be sent in the same PPDU
- An initiator sends a PPDU and a responder may transmit a response PPDU
  - Either PPDU can be an aggregate

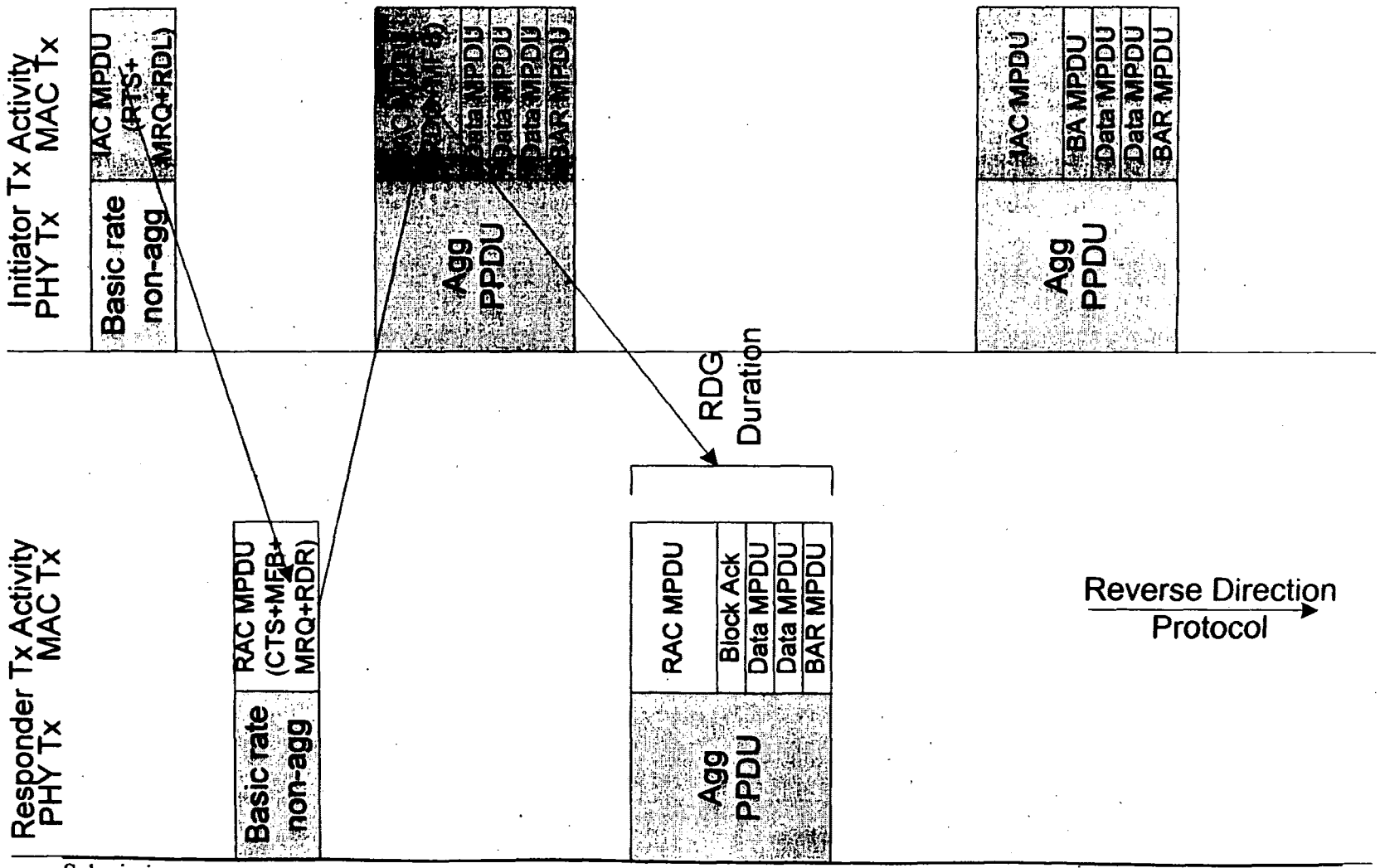
("Initiator" / "responder" are new terms relating to roles in aggregate exchange protocol)

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Basic Aggregate Exchange

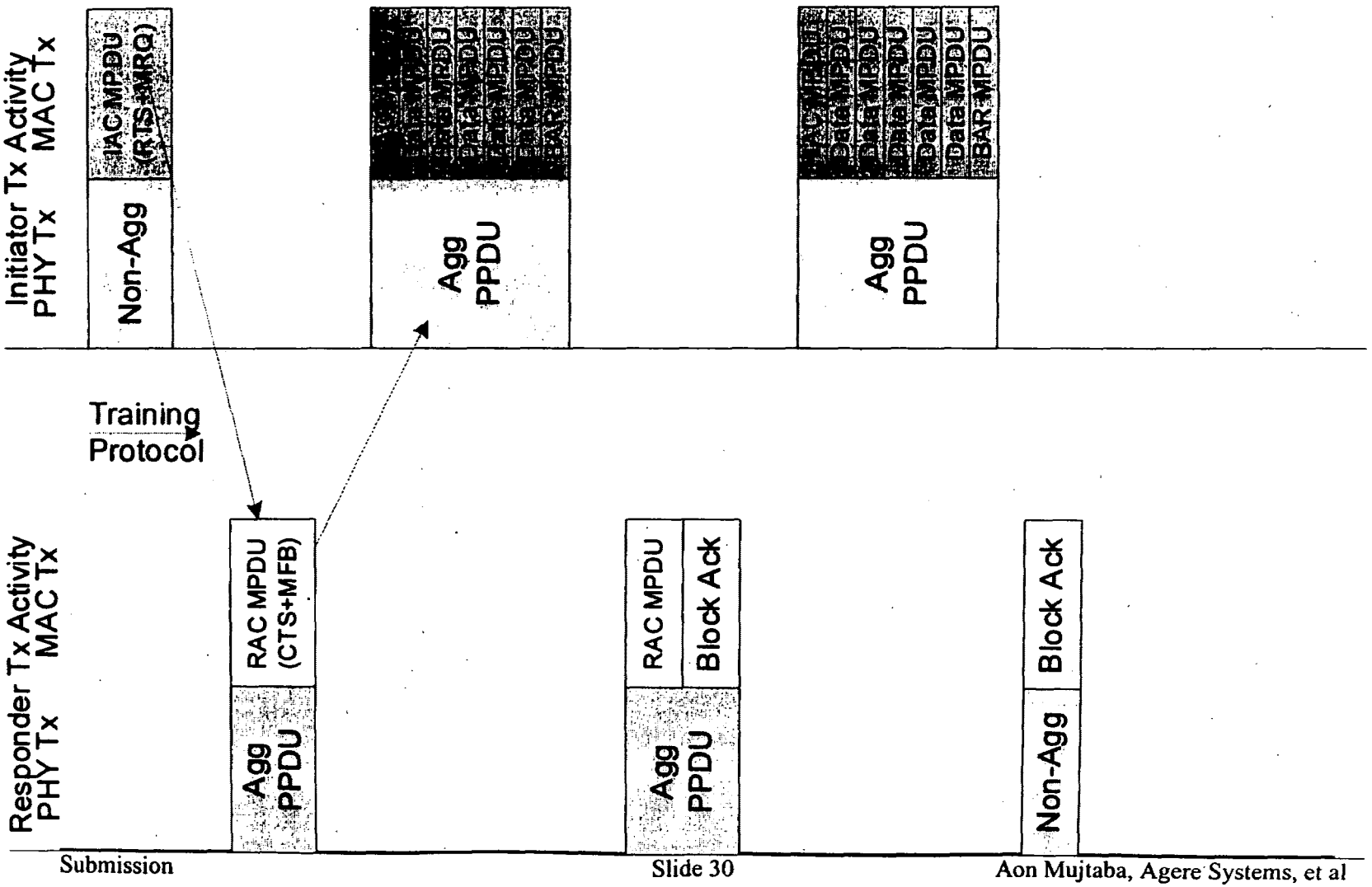


Reverse Direction Protocol



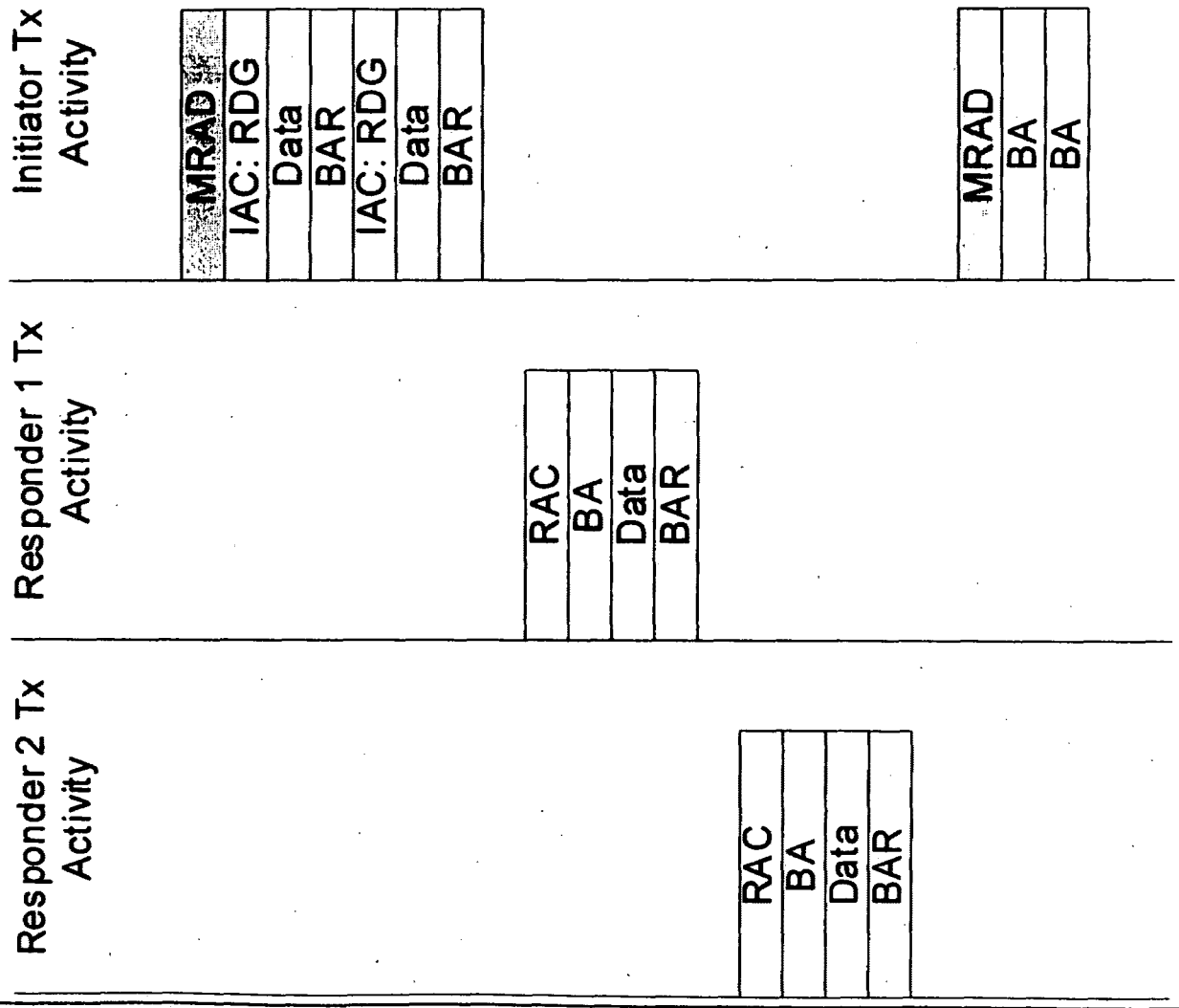
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Training Protocol



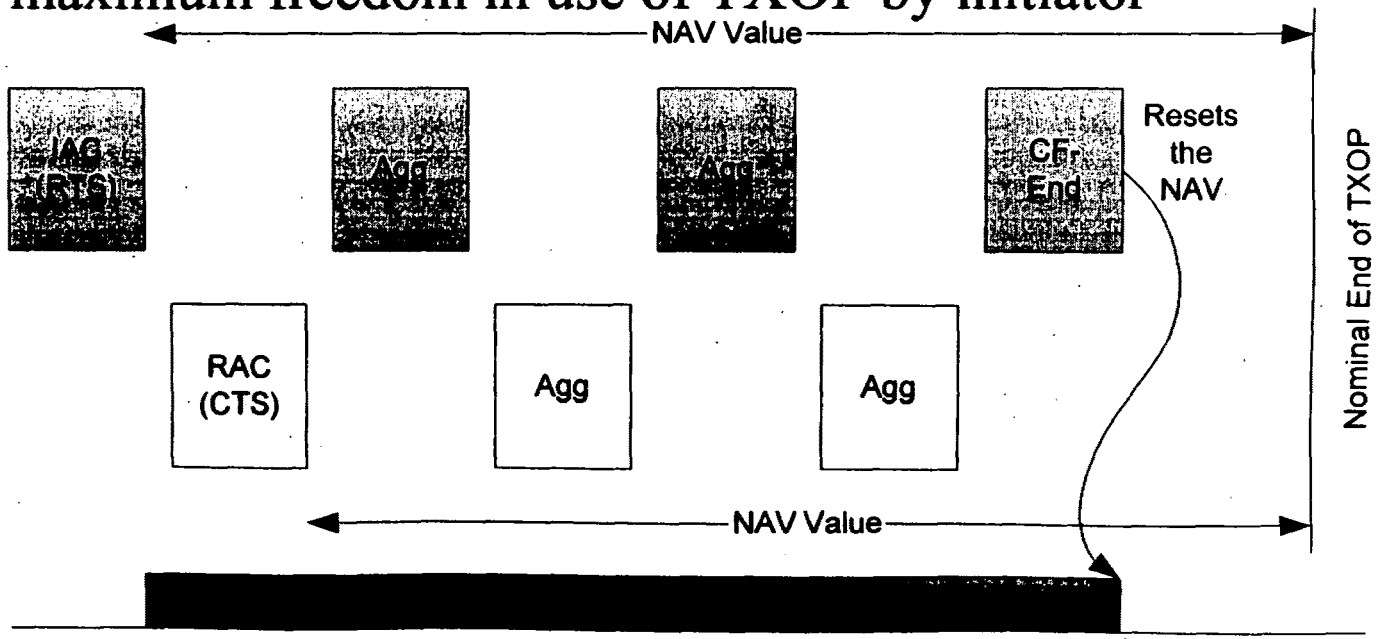
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Periodic Multi-Receiver Aggregation



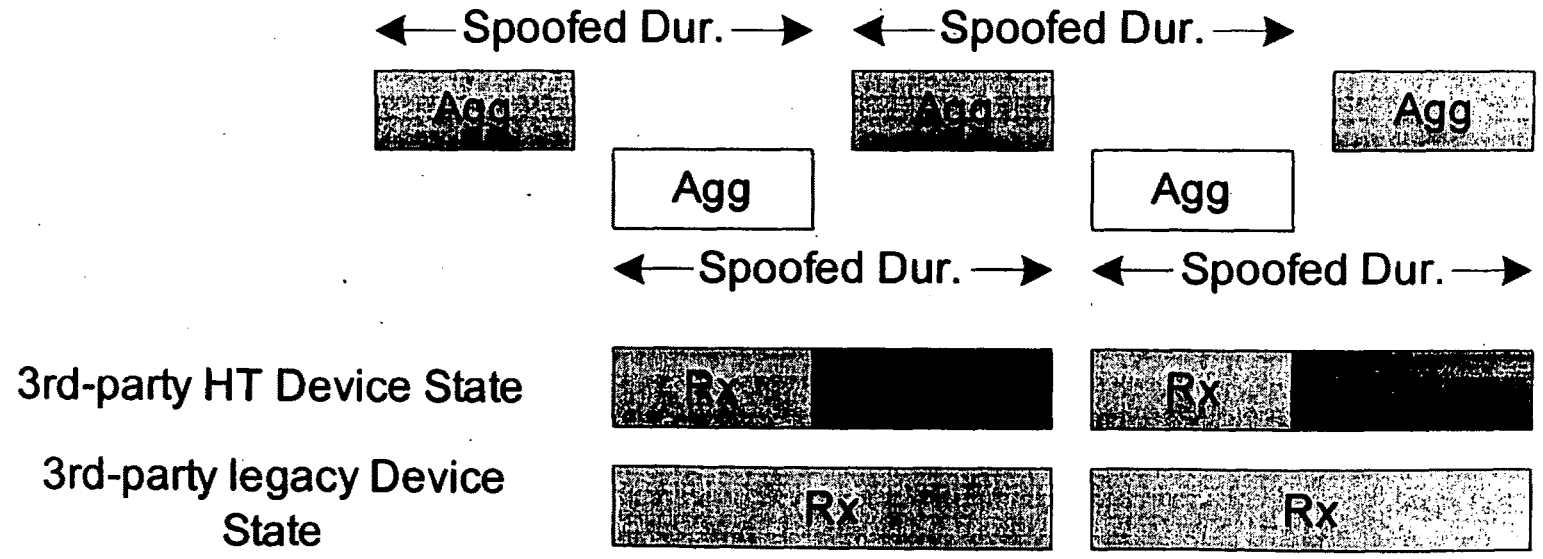
LongNAV protection

- Provides protection of a sequence of multiple PPDUs
- Provides a solution for .11b
- Comes "for free" with polled TXOP
- Gives maximum freedom in use of TXOP by initiator



Pairwise Spoofing Protection

- Protects pairs of PPDUs (current and following)
- Very low overhead, suitable for short exchanges
- Places Legacy devices into receiving mode for spoofed duration
- Spoofing is interpreted by HT devices as a NAV setting

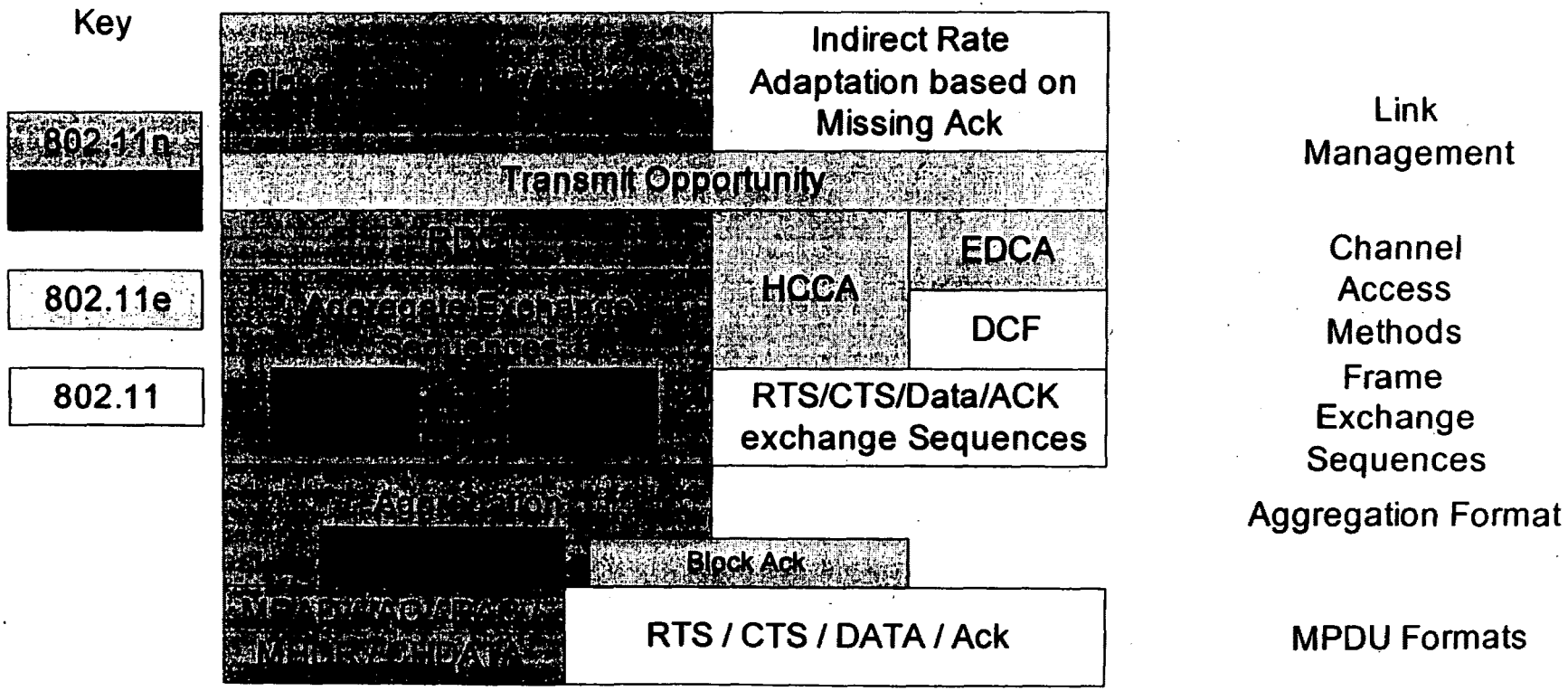


Operating Mode Selection

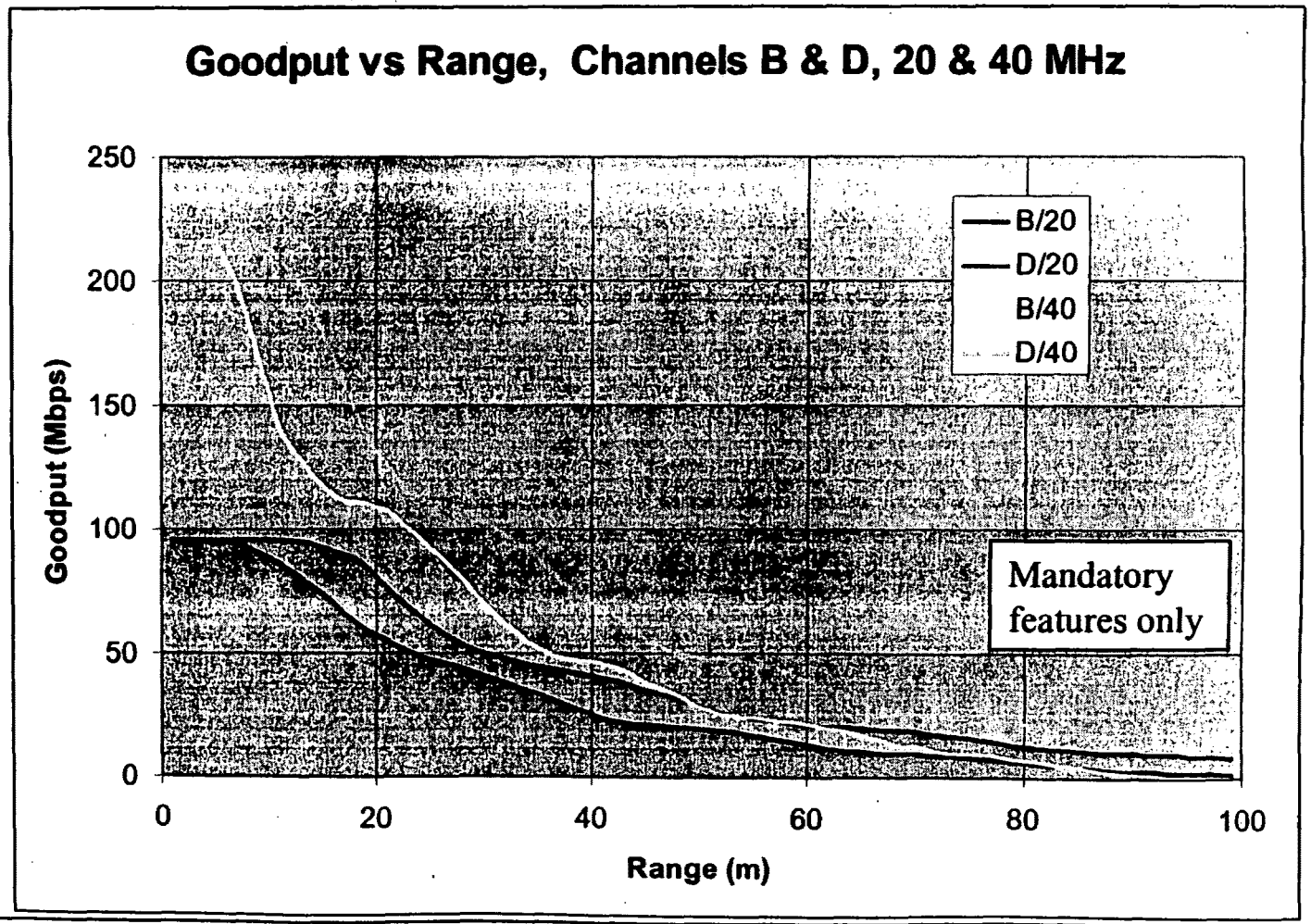
- BSS operating mode controls the use of protection mechanisms and 40/20 width switching by HT STA
  - Supports mixed BSS of legacy + HT devices
- HT AP-managed modes
  - If only the control channel is overlapped, managed mixed mode provides a low overhead alternative to mixed mode
  - If both channels are overlapped, 20 MHz base mode allows an HT AP to dynamically switch channel width for 40 MHz-capable HT STA

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MAC Architecture



CC 28/29 Performance



MAC Selected CC Performance

CC#	Name	Result	HCCA	
			2x2x20	2x2x40
CC3	List of goodput results for usage models 1, 4 and 6.	SS1 (Mbps)	55.2	76.8
		SS4	45.1	74.1
		SS6	44.9	62.1
CC18	HT Usage Models Supported (non QoS)	SS1 (Mbps/ratio)	2.76/0.09	24.4/0.8
		SS4	36.0/0.07	65.0/0.14
		SS6	0.1/0.005	17.24/0.86
CC19	HT Usage Models Supported (QoS)	SS1	17/17	17/17
		SS4	18/18	18/18
		SS6	39/39	39/39
CC58	HT Spectral Efficiency	bps/Hz	5.4	6.075

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WWiSE IEEE 802.11n Proposal

Best Available Copy

September 16, 2004

Airgo Networks, Bermai, Broadcom, Conexant, Realtek,
STMicroelectronics, Texas Instruments

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Contents

- **WWiSE approach**
- **Overview of key features**
- **Proposal description**
  - **Physical layer design**
  - **MAC features**
- **Discussion**
- **Summary**

The WWiSE approach

- WWiSE = World Wide Spectrum Efficiency

- The partnership was formed to develop a specification for next generation WLAN technology suitable for worldwide deployment
- Mandatory modes of the WWiSE proposal comply with current requirements in all major regulatory domains: Europe, Asia, Americas
- Proposal design emphasizes compatibility with existing installed base, building on experience with interoperability in 802.11g and previous 802.11 amendments
- All modes are compatible with QoS and 802.11e
- Maximal spectral efficiency translates to highest performance and throughput in all modes

The WWiSE approach, contd.

One solution applicable to all markets

"Synergy and mutual reinforcement is only possible if the following conditions are met:

- *The same HT technology is able to function in all three markets and environments [home, enterprise, hotspot]– this enhances the utility of HT for the users*
- *... "*

  – Wi-Fi Alliance MRD for High Throughput Technology, Nov. 2003 (doc. 11-03/879r2)

Overview of key mandatory features

- The WWiSE proposal's mandatory modes are:
  - 2 transmit antennas
  - 20 MHz operation
  - 135 Mbps maximum PHY rate
  - 2x1 transmit diversity modes, 20 MHz
  - Mixed mode preambles enabling on-the-air legacy compatibility
  - Efficient greenfield preambles – no increase in length over legacy
  - Enhanced efficiency MAC mechanisms
  - All components based on enhancement of existing COFDM PHY

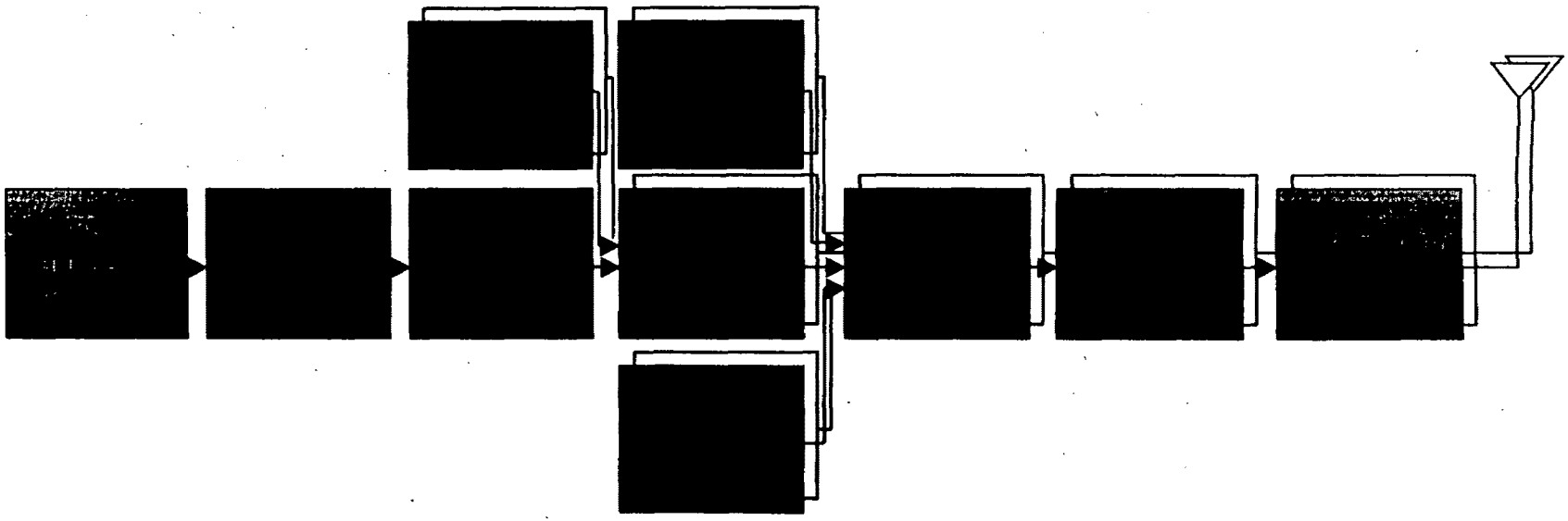
2x2 MIMO operation in a 20 MHz channel: Goal is a robust, efficient, small-form-factor, universally compliant 100 Mbps mode that fits naturally with the existing installed base

Overview of key optional features

- The WWiSE proposal's optional modes are:
  - 3 and 4 transmit antennas
  - 40 MHz operation
  - Up to 540 Mbps PHY rate
  - 2x1, 3x2, 4x2, 4x3 transmit diversity modes
  - Advanced coding: Rate-compatible LDPC code

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Transmitter block diagram



Unified format

Code rate	Cyclic prefix, ns	Code	Constellation
1/2	800	BCC, LDPC	16-QAM
3/4	800	BCC, LDPC	16-QAM
2/3	800	BCC, LDPC	64-QAM
3/4	800	BCC, LDPC	64-QAM
5/6	800	BCC, LDPC	64-QAM

All combinations of 2, 3, 4 transmit antennas and 20/40 MHz offer exactly these 5 modes

All 20 MHz modes have 54 data subcarriers, 2 pilots.
All 40 MHz modes have 108 data subcarriers, 4 pilots

Advantages of unified format

- Minimization of cost:
  - Development time, testing of modes, and interoperability are significant sources of cost
  - A unified basic plan simplifies these tasks
- Market acceptance and growth
  - Faster time to market
  - The most straightforward scalability
- Rate selection and management:
  - One basic plan across all antenna configurations and bandwidths

2 transmitter SDM, 20 MHz (mandatory)

PHY rate	Data carriers	Pilots	Code rate	Cyclic prefix, ns	Code	Constellation
54 Mbps	54	2	1/2	800	BCC	16-QAM
81 Mbps	54	2	3/4	800	BCC	16-QAM
108 Mbps	54	2	2/3	800	BCC	64-QAM
121.5 Mbps	54	2	3/4	800	BCC	64-QAM
135 Mbps	54	2	5/6	800	BCC	64-QAM

2x1 modes, 20 MHz (mandatory)

PHY rate	Data carriers	Pilots	Code rate	Cyclic prefix, ns	Code	Constellation
6.75 Mbps	54	2	1/2	800	BCC	BPSK
10.125 Mbps	54	2	3/4	800	BCC	BPSK
13.5 Mbps	54	2	1/2	800	BCC	QPSK
20.25 Mbps	54	2	3/4	800	BCC	QPSK
27 Mbps	54	2	1/2	800	BCC	16-QAM
40.5 Mbps	54	2	3/4	800	BCC	16-QAM
54 Mbps	54	2	2/3	800	BCC	64-QAM
60.75 Mbps	54	2	3/4	800	BCC	64-QAM

Optional data modes

- 20 MHz:
  - 3 Tx space-division multiplexing
  - 4 Tx space division multiplexing
  - 3x2, 4x2, 4x3 space-time transmit diversity
- 40 MHz: (all 40 MHz modes optional)
  - 1 Tx antenna
  - 2 Tx space division multiplexing
  - 3 Tx space division multiplexing
  - 4 Tx space division multiplexing
  - 2x1, 3x2, 4x2, 4x3 space-time transmit diversity
- LDPC code option
  - An option in all proposed MIMO configurations and channel bandwidths

Optional mode data rates

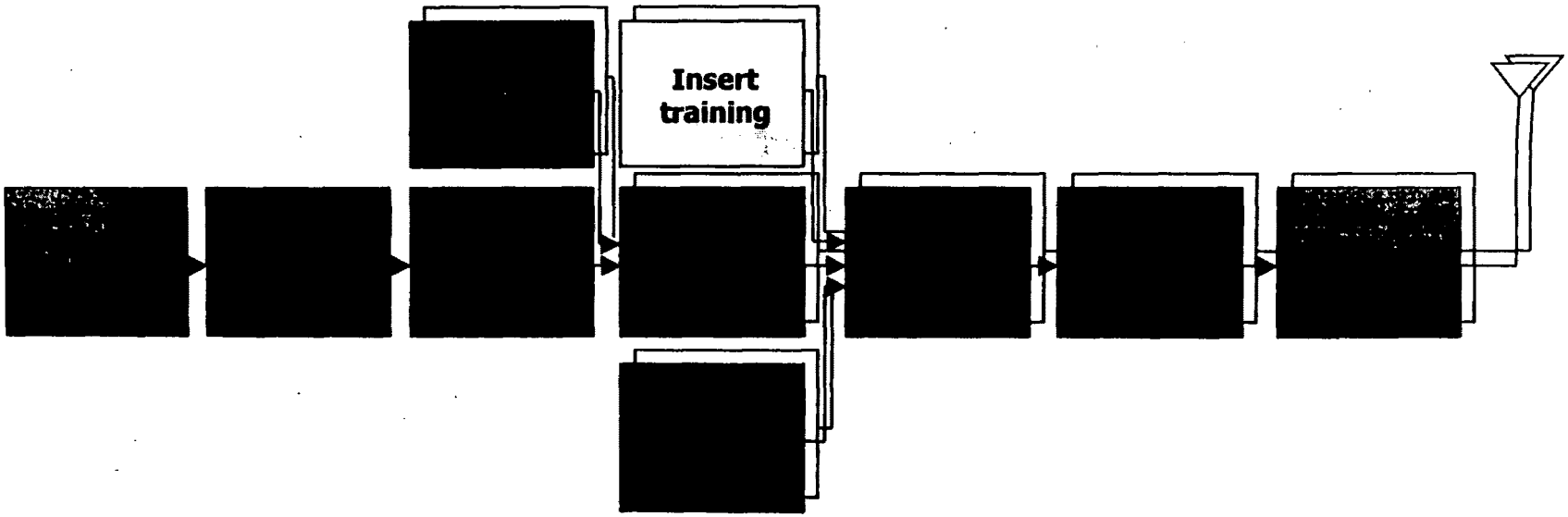
20 MHz:

Configuration	*Rate ½, 16-QAM*	*Rate ¾, 16-QAM*	*Rate 2/3, 64-QAM*	*Rate ¾, 64-QAM*	*Rate 5/6, 64-QAM*
3 Tx, 20 MHz	81	121.5	162	182.25	202.5
4 Tx, 20 MHz	108	162	216	243	270

40 MHz:

Configuration	*Rate ½, 16-QAM*	*Rate ¾, 16-QAM*	*Rate 2/3, 64-QAM*	*Rate ¾, 64-QAM*	*Rate 5/6, 64-QAM*
1 Tx, 40 MHz	54	81	108	121.5	135
2 Tx, 40 MHz	108	162	216	243	270
3 Tx, 40 MHz	162	243	324	364.5	405
4 Tx, 40 MHz	216	364	432	486	540

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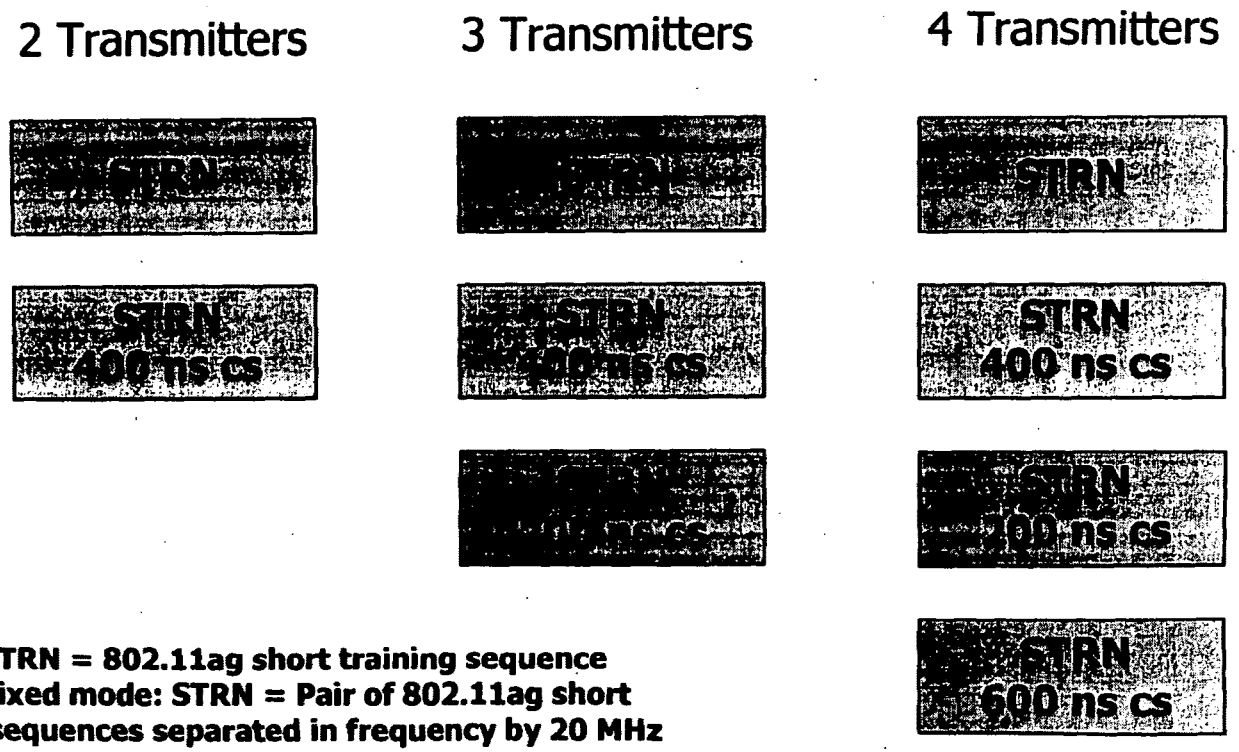

Insert
training

Preambles

- Mixed-mode preambles:
  - Capable of operation in presence of legacy 11a/g devices
  - Ensure correct deferral behavior by devices compliant to legacy spec
- Green-field preambles:
  - Operate in time interval or environment with only 11n devices on the air
  - May be used with protection mechanisms, *as in 11g*, or with new burst mode; or in 11n-only BSS
  - Greater efficiency than mixed-mode preambles

Both preamble types are derived from a common basic structure, providing reuse in algorithms

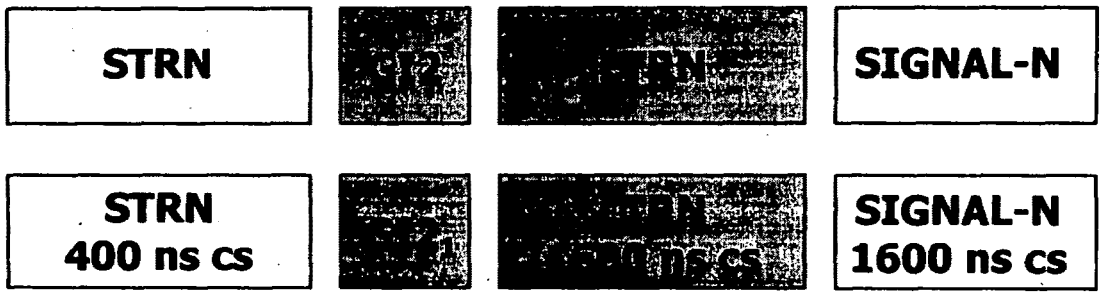
Short training sequence



20 MHz: STRN = 802.11ag short training sequence
40 MHz mixed mode: STRN = Pair of 802.11ag short sequences separated in frequency by 20 MHz
40 MHz green field: STRN = Newly defined sequence

cs = Cyclic shift

Long training sequence and SIGNAL-N, green-field, 2 transmitters

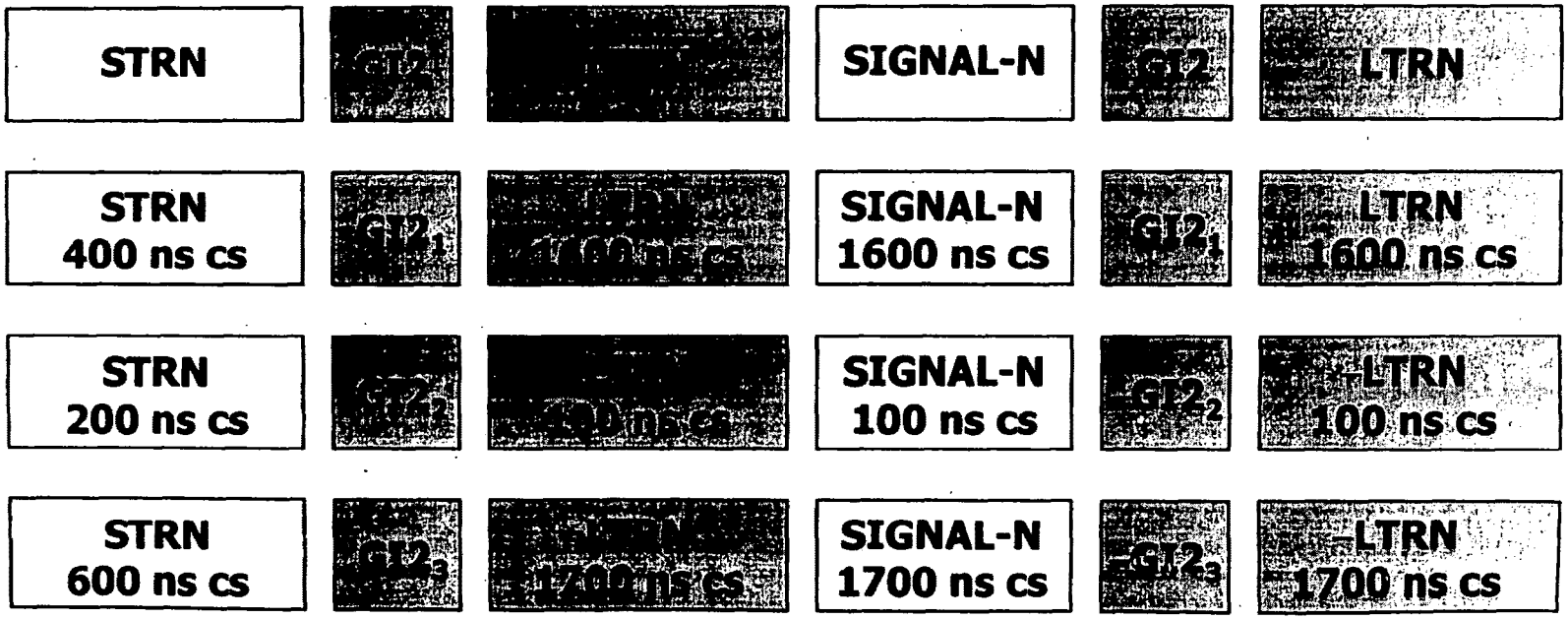


20 MHz: LTRN = 802.11ag long training sequence with four extra tones, 6.4 usec
40 MHz: LTRN = Newly defined sequence, 6.4 usec

$GI2_1$ = GI2 for LTRN with 1600 ns cyclic shift

SIGNAL-N = 54 bits, 4 usec

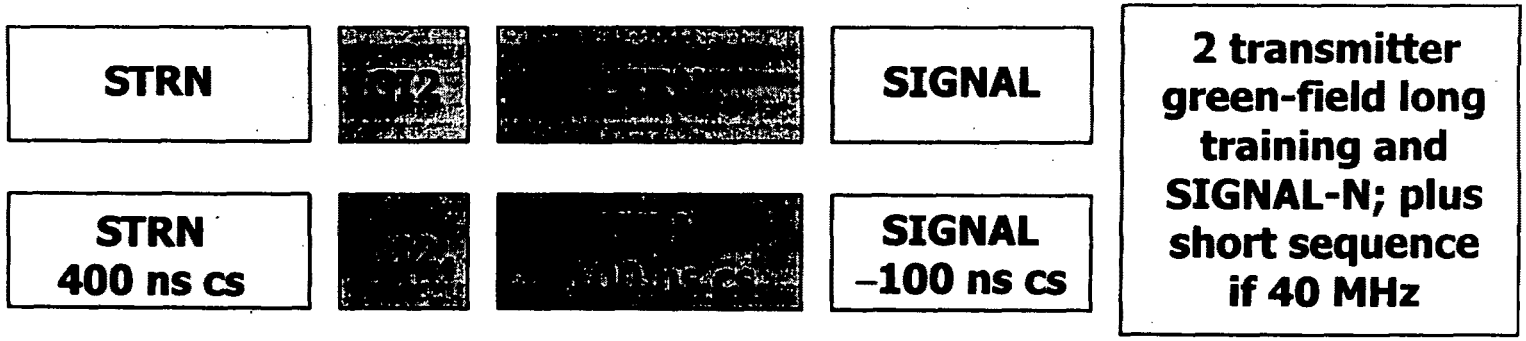
Long training sequence and SIGNAL-N, green-field, 3 and 4 transmitters



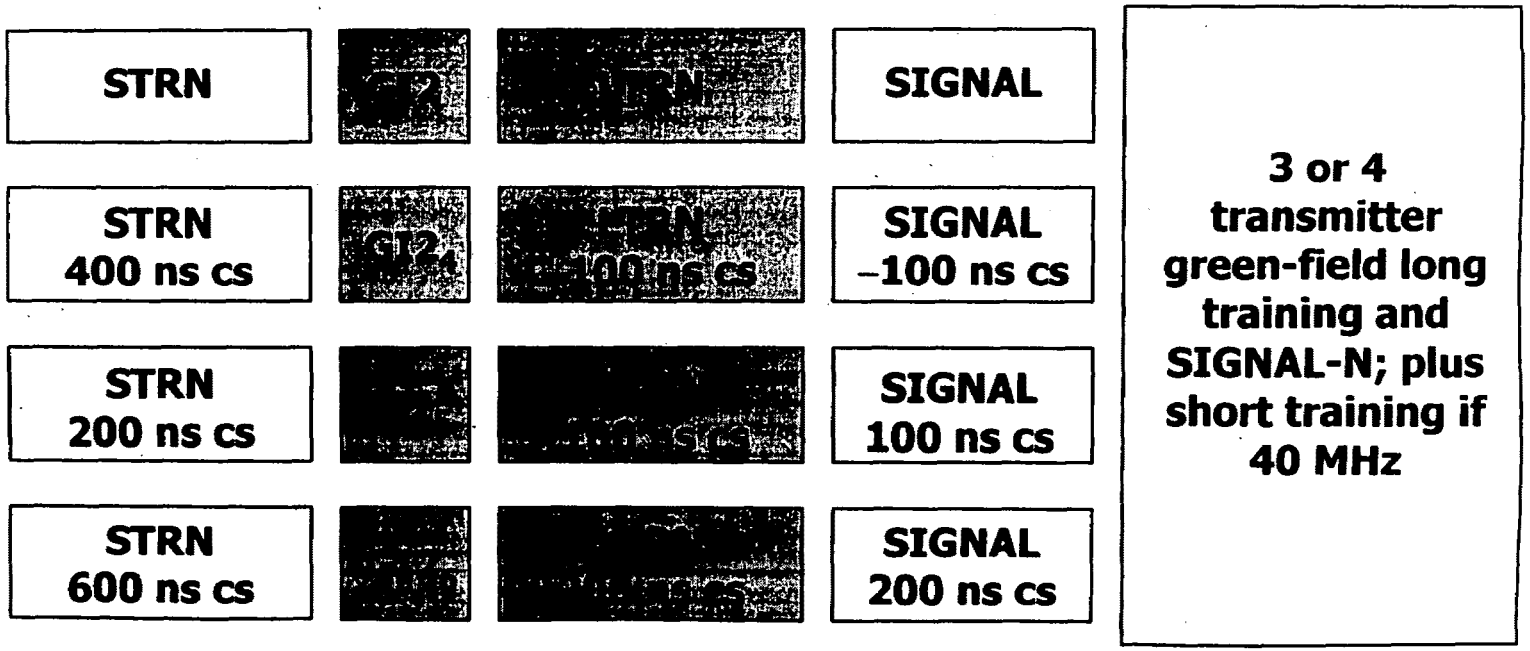
For 3 transmitters, the first three rows are used

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Long training and SIGNAL fields, mixed mode, 2 transmitters



Long training and SIGNAL fields, mixed mode, 3 and 4 transmitters



For 3 transmitters, the first three rows are used

Preamble lengths (20 & 40 MHz)

Green-field

Configuration	Short	First long	SIGNAL	Second long	Total
1x1	8	8	4	0	**20**
2x2	8	8	4	0	**20**
3x3	8	8	4	8	**28**
4x4	8	8	4	8	**28**

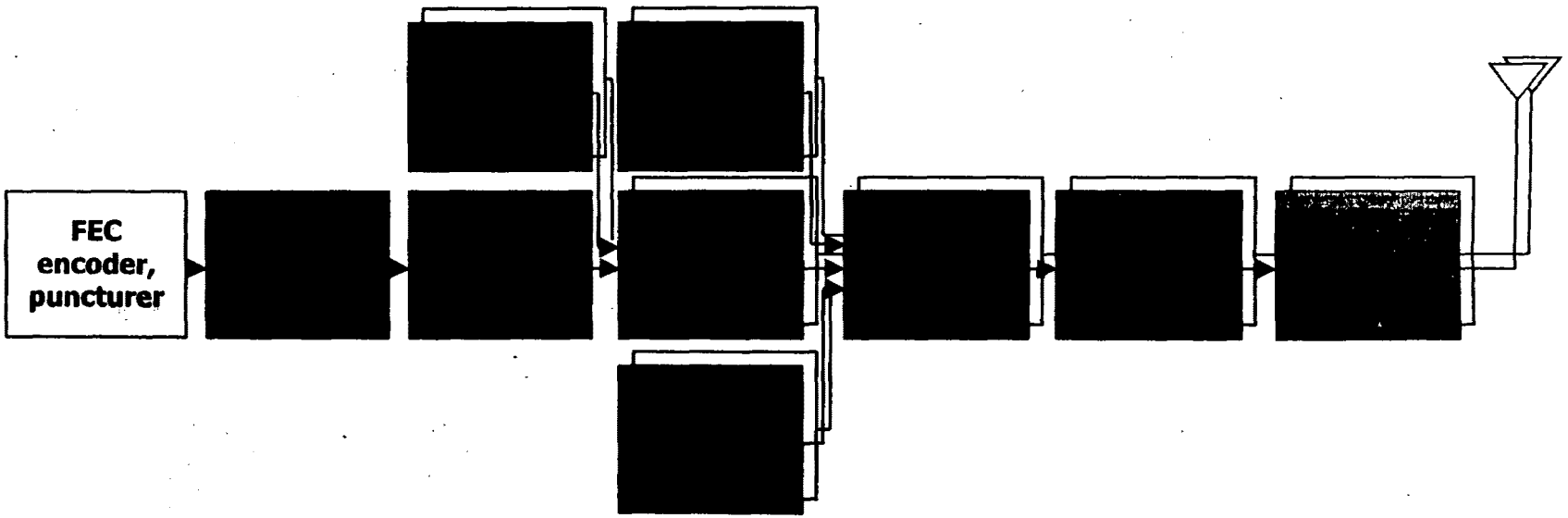
All space-time block codes follow the pattern with the same number of transmit antennas

Preamble lengths (20 & 40 MHz), contd.

Mixed mode

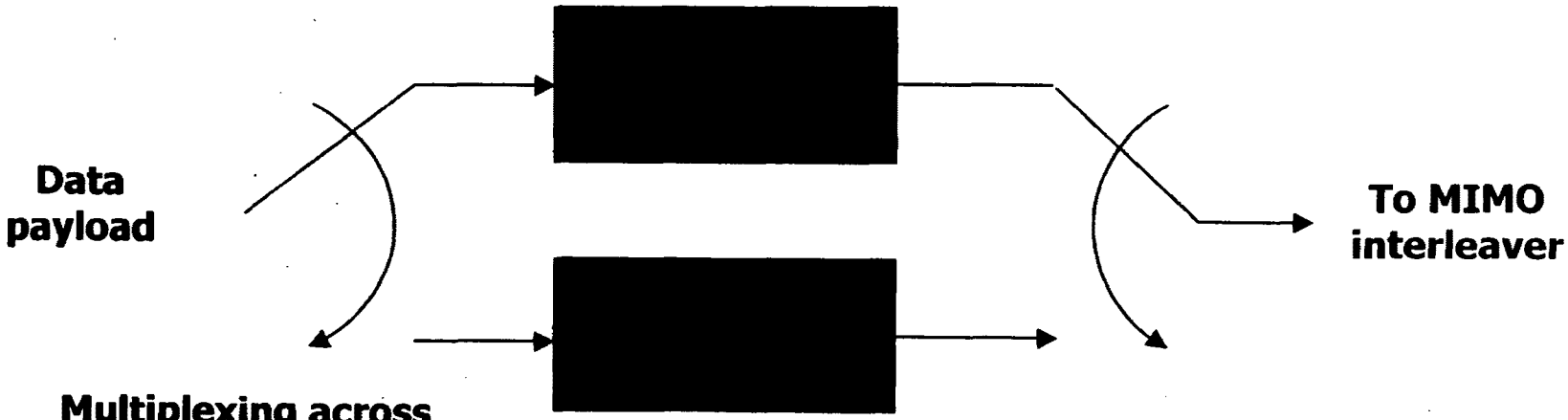
Configuration	Short	First long	SIGNAL	Second short	Second long	Second SIGNAL	Third long	Total
1x1	8	8	4	–/8	8	4	0	**–/40**
2x2	8	8	4	0/8	8	4	0	**32/40**
3x3	8	8	4	0/8	8	4	8	**40/48**
4x4	8	8	4	0/8	8	4	8	**40/48**

All space-time block codes follow the pattern with the same number of transmit antennas


FEC
encoder,
puncturer

Parallel encoders

- For 40 MHz modes with more than two spatial streams, two parallel BCC encoders are used:



Advanced coding option

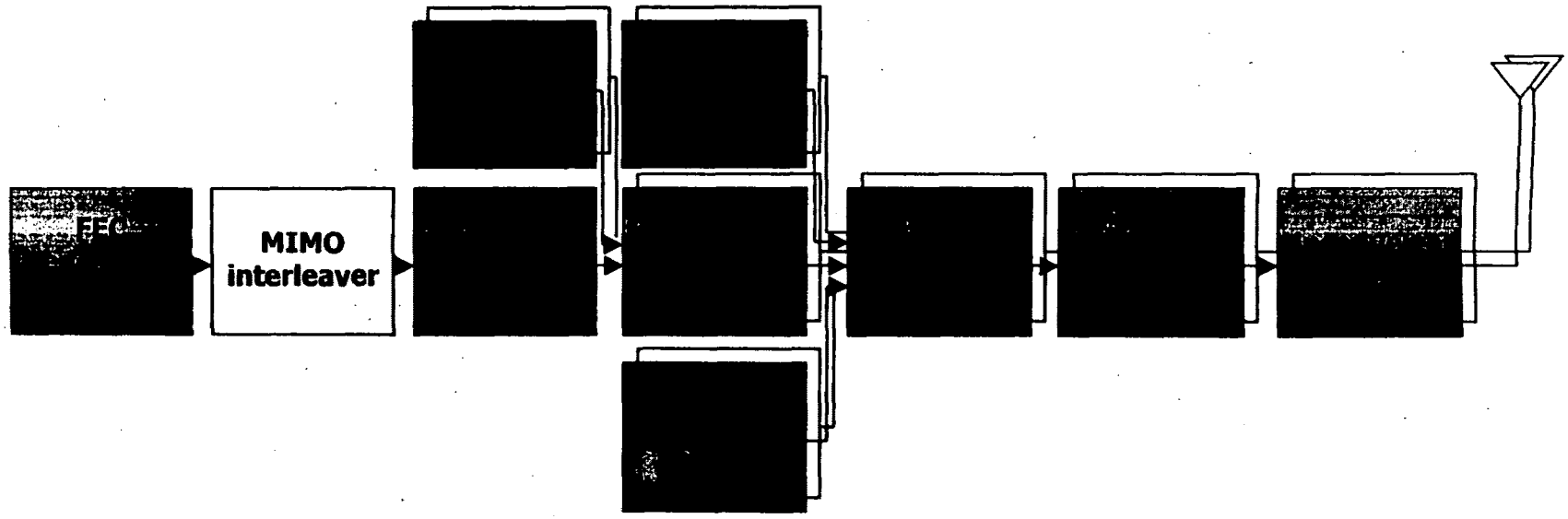
- Rate-compatible LDPC code with the following parameters:

Rate	Information bits	Block length
1/2	972	1944
2/3	1296	1944
3/4	1458	1944
5/6	1620	1944

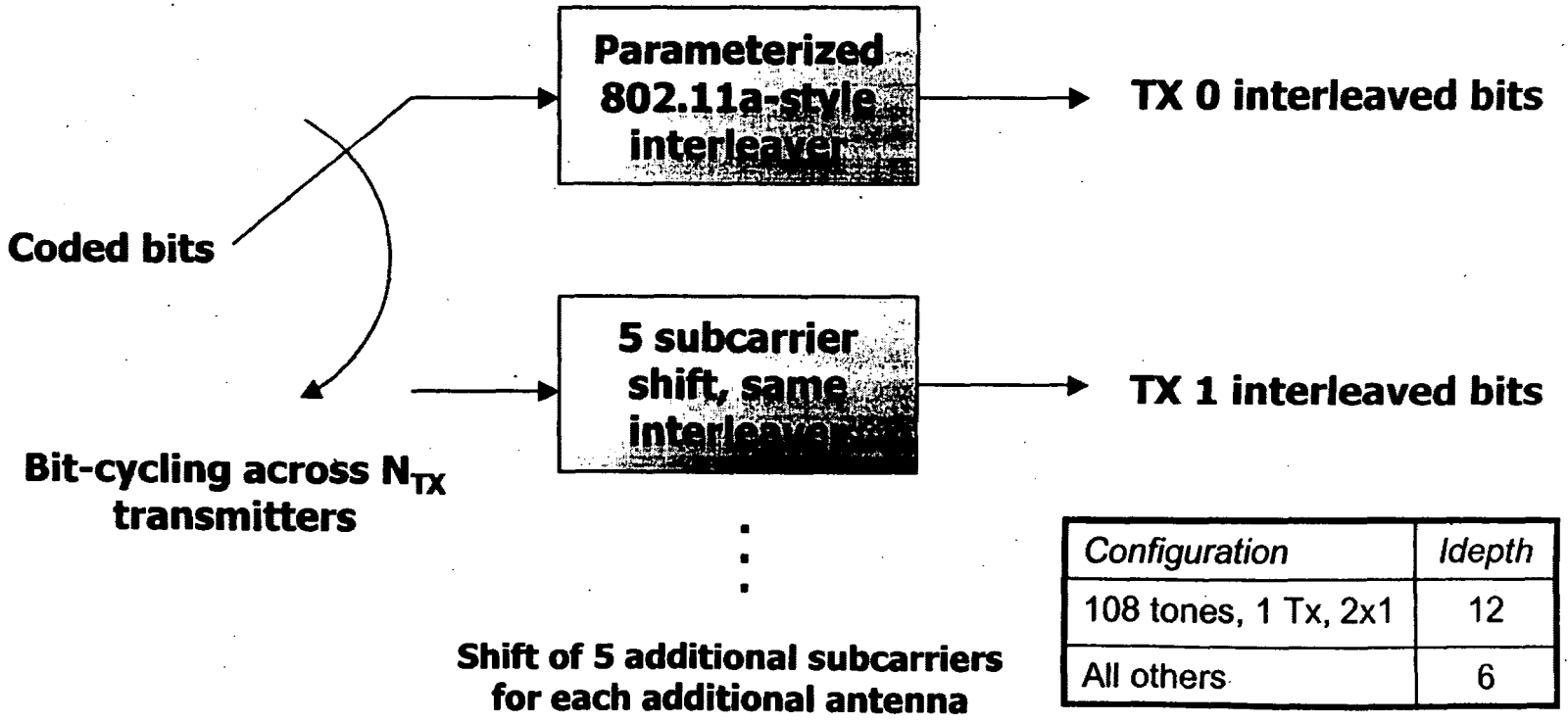
- Transmitter block diagram as for BCC modes, except symbol interleaver, rate-compatible puncturing, and tail bits are not used

LDPC code, contd.

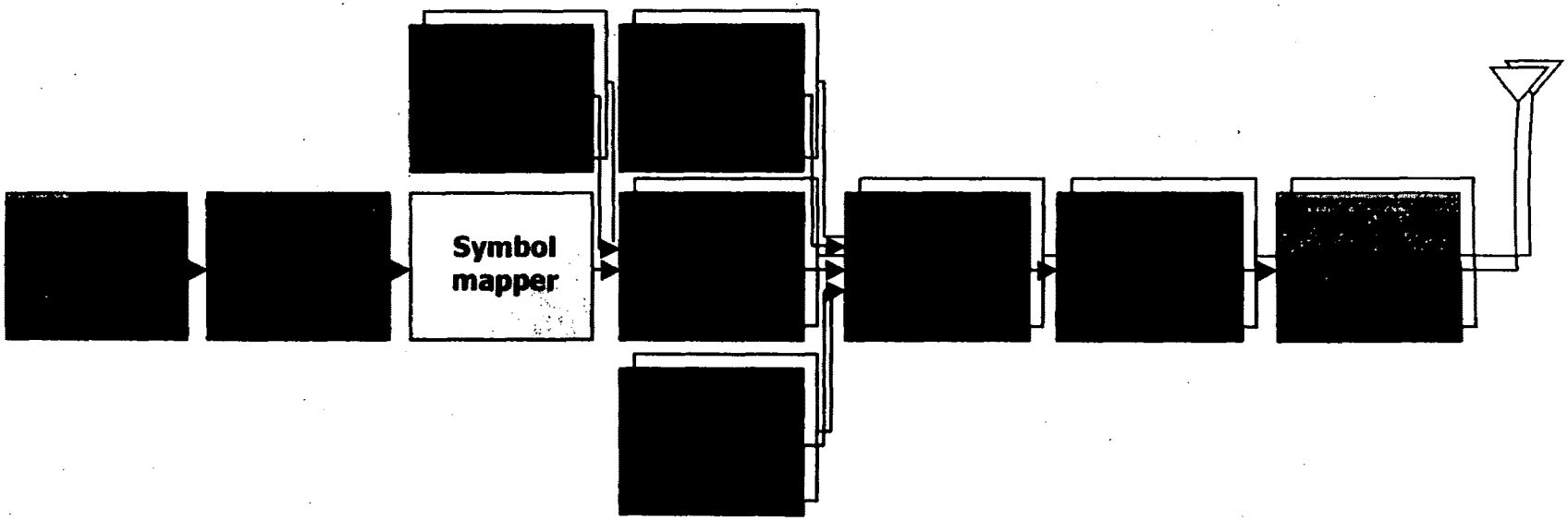
- There is no change required to SIFS or to any other system timing parameters when the advanced coding option is used
- The block size of 1944 reduces or eliminates the need for pad bits at the end of a packet
  - Pad bits are eliminated for 2 transmitter operation in 20 MHz channels, and 2x1 and 1x1 in 40 MHz channels
- The four parity check matrices are derived from the rate-1/2 matrix via row combining
- The parity check matrices are structured and based on square-shaped building blocks of size 27x27
- The parity check matrices are structured to enable efficient encoding


FEC
MIMO
interleaver

MIMO interleaving

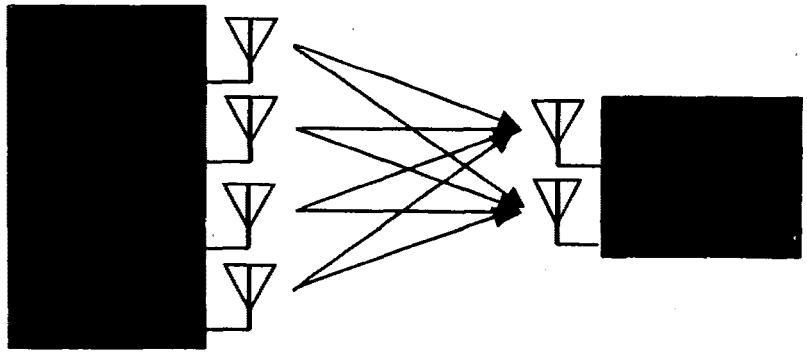


Configuration	*Idepth*
108 tones, 1 Tx, 2x1	12
All others	6


Symbol
mapper

Space-time block codes and asymmetry

- Simple space-time block codes (STBCs) are used to handle asymmetric antenna configurations
  - STBC rate always is an integer
    - No new PHY rates result from STBC encoding of streams
  - Block size is always two OFDM symbols
  - STBC encoding follows the stream encoding



Asymmetric modes, contd.

- These modes are all *open-loop*
  - No channel state information required at transmitter
  - No calibration required
  - No overhead from exchanging channel state information
  - No sensitivity to channel state information errors

Space-time block codes

- 2x1:

	t_1	t_2
Tx 1	s_1	s_2
Tx 2	$-s_2^*$	s_1^*

- 4x2:

	t_1	t_2
Tx 1	s_1	s_2
Tx 2	$-s_2^*$	s_1^*
Tx 3	s_3	s_4
Tx 4	$-s_4^*$	s_3^*

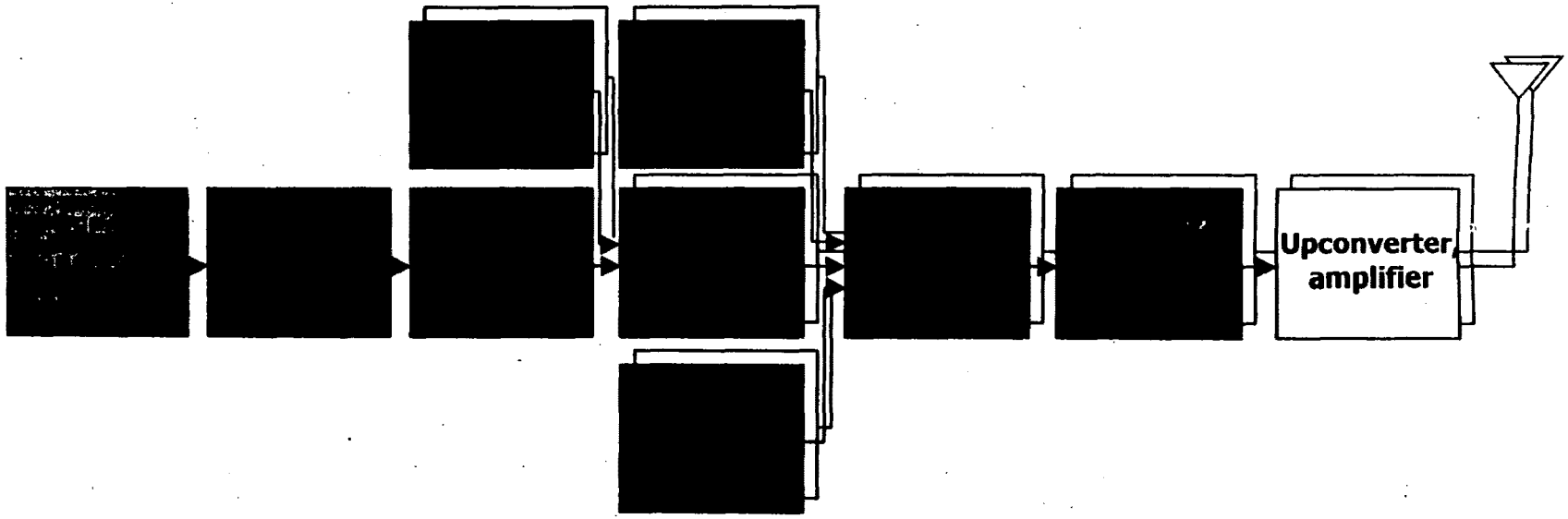
- 3x2:

	t_1	t_2
Tx 1	s_1	s_2
Tx 2	$-s_2^*$	s_1^*
Tx 3	s_3	s_4

- 4x3:

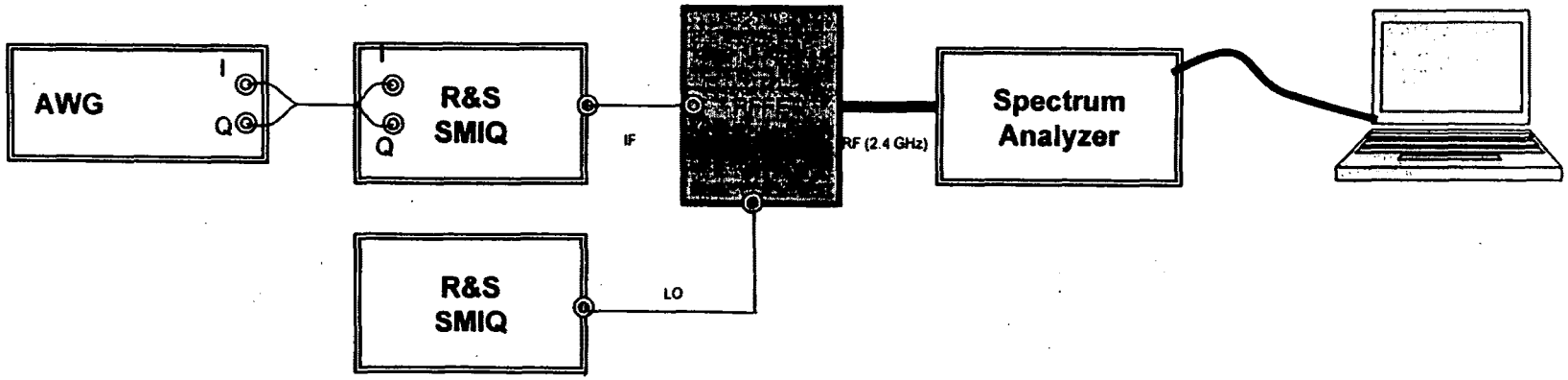
	t_1	t_2
Tx 1	s_1	s_2
Tx 2	$-s_2^*$	s_1^*
Tx 3	s_3	s_4
Tx 4	s_5	s_6

The STBC is applied independently to each OFDM subcarrier

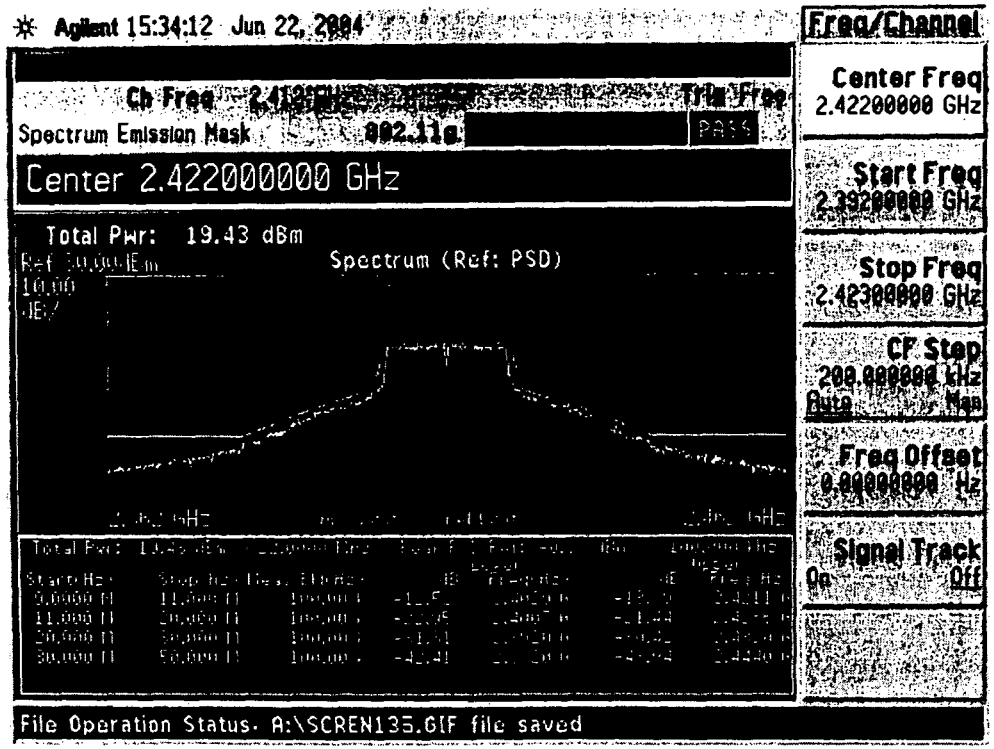

Upconverter
amplifier

Power spectral density, 20 MHz

- An AWG is loaded with files representing signal formats of interest.
  - Each file represents about 0.5 msec of randomly modulated OFDM symbols, prepended with short and long training sequences
- Output of AWG is modulated using an R&S SMIQ to IF frequency
- The output of the SMIQ is input to a board with RFFE+PA
  - The PA distorts the input spectrum, producing spectral regrowth.
- The resulting spectrum is recorded on a spectrum analyzer.



56-tone OFDM signals



- This is a 56 tone OFDM signal with a short trapezoidal window
- The PA is operated 3.5 dB backed off from PO-1 dB compression point
- The signal meets spectral mask
- The "standard" 52 tone OFDM signal with same window meets mask with a backoff of 3.0 dB

2 pilot symbols

- MIMO systems have multiple receive chains, providing receive diversity
- Format uses cyclic modulation of pilot symbols in time and space, for 20 MHz and 40 MHz
  - This provides transmit diversity gain over a static modulation
- Overall the scheme provides robust synchronization with MIMO-OFDM transmission

MAC features

MAC features

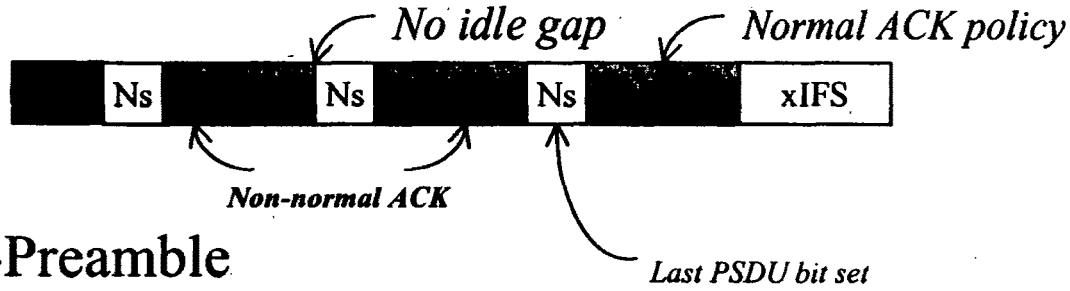
- The WWiSE proposal builds on 802.11e functionality as much as possible, in particular EDCA, HCCA, and Block Ack
  - Block Ack mandatory
- Backward compatibility
- Simplicity
  - Shorter time to standardization
  - Shorter time to productization
- Effectiveness
  - Eliminate the big bottlenecks

Aggregation

- Bursting and Aggregation:
  - MSDU aggregation
    - Increased maximum PSDU length, to 8191 octets
  - PSDU aggregation = HTP burst:
    - sequence of MPDUs from same transmitter
    - Reduced interframe spacing
      - 0 usec if at same Tx power level and PHY configuration
      - 2 usec otherwise (with preamble)
      - Not dependent on RA

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HTP Burst



= N-Preamble

Ns = N-Signal field @ robust encoding rate

- = PPDU aggregation
- Multiple RA allowed within the burst
- Block Ack Request and Block Ack frames allowed within the burst
- Last PSDU bit indicates to receiver that it should revert to preamble search

HTP Burst vs. MSDU Aggregation

- HTP burst allows aggregation without incurring latency cost (on-the-fly aggregation)
- HTP allows multiple RA per burst
- HTP allows multiple rates within burst
- HTP allows varying TX power within burst

Block Ack – Ack Policy

- Block Ack frames now have ACK policy bits
  - Allows:
    - Normal ACK behavior per 802.11e draft
    - No-ACK
    - other settings reserved
  - Reduces Block Ack overhead
    - by eliminating explicit ACKs (as an option)

Block Ack – Ack Policy, contd.

- Allows multiple RA + Block Ack Frames within a single HTP burst
  - if immediate ACK required:
    - HTP burst broken to allow SIFS + ACK
    - HTP burst single RA, ending with Block Ack Request + SIFS + ACK
    - HTP burst single RA, ending with Block Ack Request + Block Ack + ACK
  - without immediate ACK
    - HTP burst is allowed to continue
    - HTP burst may contain multiple Block Ack Request to multiple RA
- Effectively allows additional, more efficient modes of use for Block Ack mechanism

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Legacy Interaction

- Legacy remediation
  - N-STA detection/advertisement
    - Identification of TGn and non-TGn devices and BSSs
    - Extends ERP information element
    - Uses proven 802.11g signaling
  - Legacy Protection mechanisms
    - Existing protection mechanisms (extended to N/G case)
    - Addition of PLCP length spoofing
  - 40/20 MHz channel switching supported
    - Equitable sharing of resources with legacy

Simulations

- PHY model in MAC simulations
  - Detailed description in IEEE 802.11-04/877r3
  - TGn MIMO Channel Models
  - Impairments as specified by FRCC
  - Union bound technique to estimate PHY layer frame errors
  - Performance closely matches full simulations for mandatory phy configurations
    - Binary convolutional coding
  - Executes as MATLAB routine called by MAC simulator in NS

EDCA Simulation Results

- EDCA 2x2 – 20MHz 5GHz (max rate = 135 mbps)
  - **QOS goals met, all flows, all scenarios**
    - S-1: 54 Mbps (52q/1.5nq), latencies *excellent*
    - S-4: 44 Mbps (10q/34nq), latencies *excellent*
    - S-6: 47 Mbps (45q/2nq), latencies *very good*
- EDCA 2x2 – 40MHz 5GHz (max rate = 270 mbps)
  - **Even better, e.g.**
    - S-1: 56 Mbps (52q/3.5nq), latencies *excellent*
    - S-4: 65 Mbps (10q/55nq), latencies *excellent*
    - S-6: 51 Mbps (45q/6nq), latencies *excellent*

* HTP burst employed in sims, but no aggregation used

EDCA Simulation Parameters – AP/STA e.g., scenario 4

	CWMIN	CWMAX	AIFSN	TXOP LIMIT msec
AC_BK	31/63	511/511	4/4	2.0/1.0
AC_BE	31/63	127/255	4/4	3.0/2.5
AC_VI	15/15	31/31	3/3	2.5/1.1
AC_VO	7/15	31/31	2/2	1.2/1.0

HCCA Simulation Results

- HCCA 2x2 – 20MHz 5GHz (max rate = 135 mbps)
  - **QOS goals met, all flows, all scenarios**
    - S-1: 80 Mbps (52q/28nq), latencies *excellent*
    - S-4: 86 Mbps (10q/76nq), latencies *very good**
    - S-6: 63 Mbps (45q/18nq), latencies *excellent*
- HCCA 2x2 – 40MHz 5GHz (max rate = 270 mbps)
  - **Even better, e.g.**
    - S-1: 110 Mbps (52q/58nq), latencies *excellent*
    - S-4: 135 Mbps (10q/125nq), latencies *excellent*
    - S-6: 70 Mbps (46q/24nq), latencies *excellent*

* *scheduler tuned too much toward BE flows*

HCCA Simulation Parameters

- HTP burst employed, but no MSDU aggregation used
- Very simple scheduler employed
  - Round robin
    - Same TXOP value granted to all STA, regardless of flow characteristics, number of flows at STA, or priority of flows
    - Each STA polled once per round
    - No real effort put into making an intelligent scheduler
- Results quite good
  - Could be better
    - Better scheduler could be used
    - Could employ MSDU aggregation

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Discussion

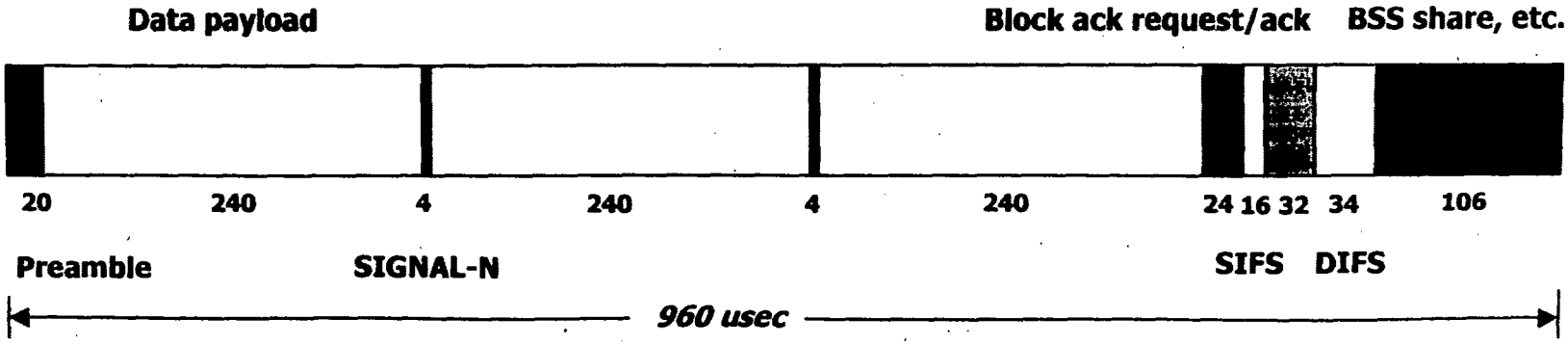
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100 Mbps throughput

- See response to CC 27 in 11/04-0877-00-000n
- Efficiency upgrades in 802.11e and further enhancements in 11n mean that the 45-50% system efficiencies of old 802.11 systems have evolved to 75-85% in contemporary systems
  - Many such enhancements are commercially available in firmware upgrades from multiple vendors
- 100 Mbps throughput is achieved from 135 Mbps PHY rate in a variety of scenarios
- 100 Mbps throughput may even be achieved from 121.5 Mbps PHY rate

100 Mbps throughput, contd.

- Example scenario:
  - 4000 byte packets
  - HTP burst transmission, 3 packets
  - Block ack
  - 10%+ for assorted other users, beacons, etc.



Modes and robustness

Ways of achieving 100 Mbps throughput robustly:

- *2x2, 20 MHz channel, 121.5 Mbps mode, BCC, MMSE detection.*
  - Requires high MAC efficiency; achievable with both HCCA and EDCA
- *2x2, 20 MHz channel, 135 Mbps mode, LDPC, MMSE detection*
- *2x3, 20 MHz channel, 135 Mbps mode, BCC, MMSE detection.*
  - Requires third radio receive chain; meets feasibility threshold easily
- *2x2, 20 MHz channel, 135 Mbps mode, near-ML detection*
  - Requires reduced-complexity algorithms for detection

Optionality of 40 MHz

Reasons why 40 MHz channels are not proposed as mandatory:

- Limited worldwide applicability
  - Europe: clause 4.4.2.2 of ETSI EN 301 893 V1.2.3
  - Japan: ARIB STD-T71
- Not necessarily better in performance than two 20 MHz channels
  - Repackaging; System and contention overhead; Dense deployments

- However there are cases where 40 MHz channels make sense
  - We offer full range of 40 MHz modes – all as optional

Summary

- One unified format for modes

Code rate	Cyclic prefix, ns	Code	Constellation
1/2	800	BCC, LDPC	16-QAM
3/4	800	BCC, LDPC	16-QAM
2/3	800	BCC, LDPC	64-QAM
3/4	800	BCC, LDPC	64-QAM
5/6	800	BCC, LDPC	64-QAM

- Used for 2, 3, 4, transmit antennas
- 20 MHz and 40 MHz channels
- Used with open-loop space-time block codes

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WWiSE patent position

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WWiSE Patent Position

- Essential patent claims owned or controlled by WWiSE companies will be available on zero royalty basis
  - Important information on terms & conditions available at
    - **http://www.wwise.org/IPinformation.htm**
    - **http://www.wwise.org/IPstatement.htm**
- IEEE strictly limits discussion of licensing terms & conditions at IEEE meetings
  - WWiSE representatives can answer any questions outside of IEEE meetings
  - Please feel free to contact any of the WWiSE representatives shown on next slide...

For More Information…

- Visit WWiSE website:
  - www.wwise.org
- Or contact:

  - **Rolf DeVegt** rolfdevegt@airgonetworks.com
  - **Neil Hamady** nhamady@bermai.com
  - **Chris Hansen** chansen@broadcom.com
  - **Jim Zyren** jim.zyren@conexant.com
  - **Thomas Chou** thomasc@realtek.com
  - **George Vlantis** george.vlantis@st.com
  - **Bill Carney** bill.carney@ti.com

References and further information

- IEEE 802.11/04-0886-03-000n, "WWiSE group PHY and MAC specification."
- IEEE 802.11/04-0877-04-000n, "WWiSE proposal response to functional requirements and comparison criteria."

See also www.wwise.org

Or send email to info@wwise.org

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P.O. Box 1450
Alexandria, Virginia 22313-1450

on Aug. 24, 2005.

Marianne Boland
Marianne Boland

In Re Application Of: Webster, et al.

Group No.: 2661

Serial No.: 11/121,661

Docket No. 50337-1020

Filed: May 4, 2005

Confirmation No.: 3553

For: **Cyclic Diversity Systems And Methods**

The following is a list of documents enclosed:

Return Postcard
Information Disclosure Statement
Form PTO-1449
Prior Cited Art (8 References)

Further, the Commissioner is authorized to charge Deposit Account No. 20-0778 for any additional fees required. The Commissioner is requested to credit any excess fee paid to Deposit Account No. 20-0778.

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE



In Re Application of:

Webster, et al.

Serial No.: 11/121,661

Filed: 05/04/2005

Confirmation No.: 3553

Group Art Unit: 2661

Examiner: TBA

Docket No.: 50337-1020

For: **Cyclic Diversity Systems And Methods**

INFORMATION DISCLOSURE STATEMENT

Mail Stop Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

Sir:

This information disclosure statement is filed in accordance with 37 C.F.R. §§ 1.56, 1.97, and 1.98, and specifically:

☒ under 37 CFR 1.97(b), or
(within Three months of filing national application; or date of entry of international application; or before mailing date of first office action on the merits; whichever occurs last)

☐ under 37 CFR 1.97(c) together with either a:
- ☐ Statement Under 37 C.F.R. 1.97(e), or
- ☐ a $180.00 fee under 37 CFR 1.17(p), or

(After the CFR 1.97(b) time period, but before the final office action or notice of allowance, whichever occurs first)

☐ under 37 CFR 1.97(d) together with a:
- ☐ Statement under 37 CFR 1.97(e), and
- ☐ a $180.00 petition fee set forth in 37 CFR 1.17(p).

(Filed after final office action or notice of allowance, whichever occurs first, but before payment of the issue fee)

Enclosed is a check in the amount of $.

Enclosed is Credit Card Payment Form (PTO-2038) in the amount of $.

Please charge $ to deposit account . At any time during the pendency of this application, please charge any fees required to Deposit Account 20-0778 pursuant to 37 CFR 1.25. The Commissioner is hereby requested to credit any overpayment to Deposit Account No. 20-0778.

☒ Applicant(s) submit herewith *Form PTO 1449A - Information Disclosure Statement by Applicant* together with copies (where required) of patents, publications or other information of which applicant(s) are aware, which applicant(s) believe(s) may or may not be material to the examination of this application and for which there may be a duty to disclose in accordance with 37 CFR 1.56. As required by 37 C.F.R. §1.98(a), a legible copy of each document is provided.

☐ A concise explanation of the relevance of foreign language patents, foreign language publications and other foreign language information listed on PTO Form 1449, as presently understood by the individual(s) designated in 37 CFR 1.56(c) most knowledgeable about the content is given on the attached sheet, or where a foreign language patent is cited in a search report or other action by a foreign patent office in a counterpart foreign application, an English

language version of the search report or action which indicates the degree of relevance found by the foreign office is listed on the form PTO 1449 and is enclosed herewith.

The following rights are reserved by the Applicant(s): the right to establish the patentability of the claimed invention over any of the listed documents should they be applied as reference, and/or the right to prove that some of these documents may not be prior art, and/or the right to prove that some of these documents may not be enabling for the teachings they purport to offer.

This statement should not be construed as a representation that an exhaustive search has been made, or that information more material to the examination of the present application does not exist. Any statements or identifications regarding the relevance of any portion(s) of cited references should not be construed as a representation that the most relevant portion(s) have been identified, and the absence of such statements or identifications should not be construed as representations that there are no relevant portion(s). The Examiner is specifically requested not to rely solely on the materials submitted herewith. The Examiner is requested to conduct an independent and thorough review of the documents, and to form independent opinions as to their significance.

It is requested that the information disclosed herein be made of record in this application and that the Examiner initial and return a copy of the enclosed PTO-1449 to indicate the documents have been considered.

Respectfully Submitted,

THOMAS, KAYDEN, HORSTEMEYER & RISLEY, L.L.P.

By: _____

David Rodack, Reg. No. 47,034

100 Galleria Parkway, Suite 1750
Atlanta, Georgia 30339-5948
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50337-1020	11/121,661
Applicant: **Webster, et al.**	
Filing Date: 05/04/2005	Group: 2661

U.S. PATENT DOCUMENTS

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FOREIGN PATENT DOCUMENTS

		Document Number	Date	Country	Class	Subclass	Translation	
							Yes	No

OTHER DOCUMENTS *(Including Author, Title, Date, Pertinent Pages, etc.)*

	A	IEEE P802.11-Task Group N-Meeting Update, http://grouper.ieee.org/groups/802/11/Reports/tgn_update.htm, pp. 1-7.
	B	Jon Rosdahl, "Draft PAR for High Throughput Study Group," November 15, 2002, Revision R1: January 16, 2003, IEEE 802.11-02/798r1, pp. 1-9.
	C	Jon Rosdahl, "Draft PAR for High Throughput Study Group," November 15, 2002, Revision R6: March 13, 2003, IEEE 802.11-02/798r6, pp. 1-8.
	D	Jon Rosdahl, "Criteria For Standards Development," (FIVE CRITERIA) November 15, 2002, IEEE 802.11-02/799r0, pp. 1-4.
	E	Jon Rosdahl, "Criteria For Standards Development," (FIVE CRITERIA) November 15, 2002, Revision 1: January 16, 2003, IEEE 802.11-02/799r1, pp. 1-4.
	F	Jon Rosdahl, "Criteria For Standards Development," (FIVE CRITERIA) November 15, 2002, Revision 1: January 16, 2003, IEEE 802.11-02/799r2, pp. 1-5.
	G	Jon Rosdahl, "Criteria For Standards Development," (FIVE CRITERIA) November 15, 2002, Revision 4: March 11, 2003, IEEE 802.11-02/799r3, pp. 1-4.
	H	Jon Rosdahl, "Criteria For Standards Development," (FIVE CRITERIA) November 15, 2002, Revision 5: March 13, 2003, IEEE 802.11-02/799r5, pp. 1-4.

* EXAMINER: Initial if citation considered, whether or not citation is in conformance with MPEP § 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to the applicant.

EXAMINER'S SIGNATURE:	DATE CONSIDERED:

Patent and Trademark Office; U. S. DEPARTMENT OF COMMERCE

IEEE P802.11 - TASK GROUP N - MEETING UPDATE:

Status of Project IEEE 802.11n

Standard for Enhancements for Higher Throughput

July 2005, San Francisco, California, US

The three proposal groups reinstated during the May meeting (TGn Sync, WWiSE and MITMOT) indicated that they have begun working together to create a single merged proposal. Consequently the task group voted to postpone the pending down select voting process until the merged document is ready. It is expected that a partial merged proposal will be posted for review during the September '05 meeting and a complete proposal will be ready for group review at the November '05 meeting; however, if a merged proposal is not delivered and approved, then the task group will resume the down selection process.
FR10 and FR11 functional requirements, describing a "single stream" mode of operation to support enhanced throughput for single spatial stream devices without MIMO capabilities, were approved for addition to the Functional Requirements document which has been updated to 03-0813 r13.

May 2005, Cairns, Queensland, Australia

TGnSync, as the single remaining technical proposal candidate, was engaged in 12 hours of presentation and discussion in the task group. This included discussion of voters comments about their reasons for voting against confirmation in the first confirmation vote held in March. After discussion, a second confirmation vote was held but the proposal failed to obtain the 75% membership approval required. As a consequence dictated by the TGn selection process, the previous three remaining proposals (TGn Sync, WWiSE and MITMOT) are reinstated for consideration by the task group. The task group will consider updated technical proposals and any mergers during its next session in July. Should there be more than one proposal entering the meeting in July, the remaining proposals will re-enter a round of elimination voting removing from consideration the proposal with the least support.

March 2005, Atlanta, Georgia, USA

Two complete proposals known by the titles TGnSync and WWiSE each authored by large groups of individuals were presented to the Task Group for consideration this week. After many hours of discussions, a down select vote was conducted that resulted in TGn Sync obtaining a majority of the votes cast. TGnSync, as the single remaining candidate was then considered for confirmation as a basis for the first draft but failed to obtain the 75% membership approval required. Voters comments about their reasons for voting against confirmation will be reviewed by TGnSync between March and the next task group meeting in May were TGnSync will present responses, proposed cures and again request

confirmation.

January 2005, Monterey, California, USA

Three complete proposals known by the titles MITMOT, TGnSync and WWiSE were presented to the Task Group for consideration during the session.
After 14 hours of presentations and discussion a down select vote was held that resulted in the elimination of the MITMOT proposal. Further consideration of the remaining two proposals and further selection voting is planned for the next meeting in March.

November 2004, San Antonio, Texas, USA

62 letters of intent were submitted in response to the TGn call for proposals that closed on Friday June 18. 32 proposals were submitted to the IEEE 802wirelessworld server by Friday August 13 and subsequently presented during the September meeting held in Berlin. 4 of these were complete and 28 partial.
Discussion of these 32 proposals continued in November with extended period of Q&A. The majority of time was spent discussing the 4 complete proposals now known by the names: MITMOT, TGnSync, WWiSE, and Qualcomm.

After the close of discussion and final remarks, there was a low hurdle vote conducted on the 4 complete proposals. Voters were asked to vote "consider" or "not consider" for each of the 4 proposals.
266 ballots were cast. with the percentage of those favoring further consideration shown as follows:

- MITMOT 47.4%
- TGnSync 73.7%
- WWiSE 64.7%
- Qualcomm 56.8%

Details of the voting are on the 802.11 member's website and in the TGn minutes. (document 04-1437)

The threshold for further consideration was 25% and therefore all proposals have passed on to the next phase.

More detailed presentations and discussions will continue in the January 2005 meeting. It is also expected that elimination voting will begin. During elimination voting each voter will register their support for only one candidate and the proposal with the lowest level of support will be eliminated.

The cycle of presentation, discussion and voting will continue until there remains only one candidate. The remaining candidate must then achieve ratification where support from at least 75% of voting members is obtained.

Should any other questions arise regarding preparations for the January meeting please contact: Bruce.kraemer@conexant.com and garth.hillman@amd.com.

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July 2004, Portland, Oregon, USA

Selection Procedure - Step 5 Has been completed.

Step 5 of the 802.11 TGn (High Throughput) Selection Procedure (described in document 11-03-665r9) was to issue a Call for Proposals. The TGn Call for Proposals notification of "intent to present", closed Friday night (midnight EDT) June 18, 2004. Thanks to all those who have expressed their intent. The total "intent" count stands at 61 with 22 "complete" and 39 "partial". The list of submissions is attached below.

During our upcoming July 12-16 meeting in Portland, Oregon we will discuss meeting logistics for the proposal presentation phase which will begin in the subsequent 802.11 meeting on September 13 in Berlin, Germany. Reminders will be issued that for the next phase of the process, each presenter is obligated to have their presentation properly submitted and loaded onto the IEEE 802.11 802wirelessworld server by Friday (midnight EDT) August 13, 2004. I have built a distribution list for each of the presenters listed below. Reminders will not be broadcast to the whole reflector.

Regards,
Bruce Kraemer
Chair TGn

First Name	Last Name	Proposal Designation
Osama	Aboul-Magd	Partial
Roberto	Aiello	Complete
Roberto	Aiello	Partial
James	Allen	Partial
Herve	Bonneville	Complete
Jeng-Hong	Chen	Partial
Sean	Coffey	Complete
Sean	Coffey	Partial
Mary	Cramer	Complete
Alexandre	Dias	Complete
Patrik	Eriksson	Partial
Takashi	Fukagawa	Partial
Jeff	Gilbert	Complete
Neil	Hamady	Complete
Marie-Helene	Hamon	Partial
Chris	Hansen	Complete
Chris	Hansen	Partial, PHY
Chris	Hansen	Partial, MAC
Eric	Jacobsen	Partial
John	Ketchum	Complete
John	Ketchum	Partial, System
John	Ketchum	Partial, MAC
John	Ketchum	Partial, PHY
John	Kowalski	Partial
Takushi	Kunihiro	Complete

Dongjun	Lee	Complete
Joseph	Levy	Partial
Pen	Li	Complete
Peter	Loc	Complete
Andy	Molisch	Complete
Yukimasa	Nagai	Partial
Michiharu	Nakamura	Partial
Seigo	Nakao	Partial
Hiroyuki	Nakase	Partial
Qiang	Ni	Partial
Atsushi	Ohta	Partial
Eldad	Perahia	Complete
Joe	Pitarresi	Complete
Aleksandar	Purkovic	Partial
Michael	Seals	Complete
Sun	Sumei	Partial, PHY
Feng-Wen	Sun	Partial, PHY
Masahiro	Takagi	Complete
Stephan	ten Brink	Partial
Pagan	Ting	Partial
Jason	Trachewsky	Complete
Jason	Trachewsky	Partial, PHY
Jason	Trachewsky	Partial, MAC
Chandra	Vaidyanthan	Partial
Nico	van Waes	Complete
Richard	VanNee	Complete
Richard	VanNee	Partial
George	Vlantis	Partial, PHY
George	Vlantis	Partial, MAC
Robert	Ward	Partial
Mark	Webster	Partial
Richard	Williams	Partial
Kue	Wong	Partial
Kim	Wu	Complete
Jung	Yee	Partial
Heejung	Yu	Partial, PHY

May 2004, Anaheim, California, USA

May Plans & Accomplishments

- Complete and adopt CCs
- Complete and adopt Usage Models
- Establish firm dates for

- Posting letter of intent
- Posting technical proposals to server

- Start presentations

- Complete Call for Proposals letter
- Review project time line
- Prepare for election of Tech Ed & V. Chair
- Receive technical presentations

Disbanded FRCC subcommittee
Releasing Call for Proposals Monday May 17

TGN Document Summary -May

- Primary Documents
- Functional Requirements 03-0813 r12
- Comparison Criteria 03-0814 r30
- Usage Models 03-0802 r23
- Channel Models 03-0940 r04
- Call for Proposals Letter 03-0858 r06

Other helpful documents:

- Selection Procedure 03-0665 r09
- FRCC Cumulative minutes 03-0815 r14
- FRCC Comments resol spreadsheet 04-0343 r11
- TGn Schedule 04-0381 r02
- Selection Procedure Minutes 03-0740 r02
- May Minutes 04-0496 r00
- Time line

Posted Technical Presentations
- Presentations heard in May

- MIMO Ant OFDM Solutions for Enhanced PHY Alexandre Dias 04-0229r0
- 20□s Effective Preamble MIMO OFDM Seigo Nakao 04-0249r1
- PCCC Turbo Codes for 802.11n Bart Van Poucke 04-0256r0
- Number of MIMO Multiplex for 11n Standards Yusuke Asai 04-0259r0
- Limitation on Range Extension using Multiple Antennas Heejung Yu 04-0279r0
- LDPC vs. Convolutional Codes: Perf and Complexity Comparison Alexsandar Purkovic 04-0337r0
- Generalized Puncturing to eliminate pad bits Stephan ten Brink 04-0298r0
- MIMO Mode Table for MIMO-OFDM Stephan ten Brink 04-0553r0

- Turbo Codes for IEEE 802.11n Brian Edmonston for Marie-Helene Hamon 04-0243r2
- Field Measurements of 2 by 2 MIMO Communications Babak Daneshrad 04-0263r0
- Maximizing MAC Throughputs by Dynamic RTS-CTS Threshold Woo-Yong Choi 04-0312r0

Plans for July

- Status of Call for Proposals
- Technical Presentations
- Overall TGn timeline
- .19 liaison planning (joint meeting)
- .21 liaison planning (joint meeting)
- regulatory issues discussion with .18
- TGn organization/officer planning

September 2003, Singapore, Singapore

The first official meeting of the IEEE 802.11n Task Group will take place at the September 2003 Session. The tentative agenda for the September 2003 session will be posted shortly. The estimate IEEE 802.11n schedule is available in document 03/488.

Conference calls on Channel Models, Usage Models and Selection procedure will be held leading up to the September 2003 Session. Meeting details will be announced to members on the IEEE 802.11 e-mail reflector. Dates for the conference calls are listed in document 03/488.

July 2003, San Francisco, California, USA

IEEE 802.11n did not meet during the July 2003 session. In July 2003, the High Throughput Study Group obtained project authorization for the formation of IEEE 802.11n. The project authorization request (PAR) and 5 Criteria are located in documents 02/798r7 and 02/799r6, respectively.

USEFUL LINKS TO OTHER SITES:

IEEE P802.11 WLANs RELATED

- FTP Site Archive
- E-mail Reflectors Archives (Members Only)

OTHER SITES

- IEEE P802 LAN/MAN Standards Committee (LMSC)
- IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

This page is maintained by Matthew B. Shoemake, IEEE 802.11 Task Group N Chairperson. Comments are welcome.

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IEEE P802.11
Wireless LANs
Draft PAR for High Throughput Study Group

Date: November 15, 2002

Revision R1: January 16, 2003

Author: Jon Rosdahl
Micro Linear
Draper, Utah
Phone: 801-617-2508
Fax: 801-617-2501
e-Mail: jrosdahl@microlinear.com

Abstract

This is the proposed PAR that the High Throughput Study Committee will submit for the creation of a Task Group. The signature page is also located at the end of this file.

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IEEE-SA Standards Board
Project Authorization Request (PAR) Form (2002)

For a review of the Standards Development Process (designed to assist the Working Group, Working Group Chair, Sponsor Chair, and Society Liaison), please click here. ☐

1. Assigned Project Number (Please contact the NesCom Administrator if this is a new PAR):
P802.11m

2. Sponsor Date of Request: _____ (YYYY-MM-DD format)

3. Type of Document (Please check one)
☒ Standard for {document stressing the verb "shall"}
☐ Recommended Practice for {document stressing the verb "should"}
☐ Guide for {document in which good practices are suggested, stressing the verb "may"}

4. Title of Document: **Draft Amendment to STANDARD [FOR] Information Technology-Telecommunications and information exchange between systems-Local and Metropolitan networks-Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Enhancements for Higher Effective Throughput**

5. Life Cycle
☒ Full Use (5-year life cycle)
☐ Trial Use (2-year life cycle)

6. Type of Project:
☐ New standard
☐ Revision of existing standard (indicate Number and year existing standard was published in box to the right) (####-YYYY)
☒ Amendment to an existing standard (indicate Number and year existing standard was published in box to the right) 802.11-2003

☐ Corrigendum to an existing standard (indicate Number and year existing standard was published in box to the right) (####-YYYY)
☐ Revised PAR (indicate PAR Number and Approval Date here: P - (YYYY-MM-DD)
Is this project in ballot now? No
State reason for revising the PAR in Item #18.

7. Contact information of Working Group Chair who must be an SA member as well as an IEEE and/or Affiliate Member

Name of Working Group(WG) : IEEE P802.11, Working Group for Wireless LANs

Name of Working Group Chair:
First Name: Stuart Last Name: Kerry
Telephone: +1 (408) 474-7356

FAX: +1 (408) 474-5343
EMAIL: stuart.kerry@philips.com

8. Contact Information of Official Reporter, Project Editor or Document Custodian if different from the Working Group Chair. The Official Report must be an SA member as well as an IEEE and/or Affiliate Member

Name of Official Reporter (if different than Working Group Chair):
First Name: Last Name:
Telephone:
FAX:
EMAIL:

9. Contact information of Sponsoring Society or Standards Coordinating Committee

Sponsoring Society and Committee:
Sponsor Committee Chair:
First Name: Last Name:
Telephone:
FAX:
EMAIL:

10. Sponsor Balloting Information (Please choose one of the following)
Choose one from the following:
☒ Individual Balloting
☐ Entity Balloting
☐ Mixed Balloting (combination of Individual and Entity Balloting)

Expected Date of Submission for Initial Sponsor Ballot:

Please review the PAR form three months prior to submitting your draft for ballot to ensure that the title, scope and purpose on the PAR form match the title, scope and purpose on the draft. If they do not match, you will need to submit a revised PAR.

Additional communication and input from other organizations or other IEEE Standards Sponsors should be encouraged through participation in the working group or the balloting pool.

11. Projected Completion Date for Submittal to RevCom: _2006-09-30__ (Format YYYY-MM-DD)

If this is a REVISED PAR and the completion date is being extended past the original four-year life of the PAR, please answer the following questions.
If this is not a revised PAR, please go to question #12

Statement of why the extension is required:

When did you begin writing the first draft?:

How many people are actively working on the project?:

How many times a year does the working group meet in person?:

How frequently is a draft version circulated to the working group via electronic means?:

How much of the Draft is stable (Format: NN%)?: %

How many significant working revisions has the Draft been through?:

Briefly describe what the development group has already accomplished, and what remains to be done:

12. Scope of Proposed Project

[Please detail the projected output including technical boundaries.
FOR REVISED DOCUMENTS ONLY – Please detail the projected output including the scope of the original standard, amendments and additions. Please be brief (less than 5 lines).]:

To define standardized modifications to both the 802.11 PHY and the 802.11 MAC so that modes of operation can be enabled that are capable of much higher throughputs, with a target minimum throughput of 100Mbps, as measured at the MAC data SAP.

13. Purpose of Proposed Project:

[Please include the following:

- The specific aims and reason for the standardization activity, with particular emphasis on the aspects of standardization to be covered, the problems to be solved or difficulties it is intended to overcome;
- Main interests that might benefit from or be affected by the activity, such as industry, consumers, trade, governments and distributors;
- Benefits to be gained by the implementation of the proposed standard; alternatively, the loss or disadvantages if no standard is established within a reasonable time;

FOR REVISED DOCUMENTS ONLY - Purpose of the original document and reason for the document's revision. Please be brief (less than 5 lines).]:

To improve the 802.11 wireless LAN user experience by providing significantly higher throughput for current applications and to enable new applications and market segments.

14. Intellectual Property {Answer each of the questions below}

Sponsor has reviewed the IEEE patent policy with the working group?
Choose One XXYes ☐No

Sponsor is aware of copyrights relevant to this project?
Choose One ☐Yes X No

Sponsor is aware of trademarks relevant to this project?

Choose One ☐Yes X No

Sponsor is aware of possible registration of objects or numbers due to this project?
Choose One ☐Yes X No

15. Are there other standards or projects with a similar scope?
Choose One ☐Yes X No

Explanation:

If Yes, please answer the following:
Sponsor Organization:
Project Number:
Project Date:
Project Title:

16. International Sponsor Organization
Is there potential for this standard (in part or in whole) to be submitted to an international organization for review/adoption?
Choose One ?? {Yes/No/?? if you don't know at this time}

If Yes, please answer the following questions:
International Committee Name and Number:
International Organization Contact Information:
Contact First Name:
Contact Last Name:
Contact Telephone Number:
Contact FAX Number:
Contact E-mail address:

17. Will this project focus on health, safety or environmental issues?
Choose One NO {Yes/No/?? if you don't know at this time}
If Yes: Explanation?

18. Additional Explanatory Notes: {Item Number and Explanation}

Item 12.

In the process of formulating this PAR, it was found that there are multiple user scenarios. Accordingly, the task group will undertake the following steps:

1. Identify and define usage models, channel models and related MAC and application assumptions. Initial usage models envisioned include hot-spot, enterprise and residential; others are likely to be included.

2. Identify and define evaluation metrics that characterize the important aspects of a particular usage model. The evaluation metrics may include but are not limited to the items listed in Table 1, provided in illustration of the format.

Table 1: Evaluation Metrics

Evaluation Parameter	Usage Model 1	Usage Model 2	Usage Model 3
Throughput at the MAC data SAP, Mbps#			
Range , meters			
Aggregate Network Capacity □			
Power Consumption (peak and average), mW			
Spectral Flexibility □□			
Cost / Complexity Flexibility			
Backward Compatibility**			
Coexistence *			

Notes:
□Definition includes a measure of spectral efficiency (like bits/Hz/m^2).
□□That is, agnostic to a particular frequency allocation and perhaps able to implement spectral agility.
*The ability of one system to perform a task in a given shared environment in which other systems have an ability to perform their tasks and may or may not be using the same set of rules.
** Backward compatibility with non-HT 802.11 device is desirable to the extent practicalable. It is a comparison metric but is explicitly not mandated. The question of what possible tradeoffs exist between high effective throughput modes and backward compatibility mechanisms requires detailed technical information that is not now available to the HT Study Group.
It is intended that throughput will be a primary comparison metric, and at least 100Mbps is the mandatory minimum throughput for the highest throughput usage models. It is anticipated that the amended standard will contain a family of related modes, with different throughputs. It is anticipated that some of these modes will have thoughputs that are substantially below 100Mbps, but that are still substantially higher, given similar operating conditions, than any modes in the existing 802.11 standard.

3. Develop a technical requirement specification.

4. Define a process for evaluations.

The PAR Copyright Release and Signature Page must be submitted either by FAX to 208-460-5300 or as an e-mail attachment in .pdf format to the NesCom Administrator before this PAR will be sent on for NesCom and Standards Board approval.

IEEE-SA Standards Board

PAR Copyright Release and Signature Page

(revised 2003)

1. Sponsor Date of Request:

2. Assigned Project Number: P
   Title:

I hereby acknowledge my appointment as Official Reporter (usually the WG Chair) to the {Name of Working Group}

In consideration of my appointment and the publication of the Standards Publication identifying me, at my option, as an Official Reporter, I agree to avoid knowingly incorporating in the Standards Publication any copyrighted or proprietary material of another without such other's consent and acknowledge that the Standards Publication shall constitute a "work made for hire" as defined by the Copyright Act, and, that as to any work defined, I agree to and do hereby transfer any right or interest I may have in the copyright to said Standards Publication to IEEE.

I acknowledge having read and understood the **IEEE Code of Ethics** (http://www.ieee.org/portal/index.jsp?pageID=corp_level1&path=about/whatis&file=code.xml&xsl=generic.xsl). I agree to conduct myself in a manner which adheres to the IEEE Code of Ethics when engaged in official IEEE business.

Signature of Official Reporter _____ Date _____
Name of Official Reporter (usually the WG Chair):

Title in WG:	IEEE/SA/Affiliate Memb #:
Company:	Telephone:
Address:	FAX:
City/State/Zip:	EMAIL:

Submitted by: (This MUST be the Sponsor Chair or the Sponsor's Liaison Representative to the IEEE Standards Board) who MUST be an IEEE/Affiliate AND Standards Association (SA) member. If the Sponsor chair is the submitter of the PAR by EMAIL and verifiable by his sender's Email address, this form does not need to be signed by the sponsor. The submitter will be notified in writing when the PAR is received and when the PAR will be considered for approval by the Standards Board. After the Standards Board meeting, the submitter will be notified in writing of the action taken.

As submitter, I shall be responsible for the development and coordination of the standards project, for supervising the standards project from inception to completion, and for ensuring that the standards project operates according to a written set of policies and procedures (P&P) per subclause 5.1.1 of the IEEE-SA Standards Board Operations Manual.

I acknowledge having read and understood the **IEEE Code of Ethics** (http://www.ieee.org/portal/index.jsp?pageID=corp_level1&path=about/whatis&file=code.xml&xsl=generic.xsl). I agree to conduct myself in a manner which adheres to the IEEE Code of Ethics when engaged in official IEEE business.
Signature of Submitter_____ Date _____

Name of Sponsor Committee Chair:
Company:
Address:
City/State/Zip:

IEEE/SA/Affiliate Memb #:
Telephone:
FAX:
EMAIL:

Do Not Write Below This Line

Signature by IEEE-SA Officer: _____

Title: _____

Date: _____

IEEE P802.11
Wireless LANs
Draft PAR for High Throughput Study Group

Date: November 15, 2002

Revision R6: March 13, 2003

Author: Jon Rosdahl
Micro Linear
Draper, Utah
Phone: 801-617-2508
Fax: 801-617-2501
e-Mail: jrosdahl@microlinear.com

Abstract

This is the proposed PAR that the High Throughput Study Committee will submit for the creation of a Task Group. The signature page is also located at the end of this file.

```
Rev 1 Initial PAR proposal from HTSG.
Rev 2 PAR Submitted to WG for Letter Ballot 55.  Ballot Failed.
Rev 3 PAR Submission with Editing suggested by WG LB55 and ExCom Chair.
Rev 4 PAR edits for approved changes through Tuesday 3-11-03 night.
Rev 5 PAR edits for approved changes through Wed 3-12-03 night.
Rev 6 PAR Edits approved by the SG Thursday 5:30pm.
```


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IEEE-SA Standards Board
Project Authorization Request (PAR) Form (2002)

1. Assigned Project Number: **P802.11n**

2. Sponsor Date of Request: **2003-03-14**

3. Type of Document:
☒ **Standard for** {document stressing the verb "shall"}
☐ Recommended Practice for {document stressing the verb "should"}
☐ Guide for {document in which good practices are suggested, stressing the verb "may"}

4. Title of Document:

Draft Amendment to STANDARD [FOR] Information Technology-Telecommunications and information exchange between systems-Local and Metropolitan networks-Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Enhancements for Higher Throughput

5. Life Cycle
☒ **Full Use** (5-year life cycle)
☐ Trial Use (2-year life cycle)

6. Type of Project:
☐ New standard
☐ Revision of existing standard (indicate Number and year existing standard was published in box to the right) (####-YYYY)
☒ **Amendment to an existing standard (802.11-1999 (2003 edition))**
☐ Corrigendum to an existing standard (indicate Number and year existing standard was published in box to the right) (####-YYYY)
☐ Revised PAR (indicate PAR Number and Approval Date here: P - (YYYY-MM-DD)
Is this project in ballot now? No
State reason for revising the PAR in Item #18.

7. Contact information of Working Group Chair who must be an SA member as well as an IEEE and/or Affiliate Member

Name of Working Group (WG): **IEEE P802.11, Working Group for Wireless LANs**

Name of Working Group Chair:
First Name: **Stuart** Last Name: **Kerry**
Telephone: **+1 (408) 474-7356**
FAX: **+1 (408) 474-5343**
EMAIL: **stuart.kerry@philips.com**

8. Contact Information of Official Reporter, Project Editor or Document Custodian if different from the Working Group Chair. The Official Report must be an SA member as well as an IEEE and/or Affiliate Member

Name of Official Reporter (if different than Working Group Chair):
First Name: Last Name:
Telephone:
FAX:
EMAIL:

9. Contact information of Sponsoring Society or Standards Coordinating Committee:

Sponsoring Society and Committee:
Computer Society LAN/MAN Standards Committee
Sponsor Committee Chair:
First Name: **Paul** Last Name: **Nikolich**
Telephone: **978-749-9999**
FAX: **978-749-8888**
EMAIL: **p.nikolich@ieee.org**

10. Sponsor Balloting Information:
Choose one from the following:
☒ **Individual Balloting**
☐ Entity Balloting
☐ Mixed Balloting (combination of Individual and Entity Balloting)

Expected Date of Submission for Initial Sponsor Ballot: **2005-11-25**

Please review the PAR form three months prior to submitting your draft for ballot to ensure that the title, scope and purpose on the PAR form match the title, scope and purpose on the draft. If they do not match, you will need to submit a revised PAR.

Additional communication and input from other organizations or other IEEE Standards Sponsors should be encouraged through participation in the working group or the balloting pool.

11. Projected Completion Date for Submittal to RevCom: **2006-06-16**

If this is a REVISED PAR and the completion date is being extended past the original four-year life of the PAR, please answer the following questions.
If this is not a revised PAR, please go to question #12

Statement of why the extension is required:
When did you begin writing the first draft?
How many people are actively working on the project?
How many times a year does the working group meet in person?
How frequently is a draft version circulated to the working group via electronic means?
How much of the Draft is stable (Format: NN%)? %
How many significant working revisions has the Draft been through?

Briefly describe what the development group has already accomplished, and what remains to be done:

12. Scope of Proposed Project:

The scope of this project is to define an amendment that shall define standardized modifications to both the 802.11 physical layers (PHY) and the 802.11 Medium Access Control Layer (MAC) so that modes of operation can be enabled that are capable of much higher throughputs, with a maximum throughput of at least 100Mbps, as measured at the MAC data service access point (SAP).

13. Purpose of Proposed Project:

The purpose of the project is to improve the 802.11 wireless local area network (LAN) user experience by providing significantly higher throughput for current applications and to enable new applications and market segments.

14. Intellectual Property:

Sponsor has reviewed the IEEE patent policy with the working group?
Choose One **X Yes** ☐No

Sponsor is aware of copyrights relevant to this project?
Choose One ☐Yes **X No**

Sponsor is aware of trademarks relevant to this project?
Choose One ☐Yes **X No**

Sponsor is aware of possible registration of objects or numbers due to this project?
Choose One ☐Yes **X No**

15. Are there other standards or projects with a similar scope?

Choose One ☐Yes **X No**

Explanation:

If Yes, please answer the following:
Sponsor Organization:
Project Number:
Project Date:
Project Title:

16. International Sponsor Organization
Is there potential for this standard (in part or in whole) to be submitted to an international organization for review/adoption?
Choose One ?? {Yes/No/?? **if you don't know at this time**}

If Yes, please answer the following questions:
International Committee Name and Number:
International Organization Contact Information:
Contact First Name:
Contact Last Name:
Contact Telephone Number:
Contact FAX Number:
Contact E-mail address:

17. Will this project focus on health, safety or environmental issues? **No**

If Yes: Explanation?

18. **Additional Explanatory Notes:**

Item 12.
The scope of the MAC and PHY enhancements assume a baseline specification defined by 802.11 and its amendments and anticipated amendments a, b, d, e, g, h, i and j. The enhancements shall be to support higher throughput. The amendment shall not redefine mechanisms in the baseline that do not pertain to higher throughput.

Some of the modes of operation defined in the HT amendment shall be backwards compatible and interoperable with 802.11a and/or 802.11g.

Existing 802.11 standards are typically designated by their peak physical data rates. For example, 802.11a has a peak data rate of 54Mbps. This amendment has chosen to use a performance metric of throughput measured at the MAC data SAP. This amendment seeks to improve the peak throughput to at least 100Mbps, measured at the MAC data SAP. Depending on the scenario, this represents an improvement of at least 4 times the throughput obtainable using existing 802.11 systems.

In order to make efficient use of scarce spectral resources in unlicensed bands, the highest throughput mode defined by the HT amendment shall achieve a spectral efficiency of at least 3 bits per second per Hertz for the PSDU.

In the process of formulating this PAR, it was found that there are multiple user scenarios. Accordingly, the task group will undertake the following steps:

1. Identify and define usage models, channel models and related MAC and application assumptions. Initial usage models envisioned include hot-spot, enterprise and residential; others may be included.

2. Identify and define evaluation metrics that characterize the important aspects of a particular usage model. The evaluation metrics may include but are not limited to the items listed in Table 1, provided as an illustration of the format.

Table 1: Evaluation Metrics

Evaluation Parameter	Usage Model 1	Usage Model 2	Usage Model 3
Throughput at the MAC data SAP, Mbps#			

Range, meters			
Aggregate Network Capacity □			
Power Consumption (peak and average), mW			
Spectral Flexibility □□			
Cost / Complexity Flexibility			
Backward Compatibility**			
Coexistence *			

Notes:
□Definition includes a measure of spectral efficiency.
□□That is, agnostic to a particular frequency allocation and perhaps able to implement spectral agility.
*The ability of one system to perform a task in a given shared environment in which other systems have an ability to perform their tasks and may or may not be using the same set of rules.
**Backward compatibility with non-HT 802.11 device is desirable to the extent practicable. It is a comparison metric but is explicitly not mandated. The question of what possible tradeoffs exist between high effective throughput modes and backward compatibility mechanisms requires detailed technical information that is not now available to the HT Study Group.
* It is intended that throughput will be a primary comparison metric, and at least 100Mbps is the mandatory minimum throughput for the highest throughput usage models. It is anticipated that the amended standard will contain a family of related modes, with different throughputs. It is anticipated that some of these modes will have throughputs that are substantially below 100Mbps, but that are still substantially higher, given similar operating conditions, than any modes in the existing 802.11 standard.

3. Develop a technical requirement specification.

4. Define a process for evaluations.

The impact of an HT device on the operation of a legacy network shall be comparable to that of any other legacy device identified in the baseline defined above.

Note: The PAR Copyright Release and Signature Page must be submitted either by FAX to 208-460-5300 or as an e-mail attachment in .pdf format to the NesCom Administrator before this PAR will be sent on for NesCom and Standards Board approval.

IEEE-SA Standards Board

PAR Copyright Release and Signature Page

(Revised 2003)

1. Sponsor Date of Request: 2003-03-14

2. Assigned Project Number: P802.11n
   Title:

Draft Amendment to STANDARD [FOR] Information Technology-Telecommunications and information exchange between systems-Local and Metropolitan networks-Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Enhancements for Higher Effective Throughput

I hereby acknowledge my appointment as Official Reporter (usually the WG Chair) to the 802.11 Wireless LAN Working Group.

In consideration of my appointment and the publication of the Standards Publication identifying me, at my option, as an Official Reporter, I agree to avoid knowingly incorporating in the Standards Publication any copyrighted or proprietary material of another without such other's consent and acknowledge that the Standards Publication shall constitute a "work made for hire" as defined by the Copyright Act, and, that as to any work defined, I agree to and do hereby transfer any right or interest I may have in the copyright to said Standards Publication to IEEE.

I acknowledge having read and understood the **IEEE Code of Ethics** (http://www.ieee.org/portal/index.jsp?pageID=corp_level1&path=about/whatis&file=code.xml&xsl=generic.xsl). I agree to conduct myself in a manner, which adheres to the IEEE Code of Ethics when engaged in official IEEE business.

Signature of Official Reporter _____ Date _____
Name of Official Reporter (usually the WG Chair):

Title in WG:	Chairman	IEEE/SA/Affiliate Memb #:	
Company:	Philips	Telephone:	
Address:		FAX:	
City/State/Zip:		EMAIL:	

Submitted by: (This MUST be the Sponsor Chair or the Sponsor's Liaison Representative to the IEEE Standards Board) who MUST be an IEEE/Affiliate AND Standards Association (SA) member. If the Sponsor chair is the submitter of the PAR by EMAIL and verifiable by his sender's Email address, this form does not need to be signed by the sponsor. The submitter will be notified in writing when the PAR is received and when the PAR will be considered for approval by the Standards Board. After the Standards Board meeting, the submitter will be notified in writing of the action taken.

As submitter, I shall be responsible for the development and coordination of the standards project, for supervising the standards project from inception to completion, and for ensuring that the standards project operates according to a written set of policies and procedures (P&P) per subclause 5.1.1 of the IEEE-SA Standards Board Operations Manual.

I acknowledge having read and understood the **IEEE Code of Ethics** (http://www.ieee.org/portal/index.jsp?pageID=corp_level1&path=about/whatis&file=code.xml&xsl=generic.xsl). I agree to conduct myself in a manner, which adheres to the IEEE Code of Ethics when engaged in official IEEE business.
Signature of Submitter_____ Date _____

Name of Sponsor Committee Chair:	IEEE/SA/Affiliate Memb #:
Company:	Telephone:
Address:	FAX:
City/State/Zip:	EMAIL:

Do Not Write Below This Line

Signature by IEEE-SA Officer: _____

Title: _____

Date: _____

IEEE P802.11
Wireless LANs

CRITERIA FOR STANDARDS DEVELOPMENT

(FIVE CRITERIA)

Date: November 15, 2002

Author: Jon Rosdahl
Micro Linear
Draper, Utah
Phone: 801-617-2508
Fax: 801-617-2501
e-Mail: jrosdahl@microlinear.com

Abstract

This is the proposed response to the 5 Criteria for creating a new Task Group.

CRITERIA FOR STANDARDS DEVELOPMENT

(FIVE CRITERIA)

6.1 Broad Market Potential
A standards project authorized by IEEE 802 shall have a broad market potential. Specifically, it shall have the potential for:
a) Broad sets of applicability.
b) Multiple vendors and numerous users.
c) Balanced costs (LAN versus attached stations).

Demand for WLANs is expected to grow at a 50% Compounded Annual Growth Rate (CAGR) over the next five years. Over 50% of all home networking connections and over 40% of all mobile PC network connections will be over WLAN by 2005. New usages such as simultaneous transmission of multiple HDTV signals, audio, on-line gaming, etc. will drive the need for higher throughput in the home. As usage increases in the corporate and other high density environments, bandwidth restrictions of a shared media will begin to be realized. This is very similar to what happened in the wired Ethernet market. The need for higher throughput drove switching and 100Base-TX adoption. While a switching technology would ultimately be desired for WLAN, this is not technically feasible. The next logical step is to increase the data throughput of each WLAN Connection.

6.2 Compatibility
IEEE 802 defines a family of standards. All standards shall be in conformance with the IEEE 802.1 Architecture, Management and Interworking documents as follows: 802. Overview and Architecture, 802.1D, 802.1Q and parts of 802.1f. If any variances in conformance emerge, they shall be thoroughly disclosed and reviewed with 802. Each standard in the IEEE 802 family of standards shall include a definition of managed objects which are compatible with systems management standards.

6.3 Distinct Identity
Each IEEE 802 standard shall have a distinct identity. To achieve this, each authorized project shall be:
a) Substantially different from other IEEE 802 standards.

This project will result in a wireless LAN with higher throughput than provided by 802.11a, 802.11b and 802.11g. The goal is to increase the overall system throughput by considering both PHY and MAC layer enhancements.

IEEE P802.15 study group SG3*a* will support higher-rates than those currently defined by P802.15 task group 3, and similar to those targeted by this proposal. However, the applications of 802.11 and 802.15 are different. 802.15 defines standards for *wireless* personal area networks, 802.11 defines standards for wireless local area networks. The different requirements of each group may result in different standards that satisfy the purpose and scope defined in each project's PAR.

b) One unique solution per problem (not two solutions to a problem).

There are no other wireless LAN standards providing significantly higher throughput than either 802.11a or 802.11g.

c) Easy for the document reader to select the relevant specification.

The high throughput standard will be introduced as an amendment to the 802.11 specification.

6.4 Technical Feasibility
For a project to be authorized, it shall be able to show its technical feasibility. At a minimum, the proposed project shall show:
a) Demonstrated system feasibility.

b) Proven technology, reasonable testing.
c) Confidence in reliability.

Simulations are available that demonstrate the feasibility and performance of new MAC and PHY layer techniques that result in significant throughput improvement.

6.5 Economic Feasibility
For a project to be authorized, it shall be able to show economic feasibility (so far as can reasonably be estimated), for its intended applications. At a minimum, the proposed project shall show:
a) Known cost factors, reliable data.
b) Reasonable cost for performance.
c) Consideration of installation costs.

Support of the proposed standard may require the development of modified MAC and PHY implementations. This is similar in principal to the transition between 802.11b and 802.11g. The new standard will provide manufacturers the option of supporting higher throughput. Competition between manufacturers will ensure that costs are reasonable.

IEEE P802.11
Wireless LANs

CRITERIA FOR STANDARDS DEVELOPMENT

(FIVE CRITERIA)

Date: November 15, 2002

Revision 1: January 16, 2003

Author: Jon Rosdahl
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Abstract

This is the proposed response to the 5 Criteria for creating a new Task Group.

TCL 1002
p. 444

CRITERIA FOR STANDARDS DEVELOPMENT

(FIVE CRITERIA)

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IEEE 802 defines a family of standards. All standards shall be in conformance with the IEEE 802.1 Architecture, Management and Interworking documents as follows: 802. Overview and Architecture, 802.1D, 802.1Q and parts of 802.1f. If any variances in conformance emerge, they shall be thoroughly disclosed and reviewed with 802. Each standard in the IEEE 802 family of standards shall include a definition of managed objects which are compatible with systems management standards.

Compatibility with IEEE 802 requirements will result from keeping the MAC SAP interface the same as for the existing 802.11 standard. The proposed amendment shall introduce no 802.1 architectural changes. The MAC SAP definition shall not be altered ensuring that all LLC and MAC interfaces are compatible to and in conformance with the IEEE 802.1 Architecture, Management and Internetworking standards. New managed objects shall be defined as necessary in a format and structure consistent with existing 802.11 managed objects.

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IEEE P802.15 study group SG3*a* will support higher-rates than those currently defined by P802.15 task group 3, and similar to those targeted by this proposal. However, the applications of 802.11 and 802.15 are different. 802.15 defines standards for *wireless* personal area networks, 802.11 defines standards for wireless local area networks. The different requirements of each group may result in different standards that satisfy the purpose and scope defined in each project's PAR.

b) One unique solution per problem (not two solutions to a problem).

There are no other wireless LAN standards providing significantly higher throughput than either 802.11a or 802.11g.

c) Easy for the document reader to select the relevant specification.

The high throughput standard will be introduced as an amendment to the 802.11 specification.

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For a project to be authorized, it shall be able to show its technical feasibility. At a minimum, the proposed project shall show:
a) Demonstrated system feasibility.
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a) ***Simulations*** **are available that demonstrate the feasibility and performance of new MAC and PHY layer techniques that result in significant throughput improvement. The following documents are examples that support the feasibility of elements of high throughput technology:**

IEEE 802.11-02/180r0	**On the use of multiple antennas for 802.11**
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b) **The technologies referenced in some of the documents above have been in use in other fields for some time. Until the full extent of the user models referenced in the HTSG PAR is understood, the study group cannot completely assess the extent of reasonable testing for those technologies. However, the increased capabilities envisioned for the baseband and RF parts necessary to implement the proposed amendment are in line with the current progress in ASIC technology.**

c) **Analysis of current WLAN products and of proposals of potential candidate approaches provides confidence in the reliability of the proposed solutions.**

There are currently reliable WLAN solutions. The study group envisions that the proposed amendment will result in no less reliability.

6.5 Economic Feasibility
For a project to be authorized, it shall be able to show economic feasibility (so far as can reasonably be estimated), for its intended applications. At a minimum, the proposed project shall show:
a) Known cost factors, reliable data.
b) Reasonable cost for performance.
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a) Support of the proposed standard will probably require a manufacturer to develop a modified radio, modem and firmware. This is similar in principle to the transition between 802.11b and 802.11g or between 802.11b and 802.11a. The cost factors for these transitions are well known and the data for this is well understood.

b) The new standard will provide manufacturers the option of supporting higher throughput. In general, the cost factor changes needed to implement the extensions envisioned by the study group are well within the capabilities of existing technology. Competition between manufacturers will ensure that costs remain reasonable.

c) The proposed amendment has no known impact on installation costs.

IEEE P802.11
Wireless LANs

CRITERIA FOR STANDARDS DEVELOPMENT

(FIVE CRITERIA)

Date: November 15, 2002

Revision 1: January 16, 2003

Author: Jon Rosdahl
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Abstract

This is the proposed response to the 5 Criteria for creating a new Task Group.

TCL 1002
p. 448

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(FIVE CRITERIA)

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b) A wide variety of vendors currently build numerous products for the WLAN marketplace. It is expected that the majority of those vendors, and others, will participate in the standards development process and subsequent commercialization activities.

c) WLAN equipment is accepted as having balanced costs. The addition of High Throughput capabilities will not disrupt the established balance.

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TCL 1002
p. 451

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IEEE P802.11
Wireless LANs

CRITERIA FOR STANDARDS DEVELOPMENT

(FIVE CRITERIA)

Date: November 15, 2002

Revision 4: March 11, 2003

Author: Jon Rosdahl
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Abstract

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Rev 1 HTSG proposed PAR
Rev 2 sent to WG to be part of LB55 – Letter Ballot failed.
Rev 3 Apply Edits requested by LB55 and ExCom Chair
Rev 4 Edits approved by SG through Tuesday 3-11-3 Evening

CRITERIA FOR STANDARDS DEVELOPMENT

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envisioned for the baseband and RF parts necessary to implement the proposed amendment are in line with the current progress in ASIC technology.

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IEEE P802.11
Wireless LANs

CRITERIA FOR STANDARDS DEVELOPMENT

(FIVE CRITERIA)

Date: November 15, 2002

Revision 5: March 13, 2003

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Rev 5 Adhoc edits in blue proposal to the SC for Thursday afternoon.

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6.2 Compatibility
IEEE 802 defines a family of standards. All standards shall be in conformance with the IEEE 802.1 Architecture, Management and Interworking documents as follows: 802. Overview and Architecture, 802.1D, 802.1Q and parts of 802.1f. If any variances in conformance emerge, they shall be thoroughly disclosed and reviewed with 802. Each standard in the IEEE 802 family of standards shall include a definition of managed objects, which are compatible with systems management standards.

Compatibility with IEEE 802 requirements will result from keeping the MAC SAP interface the same as for the existing 802.11 standard. The proposed amendment shall introduce no 802.1 architectural changes. The MAC SAP definition shall not be altered ensuring that all LLC and MAC interfaces are compatible to and in conformance with the IEEE 802.1 Architecture, Management and Internetworking standards. New managed objects shall be defined as necessary in a format and structure consistent with existing 802.11 managed objects.

6.3 Distinct Identity

Each IEEE 802 standard shall have a distinct identity. To achieve this, each authorized project shall be:

a) Substantially different from other IEEE 802 standards.

This project will result in a wireless LAN with higher throughput than provided by 802.11a, 802.11b and 802.11g. The goal is to increase the overall system throughput by considering both PHY and MAC layer enhancements.

IEEE P802.15 study group SG3*a* intends to support higher physical data rates than those currently defined by P802.15 task group 3, and similar to those targeted by this proposal. However, the applications of 802.11 and 802.15 are different. 802.15 defines standards for short-range wireless *personal* area networks, 802.11 defines standards for relatively longer-range wireless *local* area networks. The different requirements of each group may result in different standards that satisfy the purpose and scope defined in each project's PAR.

b) One unique solution per problem (not two solutions to a problem).

There are no other wireless LAN standards providing significantly higher throughput than either 802.11a or 802.11g.

c) Easy for the document reader to select the relevant specification.

The high throughput standard will be introduced as an amendment to the 802.11 specification.

6.4 Technical Feasibility

For a project to be authorized, it shall be able to show its technical feasibility. At a minimum, the proposed project shall show:

a) Demonstrated system feasibility.

b) Proven technology, reasonable testing.

c) Confidence in reliability.

a) **Simulations are available that demonstrate the feasibility and performance of new MAC and PHY layer techniques that result in significant throughput improvement. The following documents are examples that support the feasibility of elements of high throughput technology:**

IEEE 802.11-02/180r0	**On the use of multiple antennas for 802.11**
IEEE 802.11-02/138r0	**Throughput Analysis for IEEE 802.11a Higher Data Rates**
IEEE 802.11-02/232r0	**Extended data rate 802.11a**
IEEE 802.11-02/294r1	**HDR 802.11a solution using MIMO-OFDM**
IEEE 802.11-02/320r0	**¼ Giga-bit/s WLAN**
IEEE 802.11-03/025r0	**Benefits of smart antennas in 802.11 networks**
IEEE 802.11-02/708r0	**MIMO-OFDM for high throughput WLAN: experimental results**

b) The technologies referenced in some of the documents above have been in use in other fields for some time. Until the full extent of the user models referenced in the HTSG PAR is understood, the study group cannot completely assess the extent of

reasonable testing for those technologies. However, the increased capabilities envisioned for the baseband and RF parts necessary to implement the proposed amendment are in line with the current progress in semiconductor technology.

c) Analysis of current WLAN products and of proposals of potential candidate approaches provides confidence in the reliability of the proposed solutions. There are currently reliable WLAN solutions. The study group envisions that the proposed amendment will result in similar or improved reliability over current levels.

6.5 Economic Feasibility
For a project to be authorized, it shall be able to show economic feasibility (so far as can reasonably be estimated), for its intended applications. At a minimum, the proposed project shall show:
a) Known cost factors, reliable data.
b) Reasonable cost for performance.
c) Consideration of installation costs.

a) Support of the proposed standard will probably require a manufacturer to develop a modified radio, modem and firmware. This is similar in principle to the transition between 802.11b and 802.11g or between 802.11b and 802.11a. The cost factors for these transitions are well known and the data for this is well understood.

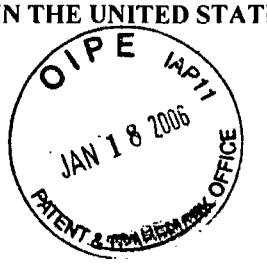
b) The new standard will provide manufacturers the option of supporting higher throughput. In general, the cost factor changes needed to implement the extensions envisioned by the study group are well within the capabilities of existing technology. Competition between manufacturers will ensure that costs remain reasonable.

c) The proposed amendment has no known impact on installation costs.

IFW

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE



In Re Application of:

Webster et al.

Serial No.: 11/121,661

Filed: May 4, 2005

For: Cyclic Diversity Systems an Methods

Group Art Unit: To Be Assigned

Examiner: To Be Assigned

Docket No.: 50337-1020

INFORMATION DISCLOSURE STATEMENT

Mail Stop Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

Sir:

This information disclosure statement is filed in accordance with 37 C.F.R. §§ 1.56, 1.97, and 1.98, and specifically:

☒ under 37 CFR 1.97(b), or
(within Three months of filing national application; or date of entry of international application; or before mailing date of first office action on the merits; whichever occurs last)

☐ under 37 CFR 1.97(c) together with either a:
- ☐ Statement Under 37 C.F.R. 1.97(e), or
- ☐ a $180.00 fee under 37 CFR 1.17(p), or

(After the CFR 1.97(b) time period, but before the final office action or notice of allowance, whichever occurs first)

☐ under 37 CFR 1.97(d) together with a:
- ☐ Statement under 37 CFR 1.97(e), and
- ☐ a $180.00 petition fee set forth in 37 CFR 1.17(p).

(Filed after final office action or notice of allowance, whichever occurs first, but before payment of the issue fee)

Enclosed is a check in the amount of $0.00.

Enclosed is Credit Card Payment Form (PTO-2038) in the amount of $0.00.

Please charge $0.00 to deposit account 20-0778. At any time during the pendency of this application, please charge any fees required to Deposit Account 20-0778 pursuant to 37 CFR 1.25. The Commissioner is hereby requested to credit any overpayment to Deposit Account No. 20-0778.

☒ Applicant(s) submit herewith *Form PTO 1449A - Information Disclosure Statement by Applicant* together with copies (where required) of patents, publications or other information of which applicant(s) are aware, which applicant(s) believe(s) may or may not be material to the examination of this application and for which there may be a duty to disclose in accordance with 37 CFR 1.56. As required by 37 C.F.R. §1.98(a), a legible copy of each document is provided.

☐ A concise explanation of the relevance of foreign language patents, foreign language publications and other foreign language information listed on PTO Form 1449, as presently understood by the individual(s) designated in 37 CFR 1.56(c) most knowledgeable about the content is given on the attached sheet, or where a foreign language patent is cited in a search report or other action by a foreign patent office in a counterpart foreign application, an English language version of the search report or action which indicates the degree of relevance found by the foreign office is listed on the form PTO 1449 and is enclosed herewith.

The following rights are reserved by the Applicant(s): the right to establish the patentability of the claimed invention over any of the listed documents should they be applied as reference, and/or the right to prove that some of these documents may not be prior art, and/or the right to prove that some of these documents may not be enabling for the teachings they purport to offer.

This statement should not be construed as a representation that an exhaustive search has been made, or that information more material to the examination of the present application does not exist. Any statements or identifications regarding the relevance of any portion(s) of cited references should not be construed as a representation that the most relevant portion(s) have been identified, and the absence of such statements or identifications should not be construed as representations that there are no relevant portion(s). The Examiner is specifically requested not to rely solely on the materials submitted herewith. The Examiner is requested to conduct an independent and thorough review of the documents, and to form independent opinions as to their significance.

It is requested that the information disclosed herein be made of record in this application and that the Examiner initial and return a copy of the enclosed PTO-1449 to indicate the documents have been considered.

Respectfully Submitted,

THOMAS, KAYDEN, HORSTEMEYER & RISLEY, L.L.P.

By: _____

David Rodack, Reg. No. 47,034

100 Galleria Parkway, Suite 1750
Atlanta, Georgia 30339-5948
770-933-9500

CERTIFIED MAILING

I hereby certify that this correspondence is being deposited with the United States Postal Service as **"First Class Mail,"** in an envelope addressed to: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on January 12, 2006

_____
Signature

OIPE JAN 18 2006 PATENT & TRADEMARK OFFICE

CERTIFICATE OF MAILING

I hereby certify that the below listed items are being deposited with the U.S. Postal Service as first class mail in an envelope addressed to:

Mail Stop Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

on January 12, 2006.

Gina Silverio

Gina Silverio

In Re Application Of: Webster, et al.

Group No.: 2661

Serial No.: 11/121,661

Docket No. 50337-1020

Filed: May 4, 2005

Confirmation No.: 3553

For: **Cyclic Diversity Systems And Methods**

The following is a list of documents enclosed:

Return Postcard
Information Disclosure Statement
Form PTO-1449
Prior Cited Art (3 References)

Further, the Commissioner is authorized to charge Deposit Account No. 20-0778 for any additional fees required. The Commissioner is requested to credit any excess fee paid to Deposit Account No. 20-0778.

OIPE JAN 18 2006 PATENT & TRADEMARK OFFICE

Form PTO-1449

INFORMATION DISCLOSURE CITATION

(Use several sheets if necessary)

Attorney Docket No.	Serial No.
50337-1020	**11/121,661**
Applicant: **Webster et al.**	
Filing Date: **05/04/05**	Group: **To Be Assigned**

U.S. PATENT DOCUMENTS

Examiner Initials	Item	Document Number	Date	Name	Class	Subclass	Filing Date If Appropriate
	A	US 2004/0047284	03/11/04	Eidson	370	203	
	B	US 2004/0266339	12/30/04	Larsson	455	7	
	C	6,842,487	01/11/05	Larsson	375	260	
	D						
	E						
	F						
	G						
	H						
	I						
	J						
	K						

FOREIGN PATENT DOCUMENTS

		Document Number	Date	Country	Class	Subclass	Translation	
							Yes	No
	L							
	M							
	N							
	O							

OTHER DOCUMENTS *(Including Author, Title, Date, Pertinent Pages, etc.)*

	P	Forms PCT/ISA/220, PCT/ISA/210 and PCT/ISA/237
	Q	
	R	

* EXAMINER: Initial if citation considered, whether or not citation is in conformance with MPEP § 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to the applicant.

EXAMINER'S SIGNATURE:	DATE CONSIDERED:

050337-1020 +
050337-2010

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

COPY PCT

To:
DAVID RODACK
THOMAS, KAYDEN, HORSTEMEYER & RISLEY, LLP
100 GALLERIA PKWY., NW
SUITE 1750
ATLANTA, GA 30339-5948

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT OR THE DECLARATION

(PCT Rule 44.1)

	Date of Mailing (*day/month/year*) 13 OCT 2005
Applicant's or agent's file reference 050337-2010	FOR FURTHER ACTION See paragraphs 1 and 4 below
International application No. PCT/US05/15436	International filing date (*day/month/year*) 04 May 2005 (04.05.2005)
Applicant CONEXANT SYSTEMS, INC.	

1. ☒ The applicant is hereby notified that the international search report has been established and is transmitted herewith.

   Filing of amendments and statement under Article 19:
   The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46):

   When? The time limit for filing such amendments is normally two months from the date of transmittal of the international search report.

   Where? Directly to the International Bureau of WIPO, 34, chemin des Colombettes 1211 Geneva 20, Switzerland, Facsimile No.: (41-22) 338.82.70.

   For more detailed instructions, see the notes on the accompanying sheet.

SCANNED

2. ☐ The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect is transmitted herewith.

3. ☐ **With regard to the protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:
   - ☐ the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.
   - ☐ no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Reminders**

   Shortly after **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90 *bis*.1 and 90 *bis*.3, respectively, before the completion of the technical preparations for international publication.

   Within **19 months** from the priority date, but only in respect of some designated Offices, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase **until 30 months** from the priority date (in some Offices even later); otherwise the applicant must, **within 20 months** from the priority date, perform the prescribed acts for entry into the national phase before those designated Offices.

   In respect of other designated Offices, the time limit of **30 months** (or later) will apply even if no demand is filed within 19 months.

   See the Annex to Form PCT/IB/301 and, for details about the applicable time limits, Office by Office, see the *PCT Applicant's Guide*, Volume II, National Chapters and the WIPO Internet site.

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/ US Commissioner for Patents P.O. Box 1450 Alexandria, Virginia 22313-1450 Facsimile No. (703) 305-3230	Authorized officer Min Jung Telephone No. 703-305-4750

DOCKETED

Form PCT/ISA/220 (April 2002) (*See notes on accompanying sheet*)

ISR RESPONSE DUE 12/13/05
IDS due 050337-1020 due 1/13/06
Demand due from priority date due 3/20/06

THOMAS, KAYDEN
HORSTEMEYER & RISLEY, L.L.P.

OCT 17 2005

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

To:
DAVID RODACK
THOMAS, KAYDEN, HORSTEMEYER & RISLEY, LLP
100 GALLERIA PKWY., NW
SUITE 1750
ATLANTA, GA 30339-5948

PCT

NOTIFICATION OF TRANSMITTAL OF
THE INTERNATIONAL SEARCH REPORT
OR THE DECLARATION

(PCT Rule 44.1)

Applicant's or agent's file reference 050337-2010	Date of Mailing (*day/month/year*) **FOR FURTHER ACTION** See paragraphs 1 and 4 below
International application No. PCT/US05/15436	International filing date (*day/month/year*) 04 May 2005 (04.05.2005)
Applicant CONEXANT SYSTEMS, INC.	

1. ☒ The applicant is hereby notified that the international search report has been established and is transmitted herewith.

Filing of amendments and statement under Article 19:
The applicant is entitled, if he so wishes, to amend the claims of the international application (see Rule 46):

When? The time limit for filing such amendments is normally two months from the date of transmittal of the international search report.

Where? Directly to the International Bureau of WIPO, 34, chemin des Colombettes 1211 Geneva 20, Switzerland, Facsimile No.: (41-22) 338.82.70.

For more detailed instructions, see the notes on the accompanying sheet.

2. ☐ The applicant is hereby notified that no international search report will be established and that the declaration under Article 17(2)(a) to that effect is transmitted herewith.

3. ☐ **With regard to the protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:

☐ the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.

☐ no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Reminders**

Shortly after **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90 *bis*.1 and 90 *bis*.3, respectively, before the completion of the technical preparations for international publication.

Within **19 months** from the priority date, but only in respect of some designated Offices, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase **until 30 months** from the priority date (in some Offices even later); otherwise the applicant must, **within 20 months** from the priority date, perform the prescribed acts for entry into the national phase before those designated Offices.

In respect of other designated Offices, the time limit of **30 months** (or later) will apply even if no demand is filed within 19 months.

See the Annex to Form PCT/IB/301 and, for details about the applicable time limits, Office by Office, see the *PCT Applicant's Guide*, Volume II, National Chapters and the WIPO Internet site.

Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/ US Commissioner for Patents P.O. Box 1450 Alexandria, Virginia 22313-1450 Facsimile No. (703) 305-3230	Authorized officer Min Jung Telephone No. 703-305-4750

Form PCT/ISA/220 (April 2002) *(See notes on accompanying sheet)*

BEST AVAILABLE COPY

THOMAS, KAYDEN
HORSTEMEYER & RISLEY, L.L.P.

OCT 17 2005

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 050337-2010	**FOR FURTHER ACTION**	see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.
International application No. PCT/US05/15436	International filing date (*day/month/year*) 04 May 2005 (04.05.2005)	(Earliest) Priority Date (*day/month/year*) 20 May 2004 (20.05.2004)
Applicant CONEXANT SYSTEMS, INC.		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 3 sheets.

☒ It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the Report**
   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.
   ☒ the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).
   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing:
   ☐ contained in the international application in written form.
   ☐ filed together with the international application in computer readable form.
   ☐ furnished subsequently to this Authority in written form.
   ☐ furnished subsequently to this Authority in computer readable form.
   ☐ the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   ☐ the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.
2. ☐ **Certain claims were found unsearchable** (See Box I).
3. ☐ **Unity of invention is lacking** (See Box II).
4. With regard to the **title**,
   ☒ the text is approved as submitted by the applicant.
   ☐ the text has been established by this Authority to read as follows:

5. With regard to the **abstract**,
   ☒ the text is approved as submitted by the applicant.
   ☐ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 6
   ☐ as suggested by the applicant. ☐ None of the figures
   ☒ because the applicant failed to suggest a figure.
   ☐ because this figure better characterizes the invention.

Form PCT/ISA/210 (first sheet) (July 1998)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US05/15436

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : H04J 11/00
US CL : 370/203; 375/299
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 370/203; 375/299; 455/101

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Please See Continuation Sheet

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2004/0047284 (EIDSON) 11 March 2004, see page 1, paragraphs [0007] and [0008], and page 3, paragraph [0036].	1-10
A, P	US 2004/0266339 (LARSSON) 30 December 2004, see entire document.	1-10
A, P	US 6,842,487 (LARSSON) 11 January 2005, see entire document.	1-10

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"B" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
01 September 2005 (01.09.2005)

Date of mailing of the international search report
19 OCT 2005

Name and mailing address of the ISA/US
Mail Stop PCT, Attn: ISA/US
Commissioner of Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450
Facsimile No. (703) 305-3230

Authorized officer
Min Jung
Telephone No. 703-305-4750

Form PCT/ISA/210 (second sheet) (July 1998)

INTERNATIONAL SEARCH REPORT

PCT/US05/15436

Continuation of B. FIELDS SEARCHED Item 3:
EAST
search terms: cyclic adj2 diversity, shft diversity, delay diversity, advance diversity, cyclic advance, cyclic delay, linear adj2 delay, guard, guard adj time; guard adj period; OFDM, cyclic adj extension

PATENT COOPERATION TREATY

From the
INTERNATIONAL SEARCHING AUTHORITY

To:
DAVID RODACK
THOMAS, KAYDEN, HORSTEMEYER & RISLEY, LLP
100 GALLERIA PKWY., NW
SUITE 1750
ATLANTA, GA 30339-5948

PCT

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

(PCT Rule 43*bis*.1)

Date of mailing *(day/month/year)*	13 OCT 2005
Applicant's or agent's file reference 050337-2010	FOR FURTHER ACTION See paragraph 2 below

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/US05/15436	04 May 2005 (04.05.2005)	20 May 2004 (20.05.2004)

International Patent Classification (IPC) or both national classification and IPC

IPC(7): H04J 11/00 and US Cl.: 370/203; 375/299

Applicant

CONEXANT SYSTEMS, INC.

1. This opinion contains indications relating to the following items:

- ☒ Box No. I — Basis of the opinion
- ☐ Box No. II — Priority
- ☐ Box No. III — Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- ☐ Box No. IV — Lack of unity of invention
- ☒ Box No. V — Reasoned statement under Rule 43*bis*.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- ☐ Box No. VI — Certain documents cited
- ☐ Box No. VII — Certain defects in the international application
- ☐ Box No. VIII — Certain observations on the international application

2. **FURTHER ACTION**

If a demand for international preliminary examination is made, this opinion will be considered to be a written opinion of the International Preliminary Examining Authority ("IPEA") except that this does not apply where the applicant chooses an Authority other than this one to be the IPEA and the chosen IPEA has notified the International Bureau under Rule 66.1*bis*(*b*) that written opinions of this International Searching Authority will not be so considered.

If this opinion is, as provided above, considered to be a written opinion of the IPEA, the applicant is invited to submit to the IPEA a written reply together, where appropriate, with amendments, before the expiration of 3 months from the date of mailing of Form PCT/ISA/220 or before the expiration of 22 months from the priority date, whichever expires later.

For further options, see Form PCT/ISA/220.

3. For further details, see notes to Form PCT/ISA/220.

Name and mailing address of the ISA/ US	Date of completion of this opinion	Authorized officer
Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450 Alexandria, Virginia 22313-1450 Facsimile No. (703) 305-3230	23 September 2005 (23.09.2005)	Min Jung Telephone No. 703-305-4750

Form PCT/ISA/237 (cover sheet) (April 2005)

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US05/15436

Box No. I Basis of this opinion

1. With regard to the **language**, this opinion has been established on the basis of:

☒ the international application in the language in which it was filed

☐ a translation of the international application into _____, which is the language of a translation furnished for the purposes of international search (Rules 12.3(a) and 23.1(b)).

2. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application and necessary to the claimed invention, this opinion has been established on the basis of:

a. type of material

☐ a sequence listing

☐ table(s) related to the sequence listing

b. format of material

☐ on paper

☐ in electronic form

c. time of filing/furnishing

☐ contained in the international application as filed.

☐ filed together with the international application in electronic form.

☐ furnished subsequently to this Authority for the purposes of search.

3. ☐ In addition, in the case that more than one version or copy of a sequence listing and/or table(s) relating thereto has been filed or furnished, the required statements that the information in the subsequent or additional copies is identical to that in the application as filed or does not go beyond the application as filed, as appropriate, were furnished.

4. Additional comments:

WRITTEN OPINION OF THE INTERNATIONAL SEARCHING AUTHORITY

International application No.
PCT/US05/15436

Box No. V Reasoned statement under Rule 43 *bis*.1(a)(i) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Claims 1-10	YES
	Claims NONE	NO
Inventive step (IS)	Claims 1-10	YES
	Claims NONE	NO
Industrial applicability (IA)	Claims 1-10	YES
	Claims NONE	NO

2. Citations and explanations:

Claims 1-6 meet the criteria set out in PCT Article 33(2)-(3), because the prior art does not teach or fairly suggest a cyclic diversity method comprising providing an orthogonal frequency division multiplexing segment corresponding to a first transmit antenna; and cyclically advancing, or performing the periodic equivalent of the same, one or more sections of the OFDM segment corresponding to a second transmit antenna, the duration of the cyclic advance having a duration less than a guard interval.

Claims 7-10 meet the criteria set out in PCT Article 33(2)-(3), because the prior art does not teach or fairly suggest a cyclic diversity system comprising a logic configured to cyclically advance, or perform the periodic equivalent of the same, one or more sections of an orthogonal frequency division multiplexing segment relative to the OFDM segment to be transmitted on a first transmit antenna, the segment having the one or more cyclically advanced sections to be transmitted on a second transmit antenna, the duration of the cyclic advance having a duration less than a guard interval.

NOTES TO FORM PCT/ISA/220 (continued)

The letter must indicate the differences between the claims as filed and the claims as amended. It must, in particular, indicate, in connection with each claim appearing in the international application (it being understood that identical indications concerning several claims may be grouped), whether

(i) the claim is unchanged;
(ii) the claim is cancelled;
(iii) the claim is new;
(iv) the claim replaces one or more claims as filed;
(v) the claim is the result of the division of a claim as filed.

The following examples illustrate the manner in which amendments must be explained in the accompanying letter:

1. [Where originally there were 48 claims and after amendment of some claims there are 51]:
"Claims 1 to 29, 31, 32, 34, 35, 37 to 48 replaced by amended claims bearing the same numbers; claims 30, 33 and 36 unchanged; new claims 49 to 51 added."

2. [Where originally there were 15 claims and after amendment of all claims there are 11]:
"Claims 1 to 15 replaced by amended claims 1 to 11."

3. [Where originally there were 14 claims and the amendments consist in cancelling some claims and in adding new claims]:
"Claims 1 to 6 and 14 unchanged; claims 7 to 13 cancelled; new claims 15, 16 and 17 added." or
"Claims 7 to 13 cancelled; new claims 15, 16 and 17 added; all other claims unchanged."

4. [Where various kinds of amendments are made]:
"Claims 1-10 unchanged; claims 11 to 13, 18 and 19 cancelled; claims 14, 15 and 16 replaced by amended claim 14; claim 17 subdivided into amended claims 15, 16 and 17; new claims 20 and 21 added."

"Statement under Article 19(1)" (Rule 46.4)

The amendments may be accompanied by a statement explaining the amendments and indicating any impact that such amendments might have on the description and the drawings (which cannot be amended under Article 19(1)).

The statement will be published with the international application and the amended claims.

It must be in the language in which the international application is to be published.

It must be brief, not exceeding 500 words if in English or if translated into English.

It should not be confused with and does not replace the letter indicating the differences between the claims as filed and as amended. It must be filed on a separate sheet and must be identified as such by a heading, preferably by using the words "Statement under Article 19(1)."

It may not contain any disparaging comments on the international search report or the relevance of citations contained in that report. Reference to citations, relevant to a given claim, contained in the international search report may be made only in connection with an amendment of that claim.

Consequence if a demand for international preliminary examination has already been filed

If, at the time of filing any amendments and any accompanying statement, under Article 19, a demand for international preliminary examination has already been submitted, the applicant must preferably, at the time of filing the amendments (and any statement) with the International Bureau, also file with the International Preliminary Examining Authority a copy of such amendments (and of any statement) and, where required, a translation of such amendments for the procedure before that Authority (see Rules 55.3(a) and 62.2, first sentence). For further information, see the Notes to the demand form (PCT/IPEA/401).

Consequence with regard to translation of the international application for entry into the national phase

The applicant's attention is drawn to the fact that, upon entry into the national phase, a translation of the claims as amended under Article 19 may have to be furnished to the designated/elected Offices, instead of, or in addition to, the translation of the claims as filed.

For further details on the requirements of each designated/elected Office, see the *PCT Applicant's Guide*, Volume II.

IDS

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re the application of: WEBSTER, *et al.*

Serial Number: 11/121,661

Filing Date: May 4, 2005

Title: Cyclic Diversity Systems and Methods



Confirmation: 3553

Art Unit: 2661

Examiner: TBA

Docket No.: 50337-1020

INFORMATION DISCLOSURE STATEMENT

Mail Stop Amendment
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

Sir:

This information disclosure statement is filed in accordance with 37 C.F.R. §§ 1.56, 1.97, and 1.98, and specifically:

☒ under 37 CFR 1.97(b), or
(within Three months of filing national application; or date of entry of international application; or before mailing date of first office action on the merits; whichever occurs last)

☐ under 37 CFR 1.97(c) together with either a:
- ☐ Statement Under 37 C.F.R. 1.97(e), or
- ☐ a $180.00 fee under 37 CFR 1.17(p), or

(After the CFR 1.97(b) time period, but before the final office action or notice of allowance, whichever occurs first)

☐ under 37 CFR 1.97(d) together with a:
- ☐ Statement under 37 CFR 1.97(e), and
- ☐ a $180.00 petition fee set forth in 37 CFR 1.17(p).

(Filed after final office action or notice of allowance, whichever occurs first, but before payment of the issue fee)

☐ Enclosed is a check in the amount of $.

☐ Enclosed is Credit Card Payment Form (PTO-2038) in the amount of $.

☐ Please charge $ to deposit account .

☒ At any time during the pendency of this application, please charge any fees required to Deposit Account 20-0778 pursuant to 37 CFR 1.25. The Commissioner is hereby requested to credit any overpayment to Deposit Account No.20-0778.

☒ Applicant(s) submit herewith *Form PTO 1449A - Information Disclosure Statement by Applicant* together with copies (where required) of patents, publications or other information of which applicant(s) are aware, which applicant(s) believe(s) may or may not be material to the examination of this application and for which there may be a duty to disclose in accordance with 37 CFR 1.56. As required by 37 C.F.R. §1.98(a), a legible copy of each document is provided.

☐ A concise explanation of the relevance of foreign language patents, foreign language publications and other foreign language information listed on PTO Form 1449, as presently understood by the individual(s) designated in 37 CFR 1.56(c) most knowledgeable about the content is given on the attached sheet, or where a foreign language patent is cited in a search report or other action by a foreign patent office in a counterpart foreign application, an English language version of the search report or action which indicates the degree of relevance found by the foreign office is listed on the form PTO 1449 and is enclosed herewith.

The following rights are reserved by the Applicant(s): the right to establish the patentability of the claimed invention over any of the listed documents should they be applied as reference, and/or the right to prove that some of these documents may not be prior art, and/or the right to prove that some of these documents may not be enabling for the teachings they purport to offer.

This statement should not be construed as a representation that an exhaustive search has been made, or that information more material to the examination of the present application does not exist. Any statements or identifications regarding the relevance of any portion(s) of cited references should not be construed as a representation that the most relevant portion(s) have been identified, and the absence of such statements or identifications should not be construed as representations that there are no relevant portion(s). The Examiner is specifically requested not to rely solely on the materials submitted herewith. The Examiner is requested to conduct an independent and thorough review of the documents, and to form independent opinions as to their significance.

It is requested that the information disclosed herein be made of record in this application and that the Examiner initial and return a copy of the enclosed PTO-1449 to indicate the documents have been considered.

Respectfully Submitted,

THOMAS, KAYDEN, HORSTEMEYER & RISLEY, L.L.P.

By: _____

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CERTIFIED MAILING

I hereby certify that this correspondence is being deposited with the United States Postal Service as "First Class Mail," in an envelope addressed to: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450 on August 14, 2006.

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Form PTO-1449	Attorney Docket No. 50337-1020	Serial No. 11/121/661
INFORMATION DISCLOSURE CITATION	Applicant Webster et al.	
(Use several sheets if necessary)	Filing Date May 4, 2005	Group TBA

U.S. PATENT DOCUMENTS

Examiner Initials	Item	Document Number	Date	Name	Class	Subclass	Filing Date If Appropriate
	A	US 2002/0136276 A 1	09/26/02	Franceschini, et al.	375	148	03/08/01
	B	US 6,754,170 B1	06/22/04	Ward	370	208	09/29/00
	C	US 6,574,237 B1	06/03/03	Bullman, et al.	370	465	06/30/99
	D	US 2003/0012160 A1	01/16/03	Webster, et al.	370	335	05/10/02
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	G	US 2003/0185241 A1	10/02/03	Lu, et al.	370	476	08/16/02
	H						
	I						
	J						
	K						

FOREIGN PATENT DOCUMENTS

		Document Number	Date	Country	Class	Subclass	Translation	
							Yes	No
	L							
	M							
	N							
	O							

OTHER DOCUMENTS *(Including Author, Title, Date, Pertinent Pages, etc.)*

	P	WEBSTER, et al., " LEGACY COMPATIBLE SPATIAL MULTIPLEXING SYSTEMS AND METHODS," having serial number 11/159,812, filed June 22, 2005.
	Q	WEBSTER, et al., "SYSTEMS AND METHODS FOR TRANSMITTER DIVERSITY EXPANSION," having
		serial number 11/411,619, filed April 26, 2006.
	R	WEBSTER, et al. "PACKET GENERATION SYSTEMS AND METHODS," having serial number 11/106,915, filed April 15, 2005.
	S	IEEE P802.11-Task Group N-Meeting Update, http://grouper.ieee.org/groups/802/11/Reports/tgn_update.htm, pp. 1-7.
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	DD	Aon Mujtaba, Adrian P. Stephens, Alek Purkovic, Andrew Myles, Brian Johnson, Daisuke Takeda, Darren McNamara, Dongjun (DJ) Lee, David Bagby, Eldad Perahia, Huanchun Ye, Hui-Ling Lou, James Chen, James Mike Wilson, Jan Boer, Jari Jokela, Jeff Gilbert, Joe Pitarressi, Jorg Habetha, John Sadowsky, Jon Rosdahl, Luke Qian, Mary Cramer , Masahiro Takagi, Monisha Ghosh, Nico van Waes, Osama Aboul-Magd, Paul Feinberg, Pen Li, Peter Loc, Pieter-Paul Giesberts, Richard van Leeuwen, Ronald Rietman, Seigo Nakao, Sheung Li, Stephen Shellhammer, Takushi Kunihior, Teik-Kheong, Tomoko Adachi, Tomoya Yamaura, Tsuguhide Aoki, Won-Joon Choi, Xiaowen Wang, Yasuhiko Tanabe, Yasuhiro Tanaka, Yoshiharu Doi, Yichi Morioka, Youngsoo Kim, "TGn Sync Proposal," IEEE 802.11-04/888r0, August 13, 2004.
	EE	VK Jones, Neil Hamady, Jason Trachewsky, Michael Seals, Stephan ten Brink, George Vlantis, Sean Coffey, "WwiSE IEEE 802.11n Proposal," IEEE 802.11-04/0935r3, September 16, 2004.

* EXAMINER: Initial if citation considered, whether or not citation is in conformance with MPEP § 609. Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to the applicant.

EXAMINER'S SIGNATURE:	DATE CONSIDERED:

Patent and Trademark Office; U. S. DEPARTMENT OF COMMERCE

S/N 11/159,812

LEGACY COMPATIBLE SPATIAL MULTIPLEXING SYSTEMS AND METHODS

INVENTORS
MARK A. WEBSTER
MICHAEL J. SEALS

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the priority and benefit of copending U.S. provisional application having serial no. 60/581,358, filed June 22, 2004, which is entirely incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention.

The present disclosure is generally related to communication systems, and, more particularly, is related to wireless communication systems and methods.

2. Related Art.

Wireless communication systems are widely deployed to provide various types of communication such as voice, data, and so on. These systems may be based on code division multiple access (CDMA), time division multiple access (TDMA), orthogonal frequency division multiplex (OFDM), or some other multiplexing techniques. OFDM systems may provide high performance for some channel environments. FIG. 1A is a block diagram that illustrates an exemplary single-in, single-out (SISO) orthogonal frequency division multiplexing (OFDM) communication system 100 (herein, SISO system 100) that is compliant with IEEE

802.11 standards. The SISO system 100 comprises a transmitter device 102 and a receiver device 104. The transmitter device 102 comprises a transmit (TX) processor 106, radio circuitry 108, and antenna 110. The receiver device 104 comprises an antenna 112, radio circuitry 114, and receive (RX) processor 116.

The transmitter device 102 comprises well-known circuitry that divides the high-speed data signals into tens or hundreds of lower speed signals and transmits the signals in parallel over respective frequencies within a radio frequency (RF) signal that comprise subcarrier frequencies ("subcarriers"). The frequency spectra of the subcarriers overlap so that the spacing between them is minimized. The subcarriers are also orthogonal to each other so that they are statistically independent and do not create cross-talk or otherwise interfere with each other. FIG. 1B is a schematic diagram that illustrates an exemplary OFDM symbol 118 corresponding to signals processed in the SISO system 100. In 802.11 standards, each OFDM symbol 118 provided by the transmitter device 102 comprises 52 subcarriers (partially shown for brevity) centered at a defined reference or carrier frequency, with a bandwidth (BW) of approximately 20 mega-Hertz (MHz). The spectrum resulting from processing at the receiver device 104 is typically centered at the same reference or carrier frequency.

In operation, the transmit processor 106 receives data signals (designated as TX data1 at a defined data rate designated as TX Rate1). The transmit processor 106 encodes and interleaves the data and maps the interleaved data into respective subcarrier channels as frequency domain symbols. Further processing by the transmit processor 106 may result in the insertion of training signals, cyclic

extensions (*e.g.*, guard intervals), and additional processing such as inverse fast Fourier transformations (IFFT) and wave shaping. The processed subcarriers are provided to the radio circuitry 108, which provides filtering, modulation, amplification, and upconversion functionality, ultimately resulting in the transmission of data from antenna 110.

FIG. 1C is block diagram that describes an exemplary OFDM packet structure 150 used in the transmission of information between the transmitter device 102 and the SISO receiver device 104. Additional information about the packet structure can be found in 802.11 standards. The packet structure 150 is generated in a baseband processing section (*e.g.*, in or in cooperation with an inverse fast Fourier transform (IFFT) operation) of the transmitter device 102, and comprises several sections. Sections A and B are comprised of short training symbols (STS). Section A is used by a communication system to provide signal detection, automatic gain control (AGC), and diversity selection functionality. Section B is used by a communication system to provide coarse frequency offset estimation and timing synchronization. Section C, sometimes referred to as a long training symbol (LTS), is used by a communication system to provide channel estimation and fine frequency offset estimation. Sections A-C are typically referred to as the preamble portion of a packet. Section D is referred to as the signal field or header, and contains data rate and packet length information. Sections E and F are OFDM symbols, such as OFDM symbol 118a. Sections D, E, and F provide rate length, service and data, and data, respectively.

At the receiver device 104, the antenna 112 receives the transmitted data, which is provided to radio circuitry 114 to complement the processing that occurred at radio circuitry 108. The data is then provided to receive (RX) processor 116, which provides clock recovery, cyclic extension removal, transformations (*e.g.*, fast Fourier transformation, FFT), demapping, deinterleaving, and decoding to recover the TX data1 as RX data1. Transmitter and receiver devices that are compliant to IEEE 802.11a/g standards, such as shown in FIG. 1A, are often referred to as legacy radios or legacy devices.

Continual demand for increased data rates has resulted in the advancement of communications system technology, such as the use of multiple antennas in a single device having transmitter and/or receiver functionality. In terrestrial communication systems (*e.g.*, a cellular system, a broadcast system, a multi-channel multi-point distribution system (MMDS), among others), a RF modulated signal from a transmitter device may reach a receiver device via a number of transmission paths. The characteristics of the transmission paths typically vary over time due to a number of factors such as fading and multi-path. To provide diversity against deleterious path effects and improve performance, multiple transmit and receive antennas may be used for data transmission. Spatial multiplexing refers to a technique where a transmission channel is divided into multiple "spatial channels" through which independent streams can be transmitted and received via multiple transmit and receive antennas, respectively.

FIG. 2 is a block diagram that illustrates a multiple-input multiple-output (MIMO) OFDM communication system 200 (herein, MIMO system 200). The

MIMO system 200 employs multiple transmit antennas and multiple receive antennas for data transmission. Through spatial multiplexing, a MIMO channel formed by the transmit and receive antennas may be decomposed into independent channels. Each of the independent channels is also referred to as a spatial subchannel of the MIMO channel. The MIMO system 200 comprises a transmitter device 202 and receiver device 204. The transmitter device 202 comprises transmit (TX) processors 206 and 212, radio circuitry 208 and 214, and antennas 210 and 216. The receiver device 204 comprises antennas 218 and 226, radio circuitry 220 and 228, and receive (RX) processors 224 and 230. The transmit processors 206 and 212 and the radio circuitry 208 and 214 comprise similar circuitry to that found in and described for transmit processor 106 (FIG. 1A), with the addition of circuitry for implementing spatial multiplexing. The radio circuitry 220 and 228 and receive processors 224 and 230 also share common circuitry with like components shown in and described for receiver device 104 (FIG. 1A). The receive processors may comprise signal separating functionality to remove interference caused by multiple transmit signals occupying the same bandwidth at the receive antennas 218 and 226, and thus may be used to increase the data rate.

In developing systems such as MIMO that utilize multiple-antenna devices, there is a need to consider legacy receivers (*e.g.*, single-input, single output (SISO), OFDM receivers) and the design challenges concomitant with implementing transmitters with multiple antennas in an environment that still uses legacy receivers.

SUMMARY

Embodiments of legacy compatible spatial multiplexing systems and methods are disclosed. One method embodiment, among others, comprises receiving long training symbols and cyclic shifted long training symbols corresponding to legacy preamble portions of packets corresponding to first and second transmit signals, receiving long training symbols and inverted cyclic shifted long training symbols corresponding to spatial multiplexing portions of packets corresponding to first and second transmit signals, and combining the symbols corresponding to the first and second transmit antennas to estimate the respective channels.

Other systems, methods, features, and advantages of the disclosed systems and methods will be or become apparent to one with skill in the art upon examination of the following drawings and detailed description. It is intended that all such additional systems, methods, features, and advantages be included within this description and be within the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

Many aspects of the disclosed systems and methods can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the disclosed systems and methods. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

FIG. 1A is a block diagram that illustrates an exemplary single-in, single-out (SISO) orthogonal frequency division multiplexing (OFDM) communication system.

FIG. 1B is a schematic diagram that illustrates subcarriers of an OFDM symbol processed in the SISO OFDM communication system shown in FIG. 1A.

FIG. 1C is a block diagram that illustrates an exemplary OFDM packet structure used in SISO and multiple-input, multiple-output (MIMO) OFDM communication systems.

FIG. 2 is a block diagram that illustrates a MIMO OFDM communication system.

FIG. 3 is a block diagram that illustrates an embodiment of a legacy compatible spatial multiplexing (LCSM) system.

FIG. 4A is a block diagram that illustrates an embodiment of a transmit module of the LCSM system shown in FIG. 3.

FIG. 4B is a block diagram that illustrates an embodiment of a long training symbol (LTS) generator of the transmit module shown in FIG. 4A.

FIG. 4C is a block diagram that illustrates an embodiment of a short training symbol (STS) generator of the transmit module shown in FIG. 4A.

FIG. 4D is a block diagram that illustrates an exemplary packet structure generated by the waveshape logic and transmitted from a first antenna shown in FIG. 4A.

FIG. 5A is a block diagram that illustrates an embodiment of a cyclic shift transmit module of the LCSM system shown in FIG. 3.

FIGs. 5B-5C are block diagrams that illustrate two embodiments of an inverted LTS-CS (cyclic shifted) generator shown in FIG. 5A.

FIG. 5D is a block diagram that illustrates an exemplary packet structure generated by the waveshape logic and transmitted from a second antenna shown in FIG. 5A.

FIG. 6 is a block diagram that illustrates receive module embodiments of the LCSM system shown in FIG. 3.

FIGs. 7A-7B are block diagrams that illustrate embodiments of receive logic of one of the receive modules shown in FIG. 6 corresponding to channel estimation.

FIGs. 8A-8B are block diagrams that illustrate embodiments of receive logic of one of the receive modules shown in FIG. 6 corresponding to channel estimation with at least one channel estimate having a cyclic shift.

FIG. 9 is a flow diagram that illustrates one method embodiment for generating a packet having a legacy preamble and spatial multiplexing portion.

FIG. 10 is a flow diagram that illustrates one channel estimating method embodiment.

DETAILED DESCRIPTION

Disclosed are various embodiments of legacy compatible, spatial multiplexing (SM) systems and methods (herein, referred to as LCSM systems). Such embodiments are described in the context of multiple-input multiple-output (MIMO), orthogonal frequency division multiplex (OFDM) communication systems. In one embodiment, an LCSM system comprises one or more transmit modules that

include waveshape logic configured to generate transmit waveforms (*e.g.*, packet segments) that enable a receiver to implement channel estimate processing corresponding to signals emitted from multiple transmit antennas. The waveshape logic generates, in one embodiment, a two-part packet that is employed in both MIMO spatial multiplexed packet transmission and reception and legacy transmission and reception. That is, a first portion of a packet includes a legacy preamble that is compatible for use with legacy receivers (*e.g.*, 801.11a/g receivers). Legacy receivers recognize the first portion as a normal legacy preamble, and thus process the corresponding packet in a conventional manner. A second portion of the packet includes a cyclic shifted, inverted long training symbol that is used to enable successful processing by a SM MIMO receiver (*e.g.*, 802.11n compatible receiver).

Certain LCSM system embodiments described herein reuse the cyclic shifted legacy portion of a packet to enable orthogonal channel estimation at either a MIMO receiver in a spatial multiplexing environment or a legacy receiver. With spatial multiplexing techniques, two or more signals can be delivered in the same frequency channel, providing a mechanism for a receiver to exploit multipath signals (*e.g.*, signals emitted from each transmit antenna that bounce off structures to create multiple signals arriving at different angles at a receiver) to mitigate or eliminate interference that the receiver experiences between two or more transmit signals. That is, the cyclic shift, which may be implemented as an advance or delay, mitigates (or eliminates) self-interference of a preamble portion of the transmitted signal, and enables the transmission of legacy preamble portions provided from multiple transmit antennas. By reusing the cyclic shifted preambles, channel

estimation is efficient since such channel estimation makes use of the legacy portion of the packet. Reusing the cyclic shifted portion also allows digital circuitry to be reused.

In one embodiment, channel estimation is performed using Walsh coding, which is a well-known waveform algorithm that uses addition and subtraction to separate two signals. Thus, joint channel estimation of signals, provided from multiple transmit antennas, by a receiver is enabled with reuse of the legacy preamble in the channel estimation.

Certain LCSM system embodiments are described in the context of a 2 x 2 MIMO OFDM system that utilizes Walsh code orthogonalization. However, one of ordinary skill in the art would appreciate that other spatial multiplexing orders (*e.g.*, 3 x 3, 4 x 4, *etc.*) and other channel estimation methods can be used and hence are considered within the scope of the disclosure.

FIG. 3 is a block diagram that illustrates an embodiment of a LCSM system 300. The LCSM system 300, though shown encompassing transmit and receive components, may comprise select components of one or more of the same in some embodiments. In one embodiment, the LCSM system 300 comprises a multiple-input multiple-output (MIMO), orthogonal frequency division multiplexing (OFDM) communication system that generates a packet having a legacy preamble portion and a MIMO spatial multiplexing portion, and reuses the legacy preamble portion to provide orthogonal channel estimation. The LCSM system 300 comprises a transmitter device 302 and a receiver device 304. The transmitter device 302 may include functionality of the receiver device 304, and the receiver device 304 may

comprise functionality of the transmitter device 302. Further, the described embodiments may be embodied in many wireless communication devices, including computers (desktop, portable, laptop, *etc.*), consumer electronic devices (*e.g.*, multi-media players), compatible telecommunication devices, telephone communication systems and devices (*e.g.*, voice over IP phones), personal digital assistants (PDAs), or any other type of network devices, such as printers, fax machines, scanners, hubs, switches, routers, set-top boxes, televisions with communication capability, *etc.*

The transmitter device 302 comprises two modules 334 and 336. Module 334 comprises a transmit (TX) processor 306, radio circuitry 310, and an antenna 314 (herein, also first transmit antenna, or T_{X1}). Module 336 comprises a transmit (TX) processor 308, radio circuitry 312, and antenna 316 (herein, also second transmit antenna, or T_{X2}). The transmit processors 306 and 308 comprise waveshape logic 350a and 350b, respectively. The waveshape logic 350a, 350b generate two-part packets, as described below. Briefly, for data symbols and signal fields, transmit processors 306 and 308 encode and interleave the incoming data (designated TX data1 and TX data2 at TX data rate1 and TX data rate2, respectively). Transmit processors 306 and 308 map the interleaved data into respective subcarrier channels as frequency domain symbols, and include further processing for the insertion of training signals, cyclic extensions (*e.g.*, guard intervals), preamble generation, and inverse fast Fourier transformation (IFFT) and wave shaping. The processed subcarriers are provided to the radio circuitry 310 and 312, which provides filtering, modulation, and amplification functionality.

The receiver device 304 comprises modules 338 and 340. Module 338 comprises an antenna 318 (herein, also first receive antenna, or R_{X1}), radio circuitry 322, and receive (RX) processor 326. Receive processor 326 comprises receive (RX) logic 360a, which provides channel estimation functionality and multipath separation as described below. The module 338 may comprise additional circuitry, such as a signal separator, among other components as would be understood by one having ordinary skill in the art. Module 340 comprises an antenna 320 (herein, also second receive antenna, or R_{X2}), radio circuitry 324, and receive (RX) processor 328, which comprises receive (RX) logic 360b, which provides channel estimation functionality and multipath separation as described below. The module 340 may comprise additional circuitry, such as a signal separator, among other components as would be understood by one having ordinary skill in the art.

At the receiver device 304, the antennas 318 and 320 receive the transmitted data, and provide the same to radio circuitry 322 and 324, which provide downconversion functionality among other functionality to complement the processing that occurred at radio circuitry 310 and 312. The corresponding downconverted signals are provided to receive processors 326 and 328 to separate multipath signals and recover the original data as RX data1 and RX data2. Receive processors 326 and 328 may provide clock recovery, cyclic extension removal, transformation (*e.g.*, fast Fourier transformation, FFT), demapping, deinterleaving, and/or decoding functionality, among other functionality.

One or more components of the LCSM system 300, such as the waveshape logic 350a, 350b and the receive logic 360a, 360b, can be implemented using digital

circuitry, analog circuitry, or a combination of both. Also, one or more components of the LCSM system 300 can be implemented in hardware, software, firmware, or a combination thereof. If implemented in hardware, the one or more components of the LCSM system 300 can be implemented with any or a combination of the following technologies, which are all well known in the art: a discrete logic circuit(s) having logic gates for implementing logic functions upon data signals, an application specific integrated circuit (ASIC) having appropriate combinational logic gates, a programmable gate array(s) (PGA), a field programmable gate array (FPGA), *etc.*

If implemented partly or wholly in software, the one or more components of the LCSM system 300 can be comprised of software or firmware that is stored in a memory and that is executed by a suitable instruction execution system.

FIG. 4A is a block diagram that illustrates an embodiment of the module 334 of FIG. 3. The module 334 comprises the transmit processor 306, radio 310, and first antenna 314. The transmit processor 306 comprises a waveshape logic 350a for generating the packet structure. The waveshape logic comprises a legacy preamble/signal field (SF) generator 319. The legacy preamble/SF generator 319 comprises a short training symbol (STS) generator 301, a long training symbol (LTS) generator 303a, a SF1 generator 305, and a switch 311. The STS generator 301 and LTS generator 303a are configured to generate segments of a legacy preamble. The STS generator 301 generates a STS segment and the LTS generator 303a generates a LTS segment in conformity to 802.11 standards. The SF1 generator 305 generates a signal field segment. These segments are input to the

switch 311, and based on a control signal (Select1), are provided as a coordinated output to switch 313, which also is part of the waveshape logic 350a. The waveshape logic 350a further includes a LTS generator 303b, a SF2 generator 307, and a data symbol generator 309. In one embodiment, the LTS generator 303b is the same device as the LTS generator 303a, just designated with different letters ("a" and "b") to distinguish their respective role in supply a LTS segment for a legacy preamble portion (LTS generator 303a) and a spatial multiplexing portion (LTS generator 303b). The SF2 generator 307 receives data rate information, among other information pertaining to spatial multiplexing environments, and the data symbol generator 309 receives data bits. The switch 313 receives the respective segments from generators 303b, 307, and 309, and also receives the segments from switch 311, and based on the control input (Select2), provides the segments in coordinated fashion to the digital-to-analog (D/A) converter 315a of the transmit processor 306.

It would be understood by one having ordinary skill in the art that transmit processor 306 may comprise additional circuitry, such as a forward error correction (FEC) encoder and an interleaver/mapper to be used in conjunction with data symbol and signal field processing as is known, as well as symbol shape logic, among other components. For instance, an FEC encoder (or FEC coder) may receive information from a data source and encode the received information according to one or more encoding schemes. The FEC encoder may provide the encoded information to an interleaver/mapper, which interleaves or distributes the encoded information and maps (*e.g.*, over approximately 64-subcarriers) the same for use over the first

transmit antenna 314. Symbol shape logic provides interpolator functionality as well as low-pass filter smoothing of edges between successive OFDM symbols, in one embodiment creating tapered trailer and leading edges of each OFDM symbol.

The radio 310 receives the analog signal corresponding to the packet structure generated in the waveshape logic 350a. The radio 310 comprises a modulator 314a (*e.g.*, in-phase/ quadrature (I/Q) modulator and oscillator), conversion logic 316a (*e.g.*, oscillator and mixer), and high power amplifier (HPA) 318a. It would be appreciated by one having ordinary skill in the art that fewer, additional, and/or different components can be included in the module 334. Within the radio 310, the analog transmission signals are modulated, upconverted, and amplified/filtered at modulator 314a, conversion logic 316a, and HPA 318a, respectively. The resulting signal is then transmitted over first transmit antenna 314.

FIG. 4B illustrates an embodiment of LTS generator 303a, 303b, and comprises a long training symbol (LTS) subcarrier stack 402, inverse fast Fourier transform (IFFT) circuitry 404 (*e.g.*, 64-point IFFT), and an add guard interval module 406. LTS subcarriers from the LTS subcarrier stack 402 are provided to the IFFT circuitry 404 for formation into an OFDM symbol. The IFFT circuitry 404 converts the subcarriers to its corresponding time-domain representation (an OFDM symbol), and removes various subcarriers.

FIG. 4C is a block diagram that illustrates an embodiment of the STS generator 301. Like the LTS generator 303a, 303b, the STS generator 301 generates a deterministic signal waveform that is used at a receiver to estimate channel information. The STS generator 301 comprises a STS subcarrier stack 401 that

feeds an IFFT 403. The components of the STS generator comprise similar functionality for STS generating STS segments as like components described above for the LTS segments, and thus discussion of the same is omitted for brevity.

FIG. 4D is a block diagram that illustrates an exemplary packet structure generated 400 generated by the waveshape logic 350a and transmitted from the first transmit antenna 314 (T_{X1}). Further, the description of the various segments described in association with FIG. 4D may also be applied to like segments for packet segments described below with or without cyclic shifting implemented for the respective segment. The packet structure 400 comprises a legacy preamble portion 401 and a MIMO, spatial multiplexing (SM) portion 403. The legacy preamble portion 401 comprises a short training symbol (STS) segment 420 and a long training symbol (LTS) segment 422a. Also included in the packet structure 400 is a signal field (SF1) segment 424. The MIMO, SM portion 403 comprises the reused LTS (designated as 422b to distinguish between portions) segment 422b and a signal field (SF2) segment 428. The STS segment 420 is used by the LCSM system 300 to provide signal detection, automatic gain control (AGC), and diversity selection functionality, as well as to provide coarse frequency offset estimation and timing synchronization. The LTS segments 422a, 422b are used by the LCSM system 300 to provide channel estimation and fine frequency offset estimation. The LTS segments 422a, 422b are fixed, deterministic waveforms (*e.g.*, deterministic subcarriers) that are used to perform channel estimation. The SF1 segment 424 conveys the length of a packet 400 in time, which is used by a receiver to assist the receiver in determining when a packet is complete and ready for analysis (*e.g.*, error

detection, correction, *etc.*). The SF1 segment 424 also conveys a data rate of the packet 400.

The MIMO SM portion 403 is a new portion of the packet 400 according to one embodiment. With conventional single-input, single output (SISO) receivers, each receive antenna only needed to estimate the channel corresponding to a single transmit antenna. However, with two transmit antennas as found in the LCSM system 300, two channels are estimated at each receive antenna. In other words, the LTS segment 422a is used again in portion 403 (designated 422b) to enable the receive module 338 to estimate the channels corresponding to both transmit antennas 314 and 316, as described below. With regard to signal field (SF2) segment 428, information conveyed includes data rates corresponding to MIMO SM systems (*e.g.*, 108 MBs for 802.11n systems), the SM order (*e.g.*, 2nd order for 2 x 2, 3rd order, 4th order, *etc.*), information about error detection and type (*e.g.*, Viterbi, turbo), *etc.* MIMO SM receivers acquire and process, substantially in parallel, the legacy portion 401 and MIMO SM portion 403 to enable processing according to the capabilities to which the receiver is configured.

Note that, as is true with packet portions described below, different configurations may be used. For instance, the SF2 segment 428 may immediately follow SF1 segment 424 in some embodiments. Further, the duration of the various segments described above and below may be configured differently. For instance, one embodiment for SF2 segment 428 may require 4 microseconds duration. Some embodiments may require more duration, depending on the information that is to be conveyed, among other design considerations.

FIG. 5A is a block diagram that illustrates an embodiment of module 336, which is configured to provide cyclic shifting of one or more segments of a packet structure. The module 336 comprises the transmit (TX) processor 308, the radio 312, and the second transmit antenna 316. The transmit processor 308 comprises a waveshape logic 350b for generating the cyclically shifted packet structure. The waveshape logic 350b comprises a legacy preamble/signal field (SF) generator 519. The legacy preamble/SF generator 519 comprises a short training symbol (STS) generator 501, a long training symbol (LTS) generator 503a, a SF1 generator 505, cyclic shift modules 521, and a switch 511. Note that in some embodiments, the cyclic shift functionality may be included in the respective generator. The STS generator 501 and LTS generator 503a are configured to generate segments of a legacy preamble. The STS generator 501 generates a STS segment and the LTS generator 503a generates a LTS segment in conformity to 802.11 standards. The SF1 generator 505 generates a signal field segment. These segments are input to the cyclic shift modules 521 to undergo a cyclic shift (*e.g.*, advance or delay), and then the cyclically shifted segments are provided to switch 511, and based on a control signal (Select1), are provided as a coordinated output to switch 513, which also is part of the waveshape logic 350b. The waveshape logic 350b further includes an inverted (represented with a minus sign), cyclically shifted LTS generator 503b (-LTS-CS), a SF2 generator 507, and a data symbol generator 509. In one embodiment, the inverted, cyclically shifted LTS generator 503b is the same device as the LTS generator 303a, with the addition of an inverter that can be disabled or made transparent for legacy portion LTS generation functionality. The SF2

generator 507 receives data rate information, among other information pertaining to spatial multiplexing environments, and the data symbol generator 509 receives data bits. The switch 513 receives the respective segments from generators 503b, 507, and 509, and also receives the segments from switch 511, and based on the control input (Select2), provides the segments in coordinated fashion to the digital-to-analog (D/A) converter 315b of the transmit processor 308.

It would be understood by one having ordinary skill in the art that transmit processor 306 may comprise additional circuitry, as described in association with FIG. 4A.

The radio 312 receives the analog signal corresponding to the packet structure generated in the waveshape logic 350b. The radio 312 comprises a modulator 314b (*e.g.*, in-phase/ quadrature (I/Q) modulator and oscillator), conversion logic 316b (*e.g.*, oscillator and mixer), and high power amplifier (HPA) 318b. It would be appreciated by one having ordinary skill in the art that fewer, additional, and/or different components can be included in the module 336. Within the radio 312, the analog transmission signals are modulated, upconverted, and amplified/filtered at modulator 314b, conversion logic 316b, and HPA 318b, respectively. The resulting signal is then transmitted over second transmit antenna 316 (T_{X2}).

FIGs. 5B-5C are block diagrams that illustrate two embodiments (350b-1 and 350b-2, respectively) of an inverted, cyclically shifted LTS generator 503b that provides cyclic shifting of the MIMO SM portion of a packet to be transmitted over the second transmit antenna 316 (T_{X2}). Inverted, cyclically shifted LTS generator

embodiments 350b-1 and 350b-2 comprise a LTS carrier subcarrier stack 502, IFFT 504, add guard interval 508, similar to the LTS generator 303a, 303b described in association with FIG. 4B. The inverted, cyclically shifted LTS generator 503b-1 further includes a cyclic shift module 506 to provide cyclic delay or advances to the LTS segment, and an inverter logic (X) 510. With reference to FIG. 5B, a time domain embodiment corresponding to LTS processing is shown. That is, in the inverted, cyclically shifted LTS generator 503b-1, an LTS waveform from LTS subcarrier stack 502 undergoes processing at the IFFT circuitry 504 to provide a time-domain waveform. The resultant samples are cyclically shifted at the cyclic shift module 506, a guard interval added at add guard interval module 508, and inverted at an inverter 510 located after the add guard interval module 508. The inverter module 510 multiples a minus (-) 1 with samples of the cyclically shifted LTS, thus inverting (*e.g.*, make negative) the cyclic shifted LTS in the time domain.

FIG. 5C shows a waveshape logic embodiment 350b-2 that performs inversion in the frequency domain. The waveshape logic embodiment 350b-2 comprises components 502, 504, 506, and 508 similarly structured, yet connected slightly differently compared to the embodiment 350b-1 shown in FIG. 5B. That is, the inverter module 510 is disposed between the LTS subcarrier stack 502 and the IFFT circuitry 504. Each subcarrier corresponding to a cyclically shifted LTS is made negative, and then applied to the IFFT circuitry 504, resulting in a negative cyclically shifted LTS.

FIG. 5D is a block diagram that illustrates an exemplary packet structure 500 generated by the waveshape logic 360b and transmitted from a second transmit

antenna 316 (T_{X2}). The packet structure 500 comprises a legacy preamble portion 501 and a MIMO-SM portion 503. Segments 520, 524a, 526, 528, and 530 are similar in function and structure to segments of the same name described in association with FIG. 4D, except with a cyclic shift applied, and thus discussion of the same is omitted for brevity. The MIMO SM portion 503 comprises a cyclically shifted, inverted LTS segment 524b. The signal field (SF2) segment 528 is not cyclically shifted in one embodiment, although some embodiments may cyclically shift the SF2 segment 528, as well as the data symbols 530.

Note that in one embodiment, the signal field (SF2) segment 528 and the data symbols 530 for the packet 500 may have the cyclic shift removed (or omitted during the processing). In some embodiments, the SF2 segment 528 and/or data symbols 530 may be cyclically shifted.

Before proceeding with a discussion of the receive processing of the LCSM system 300, reference is made again to FIG. 3. As shown, the LCSM system comprises multiple transmit antennas 314 (T_{X1}) and 316 (T_{X2}) and multiple receive antennas 318 (R_{X1}) and 320 (R_{X2}) in a spatial multiplexing environment. That is, multipath exists at receive first receive antenna 318, corresponding to signals provided from first transmit antenna 314 to first receive antenna 318 and from second transmit antenna 316 to first receive antenna 318. Similarly, multipath exists at second receive antenna 320, corresponding to signals provided from first transmit antenna 314 to second receive antenna 320 and from second transmit antenna 316 to second receive antenna 320. Each receive antenna 318 and 320 estimates two multipath channels, one from each of the two transmit antennas 314 and 316. For

example, since there are two receive antennas 318 and 320, four channels (H_{11}, H_{12}, H_{21}, H_{22}) can be estimated, as shown by Equation (1):

$$\begin{bmatrix} Rx_1 \\ Rx_2 \end{bmatrix} = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix} \begin{bmatrix} Tx_1 \\ Tx_2 \end{bmatrix} \quad \text{Eq. (1)}$$

Equation (1) is computed on a subcarrier by subcarrier basis in OFDM environments. For instance, at the first receive antenna 318, a subcarrier at a defined amplitude and phase emitted from first transmit antenna 314 and a subcarrier of a defined amplitude and phase from second transmit antenna 316 is received and interference may result. The equation (1) is performed for each subcarrier received to determine the amplitude and phase.

FIG. 6 is a block diagram that illustrates receive module embodiments 338 and 340. The module 338 comprises a first receive antenna 318, radio 322, and receive (RX) processor 326. The radio 322 comprises a low noise amplifier (LNA) 602a, conversion logic 604a (*e.g.*, mixer and oscillator), and automatic gain control (AGC) logic 606a. The receive (RX) processor 326 comprises analog-to-digital (A/D) converter 608a, synchronization logic 610a, cyclic extension removal logic 612a, and receive (RX) logic 360a. Additional processing blocks may be included in module 338 in some embodiments, such as a matched filter combiner(s), memory, state logic, signal separator, among other components. Module 340 comprises similar or the same components as module 338, with similar or the same connections, including a second receive antenna 320, radio 324 (comprising LNA 602b, conversion logic 604b, and AGC 606b), and receive (RX) processing 328

(comprising A/D 608b, synchronization logic 610b, cyclic extension remove logic 612b, and RX logic 360b). The discussion of module 340 is omitted for brevity, and discussion below will focus on module 338 with the understanding that the same or similar processing applies to module 340.

Referring to module 338, the signals transmitted from first and second transmit antennas 314 and 316, respectively, are received at first receive antenna 318 and provided to the low noise amplifier (LNA) 602a. The LNA 602a filters the signal and provides the filtered signal to conversion logic 604a, where the filtered signal is downconverted to baseband (*e.g.*, in-phase (I) and quadrature (Q) signals), or intermediate frequency (IF) in some embodiments. The downconverted signal is provided to AGC 606a, where the signal is amplified. In some embodiments, the AGC 606a may provide the receiver power level back to the transmitter device 302, such as to assist the transmitter device 302 in determining effective transmission methods. The amplified I and Q signals are converted to the digital domain at A/D converter 608a of the receive processor 326. The A/D converter 608a provides the digital data to the synchronization logic 610a. The synchronization logic 610a recovers the clock signal and corrects for differences between the oscillation frequency of the local oscillator of the transmitter device 302 and the oscillation frequency of the local oscillator of the receiver device 304. The digital data is further provided to the cyclic extension removal logic 612a, which removes un-needed cyclic extensions, and then to the receive logic 360a.

Assume that the receive antenna 318 receives packet 400 and 500 transmitted from first transmit antenna 314 and second transmit antenna, respectively, LTS1

corresponding to the legacy LTS 422a (from first transmit antenna 314) and cyclic shifted legacy LTS-CS 604a (from second transmit antenna 316), LTS2 corresponds to the MIMO SM LTS 422b (from first transmit antenna 314) and cyclic shifted MIMO SM LTS-CS 604b (from second transmit antenna 316). RLTS1 and RLTS2 correspond to the first receive antenna 318 receipt of the LTS1 and LTS2, respectively. That is, during reception of RLTS1, the first receive antenna 318 experiences interference corresponding to LTS1 from first transmit antenna 314 weighted by the multipath channel H_1 (*i.e*, H_{11}) interfering with the signal delivered from second transmit antenna 316 weighted by its multipath channel H_2 (*i.e.*, H_{12}). Likewise, during reception of RLTS2, two signals weighted by their respective channels (H_1 and H_2) arrive simultaneously, or substantially simultaneously, to cause interference. Processing in the receive logic 360a is performed to separate the two signals (corresponding to each transmit antenna 314 and 316), resulting in the following equations (2) and (3):

$$RLTS1 = H1 * LTS + H2 * LTS\text{-}CS, \quad \text{Eq. (2)}$$

$$RLTS2 = H1 * LTS - H2 * LTS\text{-}CS, \quad \text{Eq. (3)}$$

A Walsh transform is performed on RLTS1 and RLTS2 in either the time domain or the frequency domain. To obtain information corresponding to the first transmit antenna 314, RLTS1 is added to RLTS2 as shown in Equation (4):

$$RLTS1 + RLTS2 = 2 * H1 * LTS \quad \text{Eq. (4)}$$

The result of this operation is information corresponding to the first transmit antenna 314 (the information corresponding to the second transmit antenna 316 dropped out because of the minus sign before H_2). That is, the second transmit antenna 316

transmitted a negative, cyclic shifted copy of itself during the MIMO SM timeslot (*i.e.*, -(LTS-CS) 524b).

To obtain the information corresponding to second transmit antenna 316, the following computation is performed:

$$RLTS1 - RLTS2 = 2 * H2 * LTS\text{-}CS \qquad \text{Eq. (5)}$$

The result of this operation is that constructive addition of the information corresponding to the second transmit antenna 316 is achieved (mathematically, a negative of a negative equals a positive), dropping out the information corresponding to the first transmit antenna 314. Thus, separation of signals from the transmit antennas 314 and 316 is accomplished through the Walsh coding.

Computation of the amplitude and phase of the separated signals (channel estimation) is performed on the separated signals. For instance, by dividing both sides of equation (4) by 2LTS (*i.e.*, 2 * LTS), the following equation (6) is derived for H_1:

$$H_1 = (RLTS1 + RLTS2)/(2LTS) \qquad \text{Eq. (6)}$$

To arrive at the channel estimation for H_2, equation (5) is divided on both sides by 2LTS-CS, resulting in Equation (7):

$$H_2 = (RLTS1 - RLTS2)/(2LTS\text{-}CS) \qquad \text{Eq. (7)}$$

Thus, channel estimates for H1 and H2 have been computed.

FIGs. 7A-7B are block diagrams that illustrate an embodiment of receive logic 360a-1 and 360a-2, respectively, that performs the computations described above corresponding to equations (2) – (7). FIG. 7A corresponds to Walsh processing in the time domain, and FIG. 7B corresponds to Walsh processing in the

frequency domain. Referring to FIG. 7A, the receive logic 360a-1 comprises buffer receive (RX) LTS1 (or RLTS1 buffer) 702 and buffer receive (RX) LTS2 (or RLTS2 buffer) 710 (herein, buffers 702 and 710), adders 704 and 712, FFT modules 706 and 714, and divide-out 2X TX LTS modulation module 708 (herein module 708) and divide-out 2X TX LTS-CS modulation module 716 (herein module 716). The RLTS values are stored in buffers 702 and 710, provided to adders 704 and 718 (subtracted at adder 712, as shown by minus sign 718). The resultant values are transformed at FFT modules 706 and 714 to reproduce the frequency subcarriers, and the transformed values are divided out at modules 708 and 716 to arrive at the channel estimates H_1 and H_2.

Referring to FIG. 7B, an embodiment of receive logic 360a-2 is shown that performs Walsh coding in the frequency domain. As shown, components 702, 706, 704, 708, 710, 714, 712, and 716 are the same, but rearranged in sequence of operations such that Walsh coding occurs at adders 704 and 712 (where subtraction is represented with minus sign 718) after the FFT modules 706 and 714 transform the values to the frequency domain.

In another embodiment, a cyclic shifted channel estimate may be computed in association with the second transmit antenna 316. That is, equations (2) – (6) remain as described above, but equation (7) is replaced with equation (8), which is as follows:

$$H_2\text{-CS} = (\text{RLTS1} - \text{RLTS2})/(2\text{LTS}) \qquad \text{Eq. (8)}$$

That is, equation (5) is divided by a non-cyclic shifted LTS, and the result is a cyclic shifted version of H_2 (i.e., H_2-CS).

FIGs. 8A-8B are block diagrams that illustrate two embodiments of receiver logic 360a-3 and 360a-4, respectively, where channel estimate H_2 is cyclic shifted, and Walsh coding is performed in the time domain (FIG. 8A) and the frequency domain (FIG. 8B). With reference to FIG. 8A, the receiver logic 360a-3 comprises buffer receive (RX) LTS1 (or RLTS1 buffer) 702 and buffer receive (RX) LTS2 (or RLTS2 buffer) 710 (herein, buffers 702 and 710), adders 704 and 712, FFT modules 706 and 714, and divide-out 2X TX LTS modulation module 708a (herein module 708a) and divide-out 2X TX LTS-CS modulation module 708b (herein module 708b). Note that modules 708a and 708b may be shared logic. The RLTS values are stored in buffers 702 and 710, provided to adders 704 and 718 (subtracted at adder 712, as shown by minus sign 718). The resultant values are transformed at FFT modules 706 and 714 to reproduce the frequency subcarriers, and the transformed values are divided out at modules 708a and 708b to arrive at the channel estimates H_1 and H_2-CS.

Referring to FIG. 8B, an embodiment of receive logic 360a-4 is shown that performs Walsh coding in the frequency domain. As shown, components 702, 706, 704, 708a, 708b, 714, 712, and 716 are the same, but rearranged in sequence of operations such that Walsh coding occurs at adders 704 and 712 (where subtraction is represented with minus sign 718) after the FFT modules 706 and 714 transform the values to the frequency domain.

Although described in the context of 20 mega-Hertz (MHz) wide channels, it would be understood by those having ordinary skill in the art that 40 MHz wide channels will similarly apply. That is, two 20 MHz packets can be transmitted on

two different frequencies. For instance, corresponding to first transmit antenna 314, the lower 20 MHz channel may have the following sequence: LTS, SF1, LTS, SF2, and then data symbols, similar to the packet sequence shown in FIG. 4D. Likewise, on the upper 20 MHz channel, the same sequence may be followed. Corresponding to second transmit antenna 316, the following sequence may be employed: LTS-CS, SF1-CS, -(LTS-CS), SF2-CS (or non-cyclic shifted), and data symbols with or without CS may be employed subsequently, similar to the sequence shown in FIG. 5D.

Process descriptions or blocks in flow charts should be understood as representing modules, segments, or portions of code which include one or more executable instructions for implementing specific logical functions or steps in the process, and alternate implementations are included within the scope of the preferred embodiment of the present invention in which functions may be executed out of order from that shown or discussed, including substantially concurrently or in reverse order, depending on the functionality involved, as would be understood by those reasonably skilled in the art of the present invention.

As will be appreciated from the above description, one embodiment of a packet generation method 350 comprises, as illustrated in FIG. 9, inserting a long training symbol into a first portion of a first packet preamble corresponding to a first packet to be transmitted from a first transmit antenna (902), reusing the long training symbol in a second portion of the first packet (904), inserting a cyclic shifted long training symbol in a first portion of a second packet preamble corresponding to a second packet to be transmitted from a second transmit antenna (906), and reusing

the cyclically shifted long training symbol in inverted form in a second portion of the second packet (908).

As will be appreciated from the above description, embodiments of a packet reception method 360 comprise, as shown in FIG. 10, receiving long training symbols and cyclic shifted long training symbols corresponding to legacy preamble portions of packets corresponding to first and second transmit signals (1002), receiving long training symbols and inverted cyclic shifted long training symbols corresponding to spatial multiplexing portions of packets corresponding to first and second transmit signals (1004), and combining the symbols corresponding to the first and second transmit antennas to estimate the respective channels (1006).

Note that in some embodiments, packets from a first transmitter and a second transmitter comprise segments that, in one embodiment, are time-aligned. That is, corresponding segments are transmitted in time-aligned fashion. For example, the STS segment from a packet sent from a first transmit antennas is time-aligned (*e.g.*, has the same beginning and end time boundary, and thus duration) with a cyclic shifted STS segment corresponding to a packet transmitted from a second transmit antenna, and the LTS segment transmitted from the first transmit antennas is time aligned with the cyclic shifted LTS segment of the second transmit antennas, *etc.* This is made possible by sharing a common digital clock (synchronized digital circuits) for the signal generators both antennas. This is implicit in the transmitter device 302 shown in FIG. 3.

It should be emphasized that the above-described embodiments of the present disclosure, particularly, any "preferred" embodiments, are merely possible examples

of implementations, merely set forth for a clear understanding of the principles of the disclosed systems and methods. Many variations and modifications may be made to the above-described embodiment(s) without departing substantially in scope. All such modifications and variations are intended to be included herein within the scope of this disclosure.

CLAIMS

What is claimed:

1. A packet generation method, comprising:

inserting a long training symbol into a first portion of a first packet preamble corresponding to a first packet to be transmitted from a first transmit antenna;

reusing the long training symbol in a second portion of the first packet;

inserting a cyclic shifted long training symbol in a first portion of a second packet preamble corresponding to a second packet to be transmitted from a second transmit antenna; and

reusing the cyclically shifted long training symbol in inverted form in a second portion of the second packet.

2. The method of claim 1, further comprising transmitting the first and second packet.

3. The method of claim 1, wherein reusing the cyclically shifted long training symbol in inverted form comprises inverting the cyclically shifted long training symbol corresponding to the second packet.

4. The method of claim 1, wherein the first portion corresponds to a legacy preamble and the second portion corresponds to a spatial multiplexing portion.

5. A packet reception method, comprising:

receiving long training symbols and cyclic shifted long training symbols corresponding to legacy preamble portions of packets corresponding to first and second transmit signals;

receiving long training symbols and inverted cyclic shifted long training symbols corresponding to spatial multiplexing portions of packets corresponding to first and second transmit signals; and

combining the symbols corresponding to the first and second transmit antennas to estimate the respective channels.

6. The method of claim 5, wherein combining comprises Walsh transforming.

7. The method of claim 5, wherein combining further comprises dividing the symbols by a value corresponding to a long training symbol to obtain a channel estimate.

8. The method of claim 5, wherein combining further comprises dividing the symbols by a value corresponding to a cyclic shifted long training symbol to obtain a cyclic shifted channel estimate.

9. A packet generation system, comprising:

a first logic configured to insert a long training symbol into a first portion of a first packet preamble corresponding to a first packet to be transmitted from a first transmit antenna and reusing the long training symbol in a second portion of the first packet; and

a second logic configured to insert a cyclic shifted long training symbol in a first portion of a second packet preamble corresponding to a second packet to be transmitted from a second transmit antenna and reuse the cyclically shifted long training symbol in inverted form in a second portion of the second packet.

10. The system of claim 9, further comprising transmit logic configured to transmit the first and second packet.

11. The system of claim 9, wherein the second logic is further configured to invert the cyclically shifted long training symbol corresponding to the second packet.

12. The system of claim 9, wherein the first portion corresponds to a legacy preamble and the second portion corresponds to a spatial multiplexing portion.

13. The system of claim 9, wherein the first and second logic is comprised of one of hardware, software, or a combination of hardware and software.

14. A packet reception system, comprising:

a logic configured to receive long training symbols and cyclic shifted long training symbols corresponding to legacy preamble portions of packets corresponding to first and second transmit signals, receive long training symbols and inverted cyclic shifted long training symbols corresponding to spatial multiplexing portions of packets corresponding to first and second transmit signals, and combine the symbols corresponding to the first and second transmit antennas to estimate the respective channels.

15. The system of claim 14, wherein the logic is configured to compute a Walsh transform algorithm.

16. The system of claim 14, wherein the logic is comprised of one of hardware, software, or a combination of hardware and software.

17. The system of claim 14, wherein the logic is configured to divide the symbols by a value corresponding to a long training symbol to obtain a channel estimate.

18. The system of claim 14, wherein the logic is configured to divide the symbols by a value corresponding to a cyclic shifted long training symbol to obtain a cyclic shifted channel estimate.

19. A communication system, comprising:

means for inserting a long training symbol into a first portion of a first packet preamble corresponding to a first packet to be transmitted from a first transmit antenna;

means for reusing the long training symbol in a second portion of the first packet;

means for inserting a cyclic shifted long training symbol in a first portion of a second packet preamble corresponding to a second packet to be transmitted from a second transmit antenna; and

means for reusing the cyclically shifted long training symbol in inverted form in a second portion of the second packet.

20. The system of claim 19, further comprising:

means for receiving the first packet and the second packet; and

means for combining symbols corresponding to the first and second transmit antennas to estimate respective channels.

ABSTRACT

Embodiments of legacy compatible spatial multiplexing systems and methods are disclosed. One method embodiment, among others, comprises receiving long training symbols and cyclic shifted long training symbols corresponding to legacy preamble portions of packets corresponding to first and second transmit signals, receiving long training symbols and inverted cyclic shifted long training symbols corresponding to spatial multiplexing portions of packets corresponding to first and second transmit signals, and combining the symbols corresponding to the first and second transmit antennas to estimate the respective channels.

Systems and Methods for Transmitter Diversity Expansion

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CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to copending U.S. provisional application having ser. no. 60/675,203, filed April 26, 2005, which is entirely incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure is generally related to digital communications and, more particularly, is related to systems and methods for data transmission.

BACKGROUND

[0003] Communication networks come in a variety of forms. Notable networks include wireline and wireless. Wireline networks include local area networks (LANs), digital subscriber line (DSL) networks, and cable networks, among others. Wireless networks include cellular telephone networks, classic land mobile radio networks and satellite transmission networks, among others. These wireless networks are typically characterized as wide area networks. More recently, wireless local area networks and wireless home networks have been proposed, and standards, such as Bluetooth and IEEE 802.11, have been introduced to govern the development of wireless equipment for such localized networks.

[0004] A wireless local area network (WLAN) typically uses infrared (IR) or radio frequency (RF) communications channels to communicate between portable or mobile computer terminals and stationary access points or base stations. These access points are, in turn, connected by a wired or wireless communications channel to a network

infrastructure which connects groups of access points together to form the LAN, including, optionally, one or more host computer systems.

[0005] Wireless protocols such as Bluetooth and IEEE 802.11 support the logical interconnections of such portable roaming terminals having a variety of types of communication capabilities to host computers. The logical interconnections are based upon an infrastructure in which at least some of the terminals are capable of communicating with at least two of the access points when located within a predetermined range, each terminal being normally associated, and in communication, with a single one of the access points. Based on the overall spatial layout, response time, and loading requirements of the network, different networking schemes and communication protocols have been designed so as to most efficiently regulate the communications.

[0006] IEEE Standard 802.11 ("802.11") is set out in "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications" and is available from the IEEE Standards Department, Piscataway, N.J. IEEE 802.11 permits either IR or RF communications at 1 Mbps, 2 Mbps and higher data rates, a medium access technique similar to carrier sense multiple access/collision avoidance (CSMA/CA), a power-save mode for battery-operated mobile stations, seamless roaming in a full cellular network, high throughput operation, diverse antenna systems designed to eliminate "dead spots," and an easy interface to existing network infrastructures.

[0007] The 802.11a standard defines data rates of 6, 12, 18, 24, 36 and 54 Mbps in the 5 GHz band. Demand for higher data rates may result in the need for devices that can communicate with each other at the higher rates, yet co-exist in the same WLAN environment or area without significant interference or interruption from each other, regardless of whether the higher data rate devices can communicate with the 802.11a devices. It may further be desired that high data rate devices be able to communicate with the 802.11a devices, such as at any of the standard 802.11a rates.

[0008] One challenge in designing a wireless transmission system involves transmit beamforming using an antenna array. Beamforming focuses signals toward a receiver in such a way that they combine at the receiver resulting in a stronger signal. If signals are transmitted off multiple antennas and focused toward a designated receiver rather than being transmitted in an omni-directional fashion, the composite phase and amplitude of the transmission determines the effectiveness of the beam-forming. The

phase and amplitude relationship between the transmit antennas is adjusted to focus this energy at the intended receiver. One way to adjust a beam-forming transmitter is to incorporate additional circuitry on the radio. The circuitry is used to compute and share the conditions observed by the receiver. The transmitter then performs a complex calculation to adjust the beamforming antenna array. However, this solution can be expensive.

[0009] Increasing the effective signal strength and/or receiver sensitivity enables more efficient communications. Increased signal strength may enable service providers to more effectively use their equipment. Consumers may realize a cost savings as well.

SUMMARY

[0010] Embodiments of the present disclosure provide systems and methods for transmitter diversity expansion.

[0011] Briefly described, in architecture, one embodiment of the system, among others, can be implemented with a bypass module configured to receive K data streams and to relay the K data streams to K antennas of a set of N antennas; and

[0012] a diversity expansion module configured to provide N-K data streams for application to a set of N-K antennas based on the K data streams.

Embodiments of the present disclosure can also be viewed as providing methods for transmitter diversity expansion. In this regard, one embodiment of such a method, among others, can be broadly summarized by the following steps: receiving K data streams; providing each of the K data streams to K antennas of a set of N antennas for transmission; providing N-K data streams to N-K unused antennas of the set of N antennas based on the K data streams for transmission; and transmitting the N data streams on the N antennas.

[0013] Other systems, methods, features, and advantages of the present disclosure will be or become apparent to one with skill in the art upon examination of the following drawings and detailed description. It is intended that all such additional systems, methods, features, and advantages be included within this description, be within the scope of the present disclosure, and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Many aspects of the disclosure can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the present disclosure. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

[0015] FIG. 1 is a block diagram of an open system interconnection (OSI) layered model for data transmission.

[0016] FIG. 2 is a block diagram of a prior art system for implementing transmitter diversity.

[0017] FIG. 3 is a block diagram of an exemplary embodiment of a system for transmitter diversity expansion according to the present disclosure.

[0018] FIG. 4 is a detailed block diagram of an exemplary embodiment of the cyclic shift module of the system for transmitter diversity expansion of FIG. 3.

[0019] FIG. 5 is a block diagram of an exemplary embodiment of the system for transmitter diversity expansion of FIG. 3 with the cyclic shift module before the combine module.

[0020] FIG. 6 is a block diagram of an exemplary embodiment of the system for transmitter diversity expansion of FIG. 3 with the combine module before the cyclic shift module.

[0021] FIG. 7 is a block diagram of an exemplary embodiment of the system for transmitter diversity expansion of FIG. 5 with two data stream inputs and four transmit antennas.

[0022] FIG. 8 is a block diagram of an exemplary embodiment of the system for transmitter diversity expansion of FIG. 7 with a Walsh combination matrix.

[0023] FIG. 9 is a block diagram of an exemplary embodiment of the system for transmitter diversity expansion of FIG. 5 with two data stream inputs and three transmit antennas.

[0024] FIG. 10 is a block diagram of an exemplary embodiment of the system for transmitter diversity expansion of FIG. 5 with three data stream inputs and four transmit antennas.

[0025] FIG. 11 is a block diagram of an exemplary embodiment of the system for transmitter diversity expansion of FIG. 5 with two data stream inputs and six transmit antennas.

[0026] FIG. 12 is a flow diagram of an exemplary method embodiment of the system for transmitter diversity expansion of FIG. 5.

[0027] FIG. 13 is a flow diagram of an exemplary method embodiment of the system for transmitter diversity expansion of FIG. 6.

DETAILED DESCRIPTION

[0028] Disclosed herein are various embodiments of transmitter diversity expansion systems and methods. Such embodiments provide for the application of a number of data streams (K) to a larger number of antennas (N). One system embodiment comprises a module that applies each of the data streams to a base antenna, such that K data streams are applied to K base antennas. Also the system embodiment provides for shifting and combining of the K data streams to produce N-K data streams for application to N-K extension antennas. The described systems and methods may be embodied in any type of processor such as a PHY layer processor, though not limited to a PHY layer processor, including, but not limited to, a digital signal processor (DSP), a microprocessor (MCU), a general purpose processor, and an application specific integrated circuit (ASIC), among others.

[0029] A new standard is being proposed, referred to as IEEE 802.11n (the "802.11n proposal"), which is a high data rate extension of the 802.11a standard at 5 GHz and 802.11g at 2.4 GHz. Both of these standards use orthogonal frequency division multiplexing (OFDM), which is a signaling scheme which uses multiple, parallel tones to carry information. These tones are commonly called subcarriers. It is noted that, at the present time, the 802.11n proposal is only a draft and is not yet a completely defined standard. Other applicable standards include Bluetooth, xDSL, other sections of 802.11, etc. To increase the data rate, 802.11n is considering using multiple input, multiple output (MIMO) functionality which uses multiple transmit and receive antennas.

[0030] IEEE 802.11 is directed to wireless LANs, and in particular specifies the MAC and the PHY layers. These layers are intended to correspond closely to the two lowest layers of a system based on the ISO Basic Reference Model of OSI, i.e., the data link

layer and the physical layer. FIG. 1 shows a diagrammatic representation of an open systems interconnection (OSI) layered model 100 developed by the International Organization for Standards (ISO) for describing the exchange of information between layers in communication networks. The OSI layered model 100 is particularly useful for separating the technological functions of each layer, and thereby facilitating the modification or update of a given layer without detrimentally impacting on the functions of neighboring layers.

[0031] At a lower most layer, the OSI model 100 has a physical layer or PHY layer 102 that is responsible for encoding and decoding data into signals that are transmitted across a particular medium. Above the PHY layer 102, a data link layer 104 is defined for providing reliable transmission of data over a network while performing appropriate interfacing with the PHY layer 102 and a network layer 106. The network layer 106 is responsible for routing data between nodes in a network, and for initiating, maintaining and terminating a communication link between users connected to the nodes. A transport layer 108 is responsible for performing data transfers within a particular level of service quality. A session layer 110 is generally concerned with controlling when users are able to transmit and receive data. A presentation layer 112 is responsible for translating, converting, compressing and decompressing data being transmitted across a medium. Finally, an application layer 114 provides users with suitable interfaces for accessing and connecting to a network. This OSI model 100 can be useful for transmissions between, for example, two stations.

[0032] Exemplary embodiments of the diversity expansion techniques for a transceiver can be processed in a PHY signal processor. A PHY signal processor is configured to perform functionality of the preferred embodiments. A digital communication system may comprise such a processor, alone, or in combination with other logic or components. A system of communications may further be embodied in a wireless radio, or other communication device. Such a communication device may include many wireless communication devices, including computers (desktop, portable, laptop, *etc.*), consumer electronic devices (*e.g.*, multi-media players), compatible telecommunication devices, personal digital assistants (PDAs), or any other type of network devices, such as printers, fax machines, scanners, hubs, switches, routers, set-top boxes, televisions with communication capability, *etc.* A Medium Access Control (MAC) Protocol enables the exchange of channel

information between stations. A transmitter may shift and combine data streams to achieve higher fidelity from the transmitter, thereby increasing the sensitivity of the receiver.

[0033] Exemplary embodiments of transmitter diversity expansion systems and methods described herein may be implemented in systems employing IEEE 802.11 protocols. IEEE 802.11 modes may be implemented to use multiple transmit and receive antennas. When multiple transmit antennas are used, various purposes may be served. One purpose may include sending more data through more antennas, or increasing the data capacity of a transmission. Data streams that are sent through a transmit channel may be called "spatial streams."

[0034] Another purpose for exploiting multiple transmit antennas is to send one data stream through multiple paths. For instance, one stream can be sent multiple times through multiple antennas to increase the strength of the receive signal at another station. Multiple copies of the data stream may be sent on multiple antennas to increase the reliability of the communication. To exploit two antennas in a transmitter, two separate data streams can be sent substantially simultaneously. This method is referred to as "spatial multiplexing." Alternatively, one spatial stream may be sent twice on the two antennas. One way of sending one spatial stream twice is space-time block coding (STBC) which may improve the reliability of the data link. A disadvantage of STBC is that the receiver has to know that the transmitter is using this technique. That is, the receiver has to know how to use this technique to recover the data. STBC is not seamless to the receiver. A goal for use of multiple antennas (e.g., two, three, four, etc.) is to send multiple data streams such that the receiver requires no special method to recover the data.

[0035] One way of accomplishing this latter goal is through beamforming, which may require extra communication overhead. An exemplary embodiment of transmitter diversity expansion systems and methods uses a technique in which an extra transmit antenna may be utilized without the receiver needing special decoding circuitry. Moreover, a receiver does not need to know whether or how this technique is applied at the transmitter. One mechanism to accomplish transmit diversity expansion is through the use of cyclic shifts. The amount of cyclic shifts that is used in the implementation is not important. That is, any appropriate cyclic shift amounts may be used. One system for performing the cyclic shifts is provided in FIG. 2.

[0036] Referring to FIG. 2, a combining module 210 and a shifting module 230 is shown. A module as used herein, may be embodied in software, hardware, firmware, etc., or a combination of these embodiments. The combining module receives K spatial streams 200, where K is an integer value, greater than 1. The combining module 210 includes a unitary matrix or an extension matrix, which is applied to the K spatial streams. The matrix may be a fast Fourier transform matrix. This matrix may be a rectangular matrix, such that the output comprises N columns or rows 220 of data streams, where N is an integer value, greater than or equal to K. Since N is greater than or equal to K, K spatial streams 200 are mapped to N antennas 250. After the combining at combining module 210, a cyclic shift is applied to each of the N data streams at shifting module 230. The cyclic shift allows for the combination of the K spatial streams while enabling a discernment of the individual streams. The cyclic shift is applied to each of the N spatial streams independently. So, for a case of four spatial streams, in an exemplary embodiment, no cyclic shift is applied to the first stream of the four streams; a first cyclic shift is applied to the second stream of the four streams; a second cyclic shift is applied to the third of the four streams; and a third cyclic shift is applied to the fourth of the four streams. For example, if a two by two unitary matrix is applied to one spatial stream, they are added together, resulting in a one by two matrix.

[0037] Referring to FIG. 3, K spatial streams 300 are first passed to K base transmit antennas 310 out of a total of N transmit antennas 310, 330. The N antennas, 310, 330 comprise K base antennas 310 and K-N extension antennas 330. Then, the cyclic shift and unitary matrix are applied to the K spatial streams in module 320. Module 320 comprises functionality of modules 210 and 230 of FIG. 2. This result is applied to N-K extension antennas 330 of the N antennas 310, 330. So, K spatial streams 300 are applied to K base antennas 310 and N-K streams that have had a cyclic shift and unitary matrix applied to them are applied to N-K extension antennas 330. This is referred to herein as a "systematic mapping." This technique (systematic mapping) may be applied in the preamble portion of a packet. One advantage of such a method is that K streams 300 appear on K base antennas 310, which enables simple testing and verification. Because K transmit antennas can be connected directly to K receive antennas, the spatial streams 300 are decoded without the extension antennas 330. Then, when the extension antennas 330 are added, a verification may be performed to

verify that the same results are received with the N antennas 310, 330 as were received with the K base antennas 310.

[0038] One non-limiting embodiment for applying a cyclic shift is shown in FIG. 4. Modules 420, 440, and 460 are embodied in cyclic shifting and combining module 320 of FIG. 3. The K data streams 400 are passed straight through to K base antennas 410. In module 420, a cyclic shift of −100 nanoseconds is applied to a spatial stream of K data streams 400. The output of module 420 is sent to stage 430, which may be a combination stage or an antenna, among other stages. At module 440, a +100 nanosecond cyclic shift is applied to a spatial stream of K data streams 400 and the output is sent to stage 450, which may be a combination stage or an antenna, among other stages. In module 460, a +200 nanosecond cyclic shift is applied to a spatial stream of K data streams 400 and the output is sent to stage 470, which may be a combination stage or an antenna, among other stages. In an exemplary embodiment, each of the cyclic shifted streams may be passed to a singular antenna of N-K antennas.

[0039] Referring to FIG. 5, transmit diversity expansion system 500 including bypass module 510, cyclic shift module 530, and combining module 540 for expanding K data streams to N antennas is shown. K streams 505 are sent to bypass module 510 and sent unchanged to K base antennas 520 ... 520n. Bypass module 510 may simply be electrical conduits to pass K streams 505 to K base antennas 520 ... 520n.In cyclic shift module 530, a cyclic shift is applied to K streams 505 to provide K cyclic shifted streams 535. The K cyclic shifted streams 535 are then combined in combining module 540 to provide N-K streams 545. The N-K streams 545 are applied to N-K extension antennas 550 ... 550n. So, spatial streams 505 pass through bypass module 510 and are applied to base antennas 520 ... 520n. The spatial streams 505 are also sent to cyclic shift module 530, where various cyclic shift values are applied to each of spatial streams 505. In the case of two spatial streams, one may be shifted and one may not be. Alternatively, one can be shifted a positive amount and one shifted a negative amount, or one can be shifted a first amount and one can be shifted a second, different amount. The different amounts may be random or programmed. The shifted signals 535 are combined using a matrix, such that N-K extension streams 545 that are shifted and combined are sent to N-K extension antennas 550 ... 550n.

[0040] In one embodiment, the expansion process comprises two steps, namely cyclic shifts and combining. Both steps are linear operations that can be represented with matrix multiplication, which may comprise two matrices: one for cyclic shifts and one for combining. The system of FIG. 5 may be represented as follows:

$$W_{ext} = W_{combine} * W_{cs}$$

where $W_{combine}$ is a matrix, which defines the combining operation and W_{cs} is a matrix, which defines the cyclic shifts. W_{cs} is a diagonal matrix in which the diagonal elements are related to cyclic shift operations applied to the corresponding stream and all non-diagonal elements are zeros.

[0041] An exemplary combining matrix may be defined as follows

$$W_{combine} = (1/\sqrt{Nss})* \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix}$$

The $W_{combine}$ matrix has a Walsh-Hadamard construct. The matrix is trimmed as needed. N-K rows are retained for N-K extension antennas. K columns are retained for the K spatial streams. The matrix left-multiplies the column vector of the base signals. The vector of the base signals is loaded in the order of the K streams, with the first stream as the first (top) element in the column vector. The matrix output vector is sent to the cyclic shift module (e.g., such as module 530). Power normalization may be achieved by using a scaling constant (Nss in the equation above), such that the extension antennas (N-K antennas) are power-consistent with the base antennas (K antennas).

[0042] An exemplary cyclic shift matrix may be defined as follows:

$$W_{cs} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix}$$

This matrix is a diagonal matrix of cyclic shift operators. The cyclic shift matrix is trimmed as needed to N-K by N-K, where N-K is the number of extension antennas. An exemplary method embodiment for extending two data streams to two extension antennas for a total of four antennas is represented as follows:

$$\begin{bmatrix} Extend1 \\ Extend2 \end{bmatrix} = \begin{bmatrix} CS1 & 0 \\ 0 & CS2 \end{bmatrix} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} Base1 \\ Base2 \end{bmatrix}$$

[0043] An alternative transmitter diversity expansion system 600 for performing the cyclic shift and combine functions is provided in FIG. 6. Again, K spatial streams 605 are sent through bypass module 610 to K base antennas 620 ... 620n. K spatial streams 605 are also combined in module 635 by applying a unitary matrix to produce N-K streams 640. A cyclic shift is then applied to N-K streams 640 in cyclic shift module 645 to produce N-K cyclic shifted streams 650, which are applied to N-K extension antennas 655 ... 655n. As a non-limiting example of two spatial streams, two spatial streams 605 are sent through bypass module 610 to two base antennas 620, 620n and the two spatial streams 605 are combined in module 635 by applying a unitary matrix to produce two combined streams 640. Those two combined streams 640 are sent to cyclic shift module 645 where they are shifted to produce two (N-K) shifted streams 650 that are applied to two (N-K) base antennas 655, 655n.

[0044] In an alternative embodiment, the combining module precedes the cyclic shift module as shown in FIG. 6. This embodiment also represents a linear operation, which can be represented with a matrix multiplication containing the two aforementioned matrices of cyclic shifts and combining in reversed order as follows:

$$W_{ext} = W_{cs} * W_{combine}$$

where the $W_{combine}$ matrix defines the combining operation and the W_{cs} matrix defines the cyclic shifts. In this case, the vector of the K base signals is loaded in the order of the K streams. This vector of base signals is left-multiplied with the combining matrix to form N-K extension streams. The N-K extension streams are left-multiplied with the cyclic shift matrix W_{cs}. Again, the combining matrix $W_{combine}$ may be based on

Walsh-Hadamard construct and trimmed as needed. N-K rows are retained for N-K extension antennas. K columns are retained for the K spatial streams. An exemplary embodiment for extending two data streams to two extension antennas for a total of four antennas is represented as follows:

$$\begin{bmatrix} \text{Extend1} \\ \text{Extend2} \end{bmatrix} = \begin{bmatrix} \text{CS1} & 0 \\ 0 & \text{CS2} \end{bmatrix} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} \text{Base1} \\ \text{Base2} \end{bmatrix}$$

[0045] FIG. 7 provides another exemplary embodiment of a transmitter diversity expansion system 700 with two spatial stream inputs 701, 710 and four antennas 730, 740, 770, 780. Both streams 701, 710 pass through bypass module 720 and are applied unchanged to base antennas 730, 740 respectively. Streams 701, 710 are also applied to cyclic shift module 750. Stream 701 is shifted by cyclic shift submodule 755 and stream 710 is shifted by cyclic shift submodule 760, both within cyclic shift module 750. Cyclic shift submodule 755 shifts stream 701 by more or less than cyclic shift submodule 760 shifts stream 710, but not by the same amount. Stream 702 is the shifted version of stream 701. Stream 712 is the shifted version of stream 710. Streams 702, 712 are provided to combining module 765 in which a unitary or extension matrix is applied to the streams to produce streams 703 and 713. Streams 703 and 713 are applied to extension antennas 775 and 780. In this exemplary embodiment, streams 701, 710, 703, 713 are transmitted from respective antennas 730, 740, 775, 780 substantially simultaneously.

[0046] FIG. 8 is a similar exemplary embodiment of a transmitter diversity expansion system 800 in which a Walsh matrix is used to perform the combining module. Both streams 801, 805 pass through bypass module 810 and are applied unchanged to base antennas 815, 820 respectively. Streams 801, 805 are also applied to cyclic shift module 825. Stream 801 is shifted by cyclic shift submodule 830 and stream 805 is shifted by cyclic shift submodule 835, both within cyclic shift module 825. Cyclic shift submodule 830 shifts stream 801 by more or less than cyclic shift submodule 835 shifts stream 805, but not by the same amount. Stream 802 is the shifted version of stream 801. Similarly, stream 807 is the shifted version of stream 805. Streams 802, 807 are provided to combining module 840 in which a Walsh–Hadamard combining matrix is applied to the streams to produce streams 803 and 808. Streams 803 and 808

are applied to extension antennas 845 and 850. In this exemplary embodiment, streams 801, 805, 803, 808 are transmitted from respective antennas 815, 820, 845, 850 substantially simultaneously.

[0047] Referring now to FIG. 9, an exemplary embodiment of a transmitter diversity expansion system 900 is provided for two spatial stream inputs with three antennas. Both streams 901, 905 pass through bypass module 910 and are applied unchanged to base antennas 920, 930 respectively. Streams 901, 905 are also applied to cyclic shift module 940. Stream 901 is shifted by cyclic shift submodule 945 and stream 905 is shifted by cyclic shift submodule 950, both within cyclic shift module 940. Cyclic shift submodule 945 shifts stream 901 by more or less than cyclic shift submodule 950 shifts stream 905, but not by the same amount. Stream 902 is the shifted version of stream 901. Stream 907 is the shifted version of stream 905. Streams 902, 907 are provided to combining module 960 to produce streams 903 and 908. If two extension antennas were being used, streams 903 and 908 would be applied to extension antennas 970 and 980. However, since only one extension antenna 970 is used in this embodiment, only stream 903 is provided to extension antenna 970. Stream 908 is pruned or discarded. In this exemplary embodiment, streams 901, 905, 903 are transmitted from respective antennas 920, 930, 970 substantially simultaneously.

[0048] Referring now to FIG. 10, an exemplary embodiment of a transmitter diversity expansion system 1000 is provided for three spatial stream inputs with four antennas. Streams 1001, 1005, 1010 pass through bypass module 1015 and are applied unchanged to base antennas 1020, 1030, 1040 respectively. Streams 1001, 1005, 1010 are also applied to cyclic shift module 1050. Stream 1001 is shifted by cyclic shift submodule 1055, stream 1005 is shifted by cyclic shift submodule 1060, and stream 1010 is shifted by cyclic shift submodule 1065, all within cyclic shift module 1050. Each cyclic shift submodule 1055, 1060, 1065 shifts streams 1001, 1005, 1010 by more or less than the other two cyclic shift submodules. Stream 1002 is the shifted version of stream 1001. Stream 1007 is the shifted version of stream 1005. Stream 1012 is the shifted version of stream 1010. Streams 1002, 1007, 1012 are provided to combining module 1070 to produce streams 1017. If three extension antennas were being used, three streams would be applied to the extension antennas. However, since only one extension antenna 1080 is used in this embodiment, only stream 1017 is applied to extension antenna 1080. The other streams are pruned or discarded. In this

exemplary embodiment, streams 1001, 1005, 1010, 1017 are transmitted from respective antennas 1020, 1030, 1040, 1080 substantially simultaneously.

[0049] Referring now to FIG. 11, an exemplary embodiment of a transmitter diversity expansion system 1100 is provided for two spatial stream inputs with six antennas – two base antennas and four extension antennas. Streams 1101, 1105 pass through bypass module 1110 and are applied unchanged to base antennas 1115, 1120 respectively. Streams 1101, 1105 are also applied to cyclic shift module 1125. Stream 1101 is shifted by both cyclic shift submodule 1130 and cyclic shift submodule 1140. Stream 1105 is shifted by both cyclic shift submodule 1135 and cyclic shift submodule 1145. Cyclic shift submodules 1130, 1135, 1140, 1145 are located within cyclic shift module 1125. Each cyclic shift submodule 1130, 1135, 1140, 1145 shifts streams 1101, 1105 by more or less than the other three cyclic shift submodules. Streams 1102, 1107 are shifted versions of stream 1101. Streams 1104, 1108 are shifted versions of stream 1105. Streams 1102, 1104, 1107, 1108 are provided to combining module 1150 to produce streams 1112, 1114, 1117, 1118. In this exemplary embodiment, streams 1101, 1105, 1112, 1114, 1117, 1118 are transmitted from respective antennas 1115, 1120, 1160, 1170, 1180, 1190 substantially simultaneously. The functionality of each module described hereinabove may be distributed among one or more modules. Likewise, the entire functionality described hereinabove may be combined within a single module for some embodiments.

[0050] A flow diagram of an embodiment of a transmitter diversity expansion method 1200 is provided in FIG. 12. This flow diagram is based on the exemplary embodiment with the cyclic shift module first, followed by the combining module as provided in FIG. 5. In block 1202, K spatial streams are selected for transmission on a set of N antennas, where N is greater than K. In block 1210, the K spatial streams pass through a bypass module. In block 1220 the K spatial streams are applied to K base antennas. In block 1230, a cyclic shift is applied to the K data streams to produce K shifted spatial streams. In block 1240, the K shifted spatial streams are combined to produce N-K spatial streams. In block 1250, the N-K spatial streams are applied to N-K extension antennas. In block 1260, the combined K unchanged spatial streams and N-K shifted/combined spatial streams are transmitted on N antennas comprising K base antennas and N-K extension antennas.

[0051] Another flow diagram of an embodiment of a transmitter diversity expansion method 1300 is provided in FIG. 13. This flow diagram is based on the exemplary embodiment with the combining operation first, followed by cyclic shift operation as provided in FIG. 6. In block 1302, K spatial streams are selected for transmission on a set of N antennas, where N is greater than K. In block 1310, the K spatial streams pass through a bypass module. In block 1320 the K spatial streams are applied to K base antennas. In block 1330, K data streams are combined to produce N-K extension streams. In block 1340, a cyclic shift is applied to the N-K extension streams. In block 1350, the N-K extension streams are applied to N-K extension antennas. In block 1360, the combined K unchanged spatial streams and N-K shifted/combined spatial streams are transmitted on N antennas comprising K base antennas and N-K extension antennas.

[0052] In summation, extra transmit antennas are exploited using a systematic mapping method of expanding spatial input streams such that a receiver does not need to be aware of any special coding.

[0053] Exemplary embodiments of the present disclosure can be implemented in hardware, software, firmware, or a combination thereof. In the preferred embodiment(s), transmitter diversity expansion systems and methods are implemented in software or firmware that is stored in a memory and that is executed by a suitable instruction execution system. If implemented in hardware, as in an alternative embodiment, the systems and methods of the preferred embodiments can be implemented with any or a combination of the following technologies, which are all well known in the art: a discrete logic circuit(s) having logic gates for implementing logic functions upon data signals, an application specific integrated circuit (ASIC) having appropriate combinational logic gates, a programmable gate array(s) (PGA), a field programmable gate array (FPGA), *etc.*

[0054] The flow diagrams of FIGs. 12 and 13 show the architecture, functionality, and operation of possible implementations of the transmitter diversity expansion software implementing transmitter diversity expansion methods. In this regard, each block represents a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function(s). It should also be noted that in some alternative implementations, the functions noted in the blocks may occur out of the order noted in FIGs. 12 and 13. For example, two blocks

shown in succession in FIG. 12 may in fact be executed substantially concurrently or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved, as would be understood by those reasonably skilled in the art of the present disclosure.

[0055] The transmitter diversity expansion program, which may comprise an ordered listing of executable instructions for implementing logical functions, can be embodied in any computer-readable medium for use by or in connection with an instruction execution system, apparatus, or device, such as a computer-based system, processor-containing system, or other system that can fetch the instructions from the instruction execution system, apparatus, or device and execute the instructions. In the context of this document, a "computer-readable medium" can be any means that can contain, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device. The computer readable medium can be, for example but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, device, or propagation medium. More specific examples (a nonexhaustive list) of the computer-readable medium would include the following: an electrical connection (electronic) having one or more wires, a portable computer diskette (magnetic), a random access memory (RAM) (electronic), a read-only memory (ROM) (electronic), an erasable programmable read-only memory (EPROM or Flash memory) (electronic), an optical fiber (optical), and a portable compact disc read-only memory (CDROM) (optical). Note that the computer-readable medium could even be paper or another suitable medium upon which the program is printed, as the program can be electronically captured, via for instance optical scanning of the paper or other medium, then compiled, interpreted or otherwise processed in a suitable manner if necessary, and then stored in a computer memory. In addition, the scope of the present disclosure includes embodying the functionality of the preferred embodiments of the present disclosure in logic embodied in hardware or software-configured mediums.

[0056] It should be emphasized that the above-described embodiments of the present disclosure, particularly, any "preferred" embodiments, are merely possible examples of implementations, set forth for a clear understanding of the principles of the disclosure. Many variations and modifications may be made to the above-described embodiment(s) of the disclosure without departing substantially from the spirit and

principles of the disclosure. All such modifications and variations are intended to be included herein within the scope of this disclosure and protected by the following claims.

CLAIMS

Therefore, at least the following is claimed:

1. A method comprising:

receiving K data streams;

providing each of the K data streams to K antennas of a set of N antennas for transmission;

providing N-K data streams to N-K unused antennas of the set of N antennas based on the K data streams for transmission; and

transmitting the N data streams on the N antennas.

2. The method of claim 1, wherein providing N-K data streams comprises combining the K data streams to produce the N-K data streams.

3. The method of claim 1, wherein providing N-K data streams comprises cyclic shifting the K data streams.

4. The method of claim 2, wherein providing N-K data streams comprises cyclic shifting the K data streams to produce the N-K data streams.

5. The method of claim 4, wherein the cyclic shifting is performed before the combining.

6. The method of claim 4, wherein the combining is performed before the cyclic shifting.

7. The method of claim 2, wherein the combining comprises applying a unitary matrix to the data streams.

8. A system comprising:

a bypass module configured to receive K data streams and to relay the K data streams to K antennas of a set of N antennas; and

a diversity expansion module configured to provide N-K data streams for application to a set of N-K antennas based on the K data streams.

9. The system of claim 8, wherein the diversity expansion module comprises a cyclic shift module configured to shift data streams to produce shifted data streams.

10. The system of claim 8, wherein the diversity expansion module comprises a combining module configured to combine data streams.

11. The system of claim 9, wherein the diversity expansion module comprises a combining module configured to combine data streams.

12. The system of claim 11, wherein the cyclic shift module is applied to the K data streams before the combining module.

13. The system of claim 11, wherein the combining module is applied to the K data streams before the cyclic shift module.

14. The system of claim 9, wherein the combining comprises applying a unitary matrix to the data streams.

15. A computer readable medium with software for performing a method comprising:

logic for receiving K data streams;

logic for providing each of the K data streams to K antennas of a set of N antennas for transmission;

logic for providing N-K data streams to N-K unused antennas of the set of N antennas based on the K data streams for transmission; and

logic for transmitting the N data streams on the N antennas.

16. The computer readable medium of claim 15, wherein logic for providing N-K data streams comprises logic for cyclic shifting and for combining the K data streams to produce the N-K data streams.

17. The computer readable medium of claim 16, wherein the logic for cyclic shifting is performed on the data streams before the logic for combining.

18. The computer readable medium of claim 16, wherein the logic for combining is performed on the data streams before the logic for cyclic shifting.

19. The computer readable medium of claim 16, wherein the logic for combining comprises logic for applying a unitary matrix to the data streams.

20. The computer readable medium of claim 19, wherein the unitary matrix is at least one of a fast Fourier transform matrix and a Walsh matrix.

ABSTRACT OF THE DISCLOSURE

Methods and systems for transmitter diversity expansion are provided. The methods and systems include steps and modules for applying a number of data streams (K) to a larger number of antennas (N). This is performed by applying each of the data streams to a single base antenna, such that K data streams are applied to K base antennas, and by shifting and combining the K data streams to produce N-K data streams to apply to N-K extension antennas.

Packet Generation Systems and Methods

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CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to copending U.S. provisional application having ser. no. 60/562,222, filed April 15, 2004, which is entirely incorporated herein by reference.

1. Field of the Invention.

The present invention is generally related to digital communications and, more particularly, is related to a system and method for increased bandwidth digital communications.

2. Related Art.

[0002] Communication networks come in a variety of forms. Notable networks include wireline and wireless. Wireline networks include local area networks (LANs), DSL networks, and cable networks, among others. Wireless networks include cellular telephone networks, classic land mobile radio networks and satellite transmission networks, among others. These wireless networks are typically characterized as wide area networks. More recently, wireless local area networks and wireless home networks have been proposed, and standards, such as Bluetooth and IEEE 802.11, have been introduced to govern the development of wireless equipment for such localized networks.

[0003] A wireless local area network (LAN) typically uses infrared (IR) or radio frequency (RF) communications channels to communicate between portable or

mobile computer terminals and stationary access points or base stations. These access points are, in turn, connected by a wired or wireless communications channel to a network infrastructure which connects groups of access points together to form the LAN, including, optionally, one or more host computer systems.

[0004] Wireless protocols such as Bluetooth and IEEE 802.11 support the logical interconnections of such portable roaming terminals having a variety of types of communication capabilities to host computers. The logical interconnections are based upon an infrastructure in which at least some of the terminals are capable of communicating with at least two of the access points when located within a predetermined range, each terminal being normally associated, and in communication, with a single one of the access points. Based on the overall spatial layout, response time, and loading requirements of the network, different networking schemes and communication protocols have been designed so as to most efficiently regulate the communications.

[0005] IEEE Standard 802.11 ("802.11") is set out in "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications" and is available from the IEEE Standards Department, Piscataway, N.J. 802.11 permits either IR or RF communications at 1 Mbps, 2 Mbps and higher data rates, a medium access technique similar to carrier sense multiple access/collision avoidance (CSMA/CA), a power-save mode for battery-operated mobile stations, seamless roaming in a full cellular network, high throughput operation, diverse antenna systems designed to eliminate "dead spots," and an easy interface to existing network infrastructures.

[0006] The 802.11a standard defines data rates of 6, 12, 18, 24, 36 and 54 Mbps in the 5 GHz band. Demand for higher data rates may result in the need for devices that can communicate with each other at the higher rates, yet co-exist in the same WLAN environment or area without significant interference or interruption from each other, regardless of whether the higher data rate devices can communicate with the 802.11a devices. It may further be desired that high data rate devices be able to communicate with the 802.11a devices, such as at any of the standard 802.11a rates.

[0007] Increasing the data rate and allowing more effective use of bandwidth for devices operating in these bands enables more efficient communications. A higher data rate may enable service providers to more effectively use their allotted spectrum. Consumers may realize a cost savings as well.

SUMMARY

This disclosure describes systems and methods for increasing packet generation in a digital communication system. In one exemplary method embodiment, multiple input signals are interpolated, shifted, and aggregated into a composite signal for transmission over a network. In an exemplary system embodiment, a system targeted at a new IEEE 802.11n standard receives two 20MHz signals compliant with IEEE 802.11a, interpolates each signal by 2, shifts one signal up 10MHz, shifts the other signal down 10 MHz, and adds the signals together to produce a composite 40MHz signal.

Other systems, methods, features and advantages of the disclosure will be or will become apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features and advantages be included within this description, be within the scope of the invention, and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the disclosed systems and methods. In the figures, like reference numerals designate corresponding parts throughout the different views.

FIG. 1 is a block diagram illustrating an International Organization for Standards (ISO) Basic Reference Model of open systems interconnection (OSI).

FIG. 2 is a block diagram of an exemplary embodiment of a local area network with devices communicating at different data rates.

FIG. 3 is a block diagram of an exemplary embodiment of a transmitter of a communications device in the local area network of FIG. 2.

FIG. 4 is a block diagram of an exemplary embodiment of a low frequency input section to the transmitter of FIG. 3.

FIG. 5 is a graphical representation of the frequency spectrum of an exemplary embodiment of an input signal for the input section provided in FIG. 4.

FIG. 6 is a graphical representation of the frequency spectrum of an exemplary embodiment of an input signal according to FIG. 5 that has been interpolated and shifted down.

FIG. 7 is a block diagram of an exemplary embodiment of a high frequency input section to the transmitter of FIG. 3.

FIG. 8 is a graphical representation of the frequency spectrum of an exemplary embodiment of an input signal according to FIG. 5 that has been interpolated and shifted up.

FIG. 9 is a block diagram of an exemplary embodiment of a system for adding the outputs of the input sections of FIGS. 4 and 7 into a composite signal.

FIG. 10 is a graphical representation of the frequency spectrum of an exemplary embodiment of the composite signal of FIG. 9.

FIG. 11 is a flow diagram of the system of FIG. 9 with an even number of input signals.

FIG. 12 is a graphical representation of the frequency spectrum of an output corresponding to the flow diagram of FIG. 11.

FIG. 13 is a flow diagram of the system of FIG. 9 with an odd number of input signals.

FIG. 14 is a graphical representation of the frequency spectrum of an output corresponding to the flow diagram of FIG. 13.

FIG. 15 is a graphical representation of the frequency versus time relationship of multiple packets in the composite signal in the exemplary embodiment of FIG. 9.

DETAILED DESCRIPTION

Disclosed herein are various embodiments of packet generation systems and methods. One system embodiment comprises logic that receives a number of digital signals, multiplies the signal sample rate by the number of received signals (*e.g.*, an interpolation), shifts the signals with respect to a center frequency, and accumulates the shifted signals into one signal. The interpolating, shifting, and accumulating may be done in any type of processor including, but not limited to, a digital signal processor (DSP), a microprocessor (MCU), a general purpose processor, an application specific integrated circuit (ASIC), among others. One system embodiment comprises receiving 20 megahertz (MHz) inputs from an 802.11a system for transmission in a 40MHz system. A new standard is being proposed, referred to as 802.11n (the "802.11n proposal"), which is a high data rate extension of the 802.11a standard at 5 GHz. It is noted that, at the present time, the 802.11n proposal is only a proposal and is not yet a completely defined standard. Although described in the context of 802.11a and an 802.11n proposal, other applicable standards include Bluetooth, xDSL, other sections of 802.11, etc.

[0008] 802.11 is directed to wireless LANs, and in particular specifies the MAC and the PHY layers. These layers are intended to correspond closely to the two lowest layers of a system based on the ISO Basic Reference Model of OSI, i.e., the data link layer and the physical layer. FIG. 1 shows a diagrammatic representation of an

open systems interconnection (OSI) layered model 100 developed by the International Organization for Standards (ISO) for describing the exchange of information between layers in communication networks. The OSI layered model 100 is particularly useful for separating the technological functions of each layer, and thereby facilitating the modification or update of a given layer without detrimentally impacting on the functions of neighboring layers.

[0009] At a lower most layer, the OSI model 100 has a physical layer or PHY layer 102 that is responsible for encoding and decoding data into signals that are transmitted across a particular medium. Above the PHY layer 102, a data link layer 104 is defined for providing reliable transmission of data over a network while performing appropriate interfacing with the PHY layer 102 and a network layer 106. The network layer 106 is responsible for routing data between nodes in a network, and for initiating, maintaining and terminating a communication link between users connected to the nodes. A transport layer 108 is responsible for performing data transfers within a particular level of service quality. A session layer 110 is generally concerned with controlling when users are able to transmit and receive data. A presentation layer 112 is responsible for translating, converting, compressing and decompressing data being transmitted across a medium. Finally, an application layer 114 provides users with suitable interfaces for accessing and connecting to a network.

[0010] FIG. 2 is a block diagram of a wireless local area network (WLAN) system 200 operating within area 202, including four WLAN devices 204, 206, 208 and 210. Devices 204 and 206 are implemented according to at least one of several embodiments compliant with the 802.11n proposal, whereas devices 208 and 210 are implemented according to the 802.11a standard. All of the devices 204-210 operate in the 5 GHz band. The devices 204-210 may include any type of wireless communication device, such as a computer (desktop, portable, laptop, etc.), a television set, infrared devices, a set-top box, a cellular phone, a portable phone, a radio, compatible telecommunication devices, a personal digital assistant (PDA), or other network device, such as printers, facsimile machines, scanners, hubs, switches,

routers, etc., or other consumer electronics device. Although described in the context of a communications environment compliant with one or more of the 802.11n proposal, the 802.11a standard, the 802.11b standard or the 5 GHz frequency band, other standards and frequencies may be utilized in some embodiments.

[0011] Devices 208 and 210 communicate with each other at any of the standard 802.11a rates. The devices 204 and 206 communicate with each other at different data rates than devices 208 and 210. In one or more embodiments, devices 204-210 may operate or coexist in the area 202 without significant interference from each other, where the devices 204, 206 communicate with each other at different data rates than the 802.11a devices 208, 210. In one embodiment, devices 204, 206 can communicate with either or both of devices 208, 210 at any one or more of the standard 802.11a data rates. In one embodiment, devices 204, 206 communicate at different data rates than devices 208 and 210 and are incompatible with the devices 208 and 210, so that the devices 204-210 are not able to coexist within the same area 202. Devices 204, 206 may be implemented to operate in the 5 GHz band, although other frequency bands are contemplated.

[0012] One embodiment of a transmitter for an 802.11 device is provided in FIG. 3. Referring to FIG. 3, a PHY unit 300 includes an orthogonal frequency division multiplex (OFDM) transmit kernel 320, a symbol wave shaper/interpolator/shifter/summer(accumulator, assimilator) 310, an IQ modulator 312, a mixer 314, high power amplifier (HPA) 316, and antenna 318. OFDM transmit kernel 320 includes an FEC coder 302 (for encoding the data received from a MAC unit), an interleaver/mapper 304, an inverse fast Fourier transform (IFFT) unit 306, and cyclic extension logic 308.

[0013] During a data transmit process, data and control information are received at the FEC coder 302. The FEC coder 302 encodes data in a forward error correction code. Any forward error correction (FEC) code can be used for this purpose. FEC code examples include a Reed-Solomon and a combination Reed-Solomon and convolution code, among others. The interleaver/mapper 304 subsequently

interleaves (reorders, distributes) the encoded data. The output of the interleaver/mapper 304 is sent to the IFFT unit 306. The IFFT unit 306 receives input from the interleaver/mapper 304 and provides OFDM symbols to the cyclic extension logic 308. The cyclic extension logic 308 inserts a cyclic prefix (*e.g.*, guard interval) to ensure that the transmitted symbol retains its orthogonal properties in the presence of multi-path delay spread. The output of the cyclic extension logic 308 is sent to the symbol wave shaper/interpolator/shifter/summer 310. Symbol wave shaper/interpolator/shifter/summer 310 comprises a low-pass filter to smooth the edges between successive OFDM symbols. The trailing edge and leading edge of each OFDM symbol is tapered to prevent spectral splattering outside the frequency channel, minimizing adjacent interference and satisfying regulatory concerns. The symbol wave shaper/interpolator/shifter/summer 310 also comprises interpolation, shifting, and summing functionality as described below.

[0014] The output of symbol wave shaper/interpolator/shifter/summer 310 is sent to modulator 312. The modulator 312 modulates the encoded data onto carriers in OFDM symbols in accordance with conventional OFDM modulation techniques. The modulation techniques may be coherent or differential. The modulation mode or type may be Binary Phase Shift Keying and Quadrature Phase Shift Keying, among others.

[0015] The output of the modulator 312 is sent to mixer 314 where it is upconverted to the desired transmit frequency. The upconversion may be performed in multiple mixer stages. From mixer 314, the upconverted signal is amplified in high powered amplifier (HPA) 316 and sent to antenna 318 for transmission.

[0016] To increase the bandwidth of the signal, a processor (not shown) in the PHY 102 (FIG. 1) manipulates the OFDM signal. This discussion will focus on a scenario with two inputs, increasing the bandwidth by a factor of 2. However, the approach is applicable to any number of substantially simultaneous inputs. In one embodiment of an 802.11n system, two 20MHz 802.11a input signals are received at the PHY unit 300 substantially simultaneously. The two signals are processed separately, one in a lower 20MHz path and one in an upper 20MHz path. A lower

20MHz path 400 is presented in FIG 4 and includes lower 20MHz OFDM transmit kernel 320a, interpolator 310a, and –10MHz frequency shifter 310b. One of the inputs is first processed by the lower 20MHz OFDM transmit kernel 320a which corresponds to the transmit kernel 320 from FIG. 3. The lower 20MHz OFDM transmit kernel 320a sends the signal to an interpolation stage 310a where the signal is interpolated by a factor of the number of signals received substantially simultaneously. Interpolation stage 310a corresponds to shaper/interpolator/shifter/summer 310 of FIG. 3. In this exemplary embodiment, two signals are received, so the interpolation factor is 2.

[0017] The interpolation stage 310a increases the sample rate of the signal. If the signal is interpolated by 2, the sample rate is doubled. Interpolation can be performed by inserting zeros (*i.e.* zero stuffing) between the original samples. Then, this zero-stuffed sample stream is low-pass filtered (*e.g.* in symbol shaper 310 of FIG. 3). The low-pass filter is designed so the original spectrum is maintained, and only the bandwidth is doubled. This zero-stuffed example is but one method of interpolation. Another method would be to duplicate each individual sample. Other methods known to one of ordinary skill in the art would also apply. The output of interpolation stage 310a is then shifted down by 10 MHz at frequency shift stage 310b. Frequency shift stage 310b corresponds to shaper/interpolator/shifter/summer 310 of FIG. 3. The frequency shift is performed by multiplying the sample by $e^{j2\Pi f_{shift}t}$, where f_{shift} is the amount of desired frequency shift.

[0018] FIG. 5 presents an exemplary 20MHz 802.11a OFDM signal 500 centered at center frequency f_c. After being processed in the interpolation stage 310a (FIG. 4) and the frequency shift stage 310b, the resulting 40MHz down-shifted signal 600 is formed, as presented in FIG. 6.

[0019] An upper 20MHz path 700 is presented in FIG 7, and comprises upper 20MHz OFDM transmit kernel 320b, interpolator 310c, and +10MHz frequency shifter 310d. One of the inputs is first processed by the upper 20MHz OFDM transmit kernel 320b which corresponds to the transmit kernel 320 from FIG. 3. The upper 20MHz OFDM transmit kernel 320b sends the signal to an interpolation stage

310c where the signal is interpolated by a factor of the number of signals received substantially simultaneously. Interpolation stage 310c corresponds to shaper/interpolator/shifter/summer 310 of FIG. 3. In this exemplary embodiment, two signals are received, so the interpolation factor is 2. The output of interpolation stage 310c is then shifted up by 10 MHz at frequency shift stage 310d. Frequency shift stage 310d corresponds to shaper/interpolator/shifter 310 of FIG. 3. The frequency shift is performed by multiplying the sample by $e^{j2\Pi f_{shift}t}$, where f_{shift} is the amount of desired frequency shift.

[0020] An exemplary 20MHz 802.11a OFDM signal 500 (as provided in FIG. 5), centered at center frequency f_c, is processed in the interpolation stage 310c and the frequency shift stage 310d. The resulting 40MHz up-shifted signal 800 is formed, as presented in FIG. 8.

[0021] FIG. 9 presents an exemplary embodiment with 2 signal paths, upper path 700 and lower path 400, each processing a 20MHz 802.11a input signal substantially simultaneously. The output of each path is aggregated in adder 310e to achieve, in this exemplary embodiment, a signal 1000 with a 40MHz bandwidth and a 40MHz sample rate as shown in FIG. 10. As provided above, this process could be easily adapted for other systems with different protocols, with different frequencies, and with more input signals.

[0022] For a system with "x" number of input signals with substantially similar bandwidths and center frequencies, received substantially simultaneously, the interpolation stage is performed by interpolating by a factor equal to "x." In the shifting stage, the method is dependent on whether "x" is odd or even.

[0023] If "x" is even, each signal is shifted from the center frequency by a succeeding multiple of the bandwidth (BW) of the signal. For example, as illustrated in FIG. 11, if six 10MHz signals (A, B, C, D, E, and F) are received, each is interpolated by a factor of six (6) in blocks 1100a-1100f. Each signal with a 10MHz sample rate is interpolated such that each has a revised sample rate of 60MHz. Then, in block 1102, signal A is shifted up by the BW/2. In block 1104, signal B is shifted down by BW/2. In block 1106, signal C is shifted up by 3*BW/2.

In block 1108, signal D is shifted down by 3*BW/2. In block 1110, signal E is shifted up by 5*BW/2. In block 1112, signal F is shifted down by 5*BW/2. In block 1114, the six shifted signals are aggregated into one composite signal for transmission. This process is applicable for any even number of input signals. Each simultaneous input is interpolated and shifted from the center frequency by a progressive odd multiple of BW/2 on alternating sides of the center frequency.

[0024] FIG. 12 demonstrates how an even number of signals are distributed from the center frequency. Signal A 1202 is shifted up by BW/2, signal B 1204 is shifted down by BW/2, signal C 1206 is shifted up by 3*BW/2, signal D 1208 is shifted down by 3*BW/2, signal E 1210 is shifted up by 5*BW/2, and signal F 1212 is shifted down by 5*BW/2.

[0025] The shifting of the signals is covered by the following expression:

$$-R*(N-1)/2 + (K-1)*R,$$

where R is the signal sample rate and N is the total number of digital inputs.

[0026] The process is slightly different for an odd number of inputs. If "x" is odd, one signal is not shifted, or, equivalently, it is shifted by a factor of zero*BW (*i.e.*, zero multiplied by the BW). Each of the other signals received substantially simultaneously is shifted from the center frequency by a succeeding multiple of the BW of the signal. For example, as demonstrated in FIG. 13, if five 10MHz signals (A, B, C, D, and E) are received, in blocks 1300a-1300e, each is first interpolated by a factor of 5 corresponding to the number of received signals. If each signal had a 10MHz sample rate, each is interpolated such that each has a revised sample rate of 50MHz. Then, in block 1302, signal A is not shifted. Each of the remaining signals (B, C, D, and E) are shifted by a multiple of the BW of the signal. In block 1304, signal B is shifted up by BW. In block 1306, signal C is shifted down by BW (*i.e.*, 1*BW). In block 1308, signal D is shifted up by 2*BW. In block 1310, signal E is shifted down by 2*BW. In block 1312, the five shifted signals are aggregated into one composite signal for transmission. This process is applicable for any odd

number of input signals. Each substantially simultaneous input is interpolated and shifted from the center frequency by a progressive multiple of the BW on alternating sides of the center frequency.

[0027] FIG. 14 demonstrates how an odd number of signals are distributed from the center frequency. Signal A 1402 is not shifted. Each of the remaining signals (B, C, D, and E) are shifted by a multiple of the BW of the signal. That is, signal B 1404 is shifted up by BW, signal C 1406 is shifted down by BW, signal D 1408 is shifted up by 2*BW, and signal E 1410 is shifted down by 2*BW.

[0028] For both odd and even numbers of signals, the process of shifting of the signals is described by the following expression:

$$-R*(N-1)/2 + (K-1)*R,$$

where R is the signal sample rate and N is the total number of digital inputs.

[0029] FIG. 15 is a graph of each signal and its frequency vs. time relationship. Each signal's start time 1502 and end time 1504 should be substantially equivalent to eliminate problems with multiple signal acquisition and termination. These problems may include transmitting and receiving simultaneously. By occupying "both" channels at the same time, simultaneous transmitting and receiving is enabled.

[0030] A receiver for such a system samples at the aggregate bandwidth. For the IEEE 802.11n exemplary embodiment, the individual halves are frequency shifted and then low-pass filtered. The output of the low-pass filters have the sample rate decimated by 2, filtering out every other sample, or, in other words, filtering out the zeros of the zero-stuffed signal.

[0031] While various embodiments of the invention have been described, it will be apparent to those of ordinary skill in the art that many more embodiments and implementations are possible that are within the scope of this invention.

CLAIMS

What is claimed is:

1. A method comprising:

increasing the sample rate of each of a plurality of digital inputs to produce increased sample rate inputs;

shifting each of the plurality of increased sample rate digital inputs to produce a plurality of shifted signals;

combining the plurality of shifted signals to produce a combination signal; and

transmitting the combination signal.

2. The method of claim 1, wherein the plurality of digital inputs are received substantially simultaneously.

3. The method of claim 1, wherein the plurality of digital inputs have a common sample rate.

4. The method of claim 3, wherein the sample rate of each of the plurality of digital inputs is increased by a factor corresponding to the number of the plurality of digital inputs received substantially simultaneously.

5. The method of claim 3, wherein increasing the sample rate of each of the plurality inputs comprises interpolating each of the digital inputs by a factor corresponding to the number of inputs.

6. The method of claim 1, wherein the increasing, the shifting and the combining is performed by at least one of a DSP, a microprocessor, a general purpose processor, or an application specific integrated circuit.

7. The method of claim 1, wherein increasing the sample rate comprises interpolating each of the plurality of digital inputs.

8. The method of claim 7, wherein each of the plurality of digital inputs is interpolated by a factor of two.

9. The method of claim 1, wherein the plurality of digital inputs are modulated signals.

10. The method of claim 9, wherein the modulated signals are orthogonal frequency division multiplexed signals.

11. The method of claim 1, wherein the shifting of each of the plurality of signals comprises multiplying each of the plurality of signals by $e^{j2\Pi ft}$, where f is the desired frequency shift.

12. The method of claim 1, further comprising indexing each of the inputs wherein K = 1, 2, ..., S, and wherein the shifting of the inputs comprises shifting each indexed signal by -R*(N-1)/2 + (K-1)*R, where R is the signal sample rate and N is the total number of digital inputs.

13. The method of claim 1, wherein the method is a method of wireless communication.

14. A system comprising:

an interpolator for increasing the sample rate of input signals to produce interpolated signals;

a frequency shifter for shifting the frequency of each of the interpolated signals to produce shifted signals; and

an assimilator for assimilating the shifted signals to produce an assimilated signal.

15. The system of claim 14, wherein the interpolator increases the sample rate by a factor of two.

16. The system of claim 14, wherein the frequency shifter multiplies each of the interpolated signals by $e^{j2\Pi ft}$, where f is the desired frequency shift.

17. The system of claim 14, wherein the input signals are digitally modulated signals.

18. The system of claim 17, wherein the digitally modulated signals are orthogonal frequency division multiplexed signals.

19. A system comprising:

means for receiving a plurality of signals;

means for increasing the sample rate of the plurality of signals;

means for shifting each of the plurality of signals to produce a plurality of shifted signals;

means for summing the plurality of shifted signals to produce a summation signal; and

means for transmitting the summation signal.

20. A transmitter for wireless communications comprising:

a first input communicatively coupled to a processor, the input configured to receive a first orthogonal frequency division multiplexed digital signal with a sample rate of approximately 20 MHz and a center frequency f_c;

the processor configured to interpolate the first orthogonal frequency division multiplexed digital signal to increase the sample rate of the first orthogonal frequency division multiplexed digital signal such that it has a sample rate of approximately 40 MHz, the processor further configured to shift the center frequency of the first orthogonal frequency division multiplexed digital signal to (f_c + 10 MHz) by multiplying the first orthogonal frequency division multiplexed digital signal by $e^{j2\Pi 10t}$;

a second input communicatively coupled to the processor, the second input configured to receive a second orthogonal frequency division multiplexed digital signal with a sample rate of approximately 20 MHz and the center frequency f_c;

the processor further configured to interpolate the second orthogonal frequency division multiplexed digital signal to increase the sample rate of the second orthogonal frequency division multiplexed digital signal such that it has a sample rate of approximately 40 MHz, the processor further configured to shift the center frequency of the second orthogonal frequency division multiplexed digital signal to (f_c - 10 MHz) by multiplying the second orthogonal frequency division multiplexed digital signal by $e^{-j2\Pi 10t}$;

the processor further configured to add the shifted first orthogonal frequency division multiplexed digital signal to the shifted second orthogonal frequency division multiplexed digital signal to produce a third orthogonal frequency division multiplexed digital signal with a sample rate of 40 MHz and a center frequency of f_c; and

an output communicatively coupled to the processor, the output configured to transmit the third orthogonal frequency division multiplexed digital signal.

ABSTRACT

Disclosed herein are various embodiments of methods, systems, and apparatus for increasing packet generation in a digital communication system. In one exemplary method embodiment, multiple input signals are interpolated, shifted, and aggregated into a composite signal for transmission over a network.

IEEE P802.11 - TASK GROUP N - MEETING UPDATE:

Status of Project IEEE 802.11n

Standard for Enhancements for Higher Throughput

July 2006, San Diego, CA, US

TGn voted to adopt a new draft version 1.02 that incorporates all of the 6700 editorial comments from the prior WG letter ballot.

The ad hoc groups chartered in May to address the 8 comment topic areas continued their work, proposing resolutions to 49% of all of the voter suggestions by the end of the week. A portion of these were formally adopted by TGn, with the comment resolution and task group adoption process to continue in future meetings.

May 2006, Jacksonville, FL, US

The WG Letter ballot issued after the March meeting failed to achieve the necessary 75% approval level. As is standard practice, the voters submitted suggestions as to how the draft could be improved. TGn began reviewing the comments received during the balloting process and proposed response text for comment resolution. To expedite the process the comments were grouped into 8 topic areas: PHY, MAC, PSMP, Coexistence, Editorial, Coexistence Assurance, Frame Format & General. For each of these topic areas an appropriate portion of the comments were allocated and an ad hoc chair was solicited from the task group to lead the discussion. Using this method it was possible to conduct several discussions in parallel.

Comment resolution activities are expected to continue via teleconferences, ad hoc meetings and regular sessions through the July and September meetings.

March 2006, Denver, Colorado, US

TGn is moving into letter ballot phase.

The specifications approved in January were converted into draft text for review by the membership. Additionally three critical, but previously absent, MIB, PICS and Coexistence Assurance document components were prepared and accepted. The draft preparation process also resulted in the identification of 150 omissions that needed to be filled. Submissions on these were prepared and approved by Task group n. All of these became "instructions to the editor to incorporate them into the draft".

At the end of the week draft version 0.04 was prepared and deemed worthy of proceeding to letter ballot

by TGn. The WG subsequently agreed and approved to move the draft specification to Working Group letter ballot. Results of the 40 day letter ballot will be collected and reviewed during the next meeting in May.

January 2006, Kona, Hawaii, US,

Task group n has voted unanimously to confirm selection of a joint proposal for high throughput wireless local area networks. This proposal will amend and extend the IEEE 802.11(TM) WirelessLAN standard to incorporate new technologies for increasing the throughput of wireless local area networks up to 600 Mbps..
Prior to and during the March session, the proposal will be formatted into draft format and further developed in preparation for issuance of a letter ballot. Additionally a coexistence assurance document, in compliance with requirements from 802.19, will be prepared for distribution with the letter ballot when it is issued.

September 2005, Garden Grove, California, US

The Joint Proposal group (now comprised of members from three proposal groups reinstated during the May meeting (TGn Sync, WWiSE and MITMOT) presented two status reports (05-0876 & 05-1001) regarding progress toward developing a merged proposal. The progress so far indicates that the goal of a complete proposal being presented and discussed during the November session is aggressive but reasonable. In anticipation of this, the November agenda incorporates extensive time for presentations and discussions followed by a confirmation vote and technical editor election.

Also discussed was the overall timeline for 11n. Based upon current status information the timeline as displayed at http://grouper.ieee.org/groups/802/11/, was deemed to be accurate. It will be reviewed again during November.

July 2005, San Francisco, California, US

The three proposal groups reinstated during the May meeting (TGn Sync, WWiSE and MITMOT) indicated that they have begun working together to create a single merged proposal. Consequently the task group voted to postpone the pending down select voting process until the merged document is ready. It is expected that a partial merged proposal will be posted for review during the September '05 meeting and a complete proposal will be ready for group review at the November '05 meeting.

Additionally, FR10 and FR11 functional requirements describing a "single stream" mode of operation were approved for addition to the Functional Requirements document which has been updated to 03-0813 r13.

May 2005, Cairns, Queensland, Australia

TGnSync, as the single remaining technical proposal candidate, was engaged in 12 hours of presentation and discussion in the task group. This included discussion of voters comments about their reasons for voting against confirmation in the first confirmation vote held in March. After discussion, a second confirmation vote was held but the proposal failed to obtain the 75% membership approval required. As a consequence dictated by the TGn selection process, the previous three remaining proposals (TGn Sync, WWiSE and MITMOT) are reinstated for consideration by the task group. The task group will consider updated technical proposals and any mergers during its next session in July. Should there be more than one proposal entering the meeting in July, the remaining proposals will re-enter a round of elimination voting removing from consideration the proposal with the least support.

March 2005, Atlanta, Georgia

Two complete proposals known by the titles TGnSync and WWiSE each authored by large groups of individuals were presented to the Task Group for consideration this week. After many hours of discussions, a down select vote was conducted that resulted in TGn Sync obtaining a majority of the votes cast. TGnSync, as the single remaining candidate was then considered for confirmation as a basis for the first draft but failed to obtain the 75% membership approval required. Voters comments about their reasons for voting against confirmation will be reviewed by TGnSync between March and the next task group meeting in May were TGnSync will present responses, proposed cures and again request confirmation.

January 2005, Monterey, California

Three complete proposals known by the titles MITMOT, TGnSync and WWiSE were presented to the Task Group for consideration during the session.

After 14 hours of presentations and discussion a down select vote was held that resulted in the elimination of the MITMOT proposal. Further consideration of the remaining two proposals and further selection voting is planned for the next meeting in March.

November 2004, San Antonio, Texas, USA

62 letters of intent were submitted in response to the TGn call for proposals that closed on Friday June 18. 32 proposals were submitted to the IEEE 802wirelessworld server by Friday August 13 and subsequently presented during the September meeting held in Berlin . 4 of these were complete and 28 partial.
Discussion of these 32 proposals continued in November with extended period of Q&A. The majority of time was spent discussing the 4 complete proposals now known by the names: MITMOT, TGnSync, WWiSE, and Qualcomm.

After the close of discussion and final remarks, there was a low hurdle vote conducted on the 4 complete proposals. Voters were asked to vote "consider" or "not consider" for each of the 4 proposals.
266 ballots were cast. with the percentage of those favoring further consideration shown as follows:

- MITMOT 47.4%
- TGnSync 73.7%

- WWiSE 64.7%
- Qualcomm 56.8%

Details of the voting are on the 802.11 member's website and in the TGn minutes. (document 04-1437)

The threshold for further consideration was 25% and therefore all proposals have passed on to the next phase.

More detailed presentations and discussions will continue in the January 2005 meeting. It is also expected that elimination voting will begin. During elimination voting each voter will register their support for only one candidate and the proposal with the lowest level of support will be eliminated.

The cycle of presentation, discussion and voting will continue until there remains only one candidate. The remaining candidate must then achieve ratification where support from at least 75% of voting members is obtained.

Should any other questions arise regarding preparations for the January meeting please contact: Bruce.kraemer@conexant.com and garth.hillman@amd.com.

July 2004, Portland, Oregon, USA

Selection Procedure - Step 5 Has been completed.

Step 5 of the 802.11 TGn (High Throughput) Selection Procedure (described in document 11-03-665r9) was to issue a Call for Proposals. The TGn Call for Proposals notification of "intent to present", closed Friday night (midnight EDT) June 18, 2004. Thanks to all those who have expressed their intent. The total "intent" count stands at 61 with 22 "complete" and 39 "partial". The list of submissions is attached below.

During our upcoming July 12-16 meeting in Portland , Oregon we will discuss meeting logistics for the proposal presentation phase which will begin in the subsequent 802.11 meeting on September 13 in Berlin, Germany . Reminders will be issued that for the next phase of the process, each presenter is obligated to have their presentation properly submitted and loaded onto the IEEE 802.11 802wirelessworld server by Friday (midnight EDT) August 13, 2004. I have built a distribution list for each of the presenters listed below. Reminders will not be broadcast to the whole reflector.

IEEE TASK GROUP CONFIRMS JOINT PROPOSAL FOR 802.11n PROJECT

Vote Advances Standards Process for Development of High Throughput Wireless Local Area Networking

PISCATAWAY, N.J., 20 Janurary 2006 **The IEEE today announced that the task group drafting**

IEEE 802.11n(TM), Amendment to Standard for Information Technology-Telecommunications and information exchange between systems-Local and Metropolitan networks- Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Enhancements for Higher Throughput, has voted unanimously to confirm selection of a joint proposal for high throughput wireless local area networks. This proposal will amend and extend the IEEE 802.11(TM) Wireless LAN standard to incorporate new technologies for increasing the throughput of wireless local area networks. The amended standard would specify methods of increasing connection speeds up to 600 Mbps.

"The IEEE 802.11 Wireless LAN working group continues the process to improve the standard to meet the evolving needs of the public and industry," said Stuart J. Kerry, Chair of the IEEE 802.11 Working Group on Wireless Local Area Networks. "Hundreds of technical experts from the world's leading technology companies, academic institutions, and government agencies have collaborated to develop the foundation for new High-Throughput wireless LAN technology."

The IEEE 802.11n standards development project, begun in 2003 expects to complete its draft development work in late 2006 toward publication of an amendment to the 802.11 standard in 2007.

"Reaching this consensus step is a significant milestone. It demonstrates the success of the IEEE consensus process in bringing together the diverse interests of enterprises and consumers. This technology will provide new capabilities to industries ranging from computer and consumer electronics, to public access and mobile telephony," said Bruce Kraemer Chair of the IEEE 802.11n High Throughput Task Group.

About the IEEE 802.11 Working Group
The IEEE 802.11 Working Group on Wireless Local Area Networks has completed ten projects since 1999 toward the development and evolution of the IEEE 802.11 WirelessLAN(R) Standard for Wireless Local Area Networks. The Working Group currently has 520 individual voting members contributing to eleven active projects. For details, see http://www.ieee802.org/11

About the IEEE Standards Association
The IEEE Standards Association, a globally recognized standards-setting body, develops consensus standards through an open process that brings diverse parts of an industry together. These standards set specifications and procedures based on current scientific consensus. The IEEE-SA has a portfolio of more than 870 completed standards and more than 400 standards in development. For information on IEEE-SA see: http://standards.ieee.org

About the IEEE

The IEEE has more than 375,000 members in approximately 150 countries. Through its members, the organization is a leading authority on areas ranging from aerospace, compuer and telecommunications to biomedicine, electric power and consumer electronics. The IEEE produces nearly 30 percent of the world's literature in the electrical and electronics engineering, computing and control technology fields. This nonprofit organization also sponsors or cosponsors more than 300 technical conferences each year. Additional information about the IEEE can be found at http://www.ieee.org

IEEE P802.11
Wireless LANs

Draft PAR for High Throughput Study Group

Date: November 15, 2002

Revision R1: January 16, 2003

Author: Jon Rosdahl
Micro Linear
Draper, Utah
Phone: 801-617-2508
Fax: 801-617-2501
e-Mail: jrosdahl@microlinear.com

Abstract

This is the proposed PAR that the High Throughput Study Committee will submit for the creation of a Task Group. The signature page is also located at the end of this file.

IEEE-SA Standards Board
Project Authorization Request (PAR) Form (2002)

For a review of the Standards Development Process (designed to assist the Working Group, Working Group Chair, Sponsor Chair, and Society Liaison), please click here. ☐

1. Assigned Project Number (Please contact the NesCom Administrator if this is a new PAR): P802.11m

2. Sponsor Date of Request: _____ (YYYY-MM-DD format)

3. Type of Document (Please check one)
☒ Standard for {document stressing the verb "shall"}
☐ Recommended Practice for {document stressing the verb "should"}
☐ Guide for {document in which good practices are suggested, stressing the verb "may"}

4. Title of Document: **Draft Amendment to STANDARD [FOR] Information Technology-Telecommunications and information exchange between systems-Local and Metropolitan networks-Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Enhancements for Higher Effective Throughput**

5. Life Cycle
☒ Full Use (5-year life cycle)
☐ Trial Use (2-year life cycle)

6. Type of Project:
☐ New standard
☐ Revision of existing standard (indicate Number and year existing standard was published in box to the right) (####-YYYY)
☒ Amendment to an existing standard (indicate Number and year existing standard was published in box to the right) 802.11-2003

☐ Corrigendum to an existing standard (indicate Number and year existing standard was published in box to the right) (####-YYYY)
☐ Revised PAR (indicate PAR Number and Approval Date here: P - (YYYY-MM-DD)
Is this project in ballot now? No
State reason for revising the PAR in Item #18.

7. Contact information of Working Group Chair who must be an SA member as well as an IEEE and/or Affiliate Member

Name of Working Group(WG) : IEEE P802.11, Working Group for Wireless LANs

Name of Working Group Chair:
First Name: Stuart Last Name: Kerry
Telephone: +1 (408) 474-7356

FAX: +1 (408) 474-5343
EMAIL: stuart.kerry@philips.com

8. Contact Information of Official Reporter, Project Editor or Document Custodian if different from the Working Group Chair. The Official Report must be an SA member as well as an IEEE and/or Affiliate Member

Name of Official Reporter (if different than Working Group Chair):
First Name: Last Name:
Telephone:
FAX:
EMAIL:

9. Contact information of Sponsoring Society or Standards Coordinating Committee

Sponsoring Society and Committee:
Sponsor Committee Chair:
First Name: Last Name:
Telephone:
FAX:
EMAIL:

10. Sponsor Balloting Information (Please choose one of the following)
Choose one from the following:
☒ Individual Balloting
☐ Entity Balloting
☐ Mixed Balloting (combination of Individual and Entity Balloting)

Expected Date of Submission for Initial Sponsor Ballot:

Please review the PAR form three months prior to submitting your draft for ballot to ensure that the title, scope and purpose on the PAR form match the title, scope and purpose on the draft. If they do not match, you will need to submit a revised PAR.

Additional communication and input from other organizations or other IEEE Standards Sponsors should be encouraged through participation in the working group or the balloting pool.

11. Projected Completion Date for Submittal to RevCom: _2006-09-30__ (Format YYYY-MM-DD)

If this is a REVISED PAR and the completion date is being extended past the original four-year life of the PAR, please answer the following questions.
If this is not a revised PAR, please go to question #12

Statement of why the extension is required:

When did you begin writing the first draft?:

How many people are actively working on the project?:

How many times a year does the working group meet in person?:

How frequently is a draft version circulated to the working group via electronic means?:

How much of the Draft is stable (Format: NN%)?: %

How many significant working revisions has the Draft been through?:

Briefly describe what the development group has already accomplished, and what remains to be done:

12. Scope of Proposed Project
[Please detail the projected output including technical boundaries.
FOR REVISED DOCUMENTS ONLY – Please detail the projected output including the scope of the original standard, amendments and additions. Please be brief (less than 5 lines).]:

To define standardized modifications to both the 802.11 PHY and the 802.11 MAC so that modes of operation can be enabled that are capable of much higher throughputs, with a target minimum throughput of 100Mbps, as measured at the MAC data SAP.

13. Purpose of Proposed Project:
[Please include the following:

- The specific aims and reason for the standardization activity, with particular emphasis on the aspects of standardization to be covered, the problems to be solved or difficulties it is intended to overcome;
- Main interests that might benefit from or be affected by the activity, such as industry, consumers, trade, governments and distributors;
- Benefits to be gained by the implementation of the proposed standard; alternatively, the loss or disadvantages if no standard is established within a reasonable time;

FOR REVISED DOCUMENTS ONLY - Purpose of the original document and reason for the document's revision. Please be brief (less than 5 lines).]:

To improve the 802.11 wireless LAN user experience by providing significantly higher throughput for current applications and to enable new applications and market segments.

14. Intellectual Property {Answer each of the questions below}

Sponsor has reviewed the IEEE patent policy with the working group?
Choose One XXYes ☐No

Sponsor is aware of copyrights relevant to this project?
Choose One ☐Yes X No

Sponsor is aware of trademarks relevant to this project?

Choose One ☐Yes X No

Sponsor is aware of possible registration of objects or numbers due to this project?
Choose One ☐Yes X No

15. Are there other standards or projects with a similar scope?
Choose One ☐Yes X No

Explanation:

If Yes, please answer the following:
Sponsor Organization:
Project Number:
Project Date:
Project Title:

16. International Sponsor Organization
Is there potential for this standard (in part or in whole) to be submitted to an international organization for review/adoption?
Choose One ?? {Yes/No/?? if you don't know at this time}

If Yes, please answer the following questions:
International Committee Name and Number:
International Organization Contact Information:
Contact First Name:
Contact Last Name:
Contact Telephone Number:
Contact FAX Number:
Contact E-mail address:

17. Will this project focus on health, safety or environmental issues?
Choose One NO {Yes/No/?? if you don't know at this time}
If Yes: Explanation?

18. Additional Explanatory Notes: {Item Number and Explanation}

Item 12.

In the process of formulating this PAR, it was found that there are multiple user scenarios. Accordingly, the task group will undertake the following steps:

1. Identify and define usage models, channel models and related MAC and application assumptions. Initial usage models envisioned include hot-spot, enterprise and residential; others are likely to be included.

2. Identify and define evaluation metrics that characterize the important aspects of a particular usage model. The evaluation metrics may include but are not limited to the items listed in Table 1, provided in illustration of the format.

Table 1: Evaluation Metrics

Evaluation Parameter	Usage Model 1	Usage Model 2	Usage Model 3
Throughput at the MAC data SAP, Mbps[#]			
Range , meters			
Aggregate Network Capacity [□]			
Power Consumption (peak and average), mW			
Spectral Flexibility [□□]			
Cost / Complexity Flexibility			
Backward Compatibility[**]			
Coexistence [*]			

Notes:
[□]Definition includes a measure of spectral efficiency (like bits/Hz/m^2).
[□□]That is, agnostic to a particular frequency allocation and perhaps able to implement spectral agility.
[*]The ability of one system to perform a task in a given shared environment in which other systems have an ability to perform their tasks and may or may not be using the same set of rules.
[**]Backward compatibility with non-HT 802.11 device is desirable to the extent practicalable. It is a comparison metric but is explicitly not mandated. The question of what possible tradeoffs exist between high effective throughput modes and backward compatibility mechanisms requires detailed technical information that is not now available to the HT Study Group.
[#] It is intended that throughput will be a primary comparison metric, and at least 100Mbps is the mandatory minimum throughput for the highest throughput usage models. It is anticipated that the amended standard will contain a family of related modes, with different throughputs. It is anticipated that some of these modes will have thoughputs that are substantially below 100Mbps, but that are still substantially higher, given similar operating conditions, than any modes in the existing 802.11 standard.

3. Develop a technical requirement specification.

4. Define a process for evaluations.

The PAR Copyright Release and Signature Page must be submitted either by FAX to 208-460-5300 or as an e-mail attachment in .pdf format to the NesCom Administrator before this PAR will be sent on for NesCom and Standards Board approval.

IEEE-SA Standards Board

PAR Copyright Release and Signature Page

(revised 2003)

1. Sponsor Date of Request:

2. Assigned Project Number: P
   Title:

I hereby acknowledge my appointment as Official Reporter (usually the WG Chair) to the {Name of Working Group}

In consideration of my appointment and the publication of the Standards Publication identifying me, at my option, as an Official Reporter, I agree to avoid knowingly incorporating in the Standards Publication any copyrighted or proprietary material of another without such other's consent and acknowledge that the Standards Publication shall constitute a "work made for hire" as defined by the Copyright Act, and, that as to any work defined, I agree to and do hereby transfer any right or interest I may have in the copyright to said Standards Publication to IEEE.

I acknowledge having read and understood the **IEEE Code of Ethics** (http://www.ieee.org/portal/index.jsp?pageID=corp_level1&path=about/whatis&file=code.xml&xsl=generic.xsl). I agree to conduct myself in a manner which adheres to the IEEE Code of Ethics when engaged in official IEEE business.

Signature of Official Reporter _____ Date _____
Name of Official Reporter (usually the WG Chair):

Title in WG:	IEEE/SA/Affiliate Memb #:
Company:	Telephone:
Address:	FAX:
City/State/Zip:	EMAIL:

Submitted by: (This MUST be the Sponsor Chair or the Sponsor's Liaison Representative to the IEEE Standards Board) who MUST be an IEEE/Affiliate AND Standards Association (SA) member. If the Sponsor chair is the submitter of the PAR by EMAIL and verifiable by his sender's Email address, this form does not need to be signed by the sponsor. The submitter will be notified in writing when the PAR is received and when the PAR will be considered for approval by the Standards Board. After the Standards Board meeting, the submitter will be notified in writing of the action taken.

As submitter, I shall be responsible for the development and coordination of the standards project, for supervising the standards project from inception to completion, and for ensuring that the standards project operates according to a written set of policies and procedures (P&P) per subclause 5.1.1 of the IEEE-SA Standards Board Operations Manual.

I acknowledge having read and understood the **IEEE Code of Ethics** (http://www.ieee.org/portal/index.jsp?pageID=corp_level1&path=about/whatis&file=code.xml&xsl=generic.xsl). I agree to conduct myself in a manner which adheres to the IEEE Code of Ethics when engaged in official IEEE business.
Signature of Submitter_____ Date _____

Name of Sponsor Committee Chair:
Company:
Address:
City/State/Zip:

IEEE/SA/Affiliate Memb #:
Telephone:
FAX:
EMAIL:

Do Not Write Below This Line

Signature by IEEE-SA Officer: _____

Title: _____

Date: _____

Intel 1002
p. 566

IEEE P802.11
Wireless LANs

Draft PAR for High Throughput Study Group

Date: November 15, 2002

Revision R6: March 13, 2003

Author: Jon Rosdahl
Micro Linear
Draper, Utah
Phone: 801-617-2508
Fax: 801-617-2501
e-Mail: jrosdahl@microlinear.com

Abstract

This is the proposed PAR that the High Throughput Study Committee will submit for the creation of a Task Group. The signature page is also located at the end of this file.

```
Rev 1 Initial PAR proposal from HTSG.
Rev 2 PAR Submitted to WG for Letter Ballot 55.  Ballot Failed.
Rev 3 PAR Submission with Editing suggested by WG LB55 and ExCom Chair.
Rev 4 PAR edits for approved changes through Tuesday 3-11-03 night.
Rev 5 PAR edits for approved changes through Wed 3-12-03 night.
Rev 6 PAR Edits approved by the SG Thursday 5:30pm.
```

IEEE-SA Standards Board
Project Authorization Request (PAR) Form (2002)

1. Assigned Project Number: **P802.11n**

2. Sponsor Date of Request: **2003-03-14**

3. Type of Document:
☒ **Standard for** {document stressing the verb "shall"}
☐ Recommended Practice for {document stressing the verb "should"}
☐ Guide for {document in which good practices are suggested, stressing the verb "may"}

4. Title of Document:

Draft Amendment to STANDARD [FOR] Information Technology-Telecommunications and information exchange between systems-Local and Metropolitan networks-Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Enhancements for Higher Throughput

5. Life Cycle
☒ **Full Use** (5-year life cycle)
☐ Trial Use (2-year life cycle)

6. Type of Project:
☐ New standard
☐ Revision of existing standard (indicate Number and year existing standard was published in box to the right) (####-YYYY)
☒ **Amendment to an existing standard (802.11-1999 (2003 edition))**
☐ Corrigendum to an existing standard (indicate Number and year existing standard was published in box to the right) (####-YYYY)
☐ Revised PAR (indicate PAR Number and Approval Date here: P - (YYYY-MM-DD)
Is this project in ballot now? No
State reason for revising the PAR in Item #18.

7. Contact information of Working Group Chair who must be an SA member as well as an IEEE and/or Affiliate Member

Name of Working Group (WG): **IEEE P802.11, Working Group for Wireless LANs**

Name of Working Group Chair:
First Name: **Stuart** Last Name: **Kerry**
Telephone: **+1 (408) 474-7356**
FAX: **+1 (408) 474-5343**
EMAIL: **stuart.kerry@philips.com**

8. Contact Information of Official Reporter, Project Editor or Document Custodian if different from the Working Group Chair. The Official Report must be an SA member as well as an IEEE and/or Affiliate Member

Name of Official Reporter (if different than Working Group Chair):
First Name: Last Name:
Telephone:
FAX:
EMAIL:

9. Contact information of Sponsoring Society or Standards Coordinating Committee:

Sponsoring Society and Committee:
Computer Society LAN/MAN Standards Committee
Sponsor Committee Chair:
First Name: **Paul** Last Name: **Nikolich**
Telephone: **978-749-9999**
FAX: **978-749-8888**
EMAIL: **p.nikolich@ieee.org**

10. Sponsor Balloting Information:
Choose one from the following:
☒ **Individual Balloting**
☐ Entity Balloting
☐ Mixed Balloting (combination of Individual and Entity Balloting)

Expected Date of Submission for Initial Sponsor Ballot: **2005-11-25**

Please review the PAR form three months prior to submitting your draft for ballot to ensure that the title, scope and purpose on the PAR form match the title, scope and purpose on the draft. If they do not match, you will need to submit a revised PAR.

Additional communication and input from other organizations or other IEEE Standards Sponsors should be encouraged through participation in the working group or the balloting pool.

11. Projected Completion Date for Submittal to RevCom: **2006-06-16**

If this is a REVISED PAR and the completion date is being extended past the original four-year life of the PAR, please answer the following questions.
If this is not a revised PAR, please go to question #12

Statement of why the extension is required:
When did you begin writing the first draft?
How many people are actively working on the project?
How many times a year does the working group meet in person?
How frequently is a draft version circulated to the working group via electronic means?
How much of the Draft is stable (Format: NN%)? %
How many significant working revisions has the Draft been through?

Briefly describe what the development group has already accomplished, and what remains to be done:

12. Scope of Proposed Project:

The scope of this project is to define an amendment that shall define standardized modifications to both the 802.11 physical layers (PHY) and the 802.11 Medium Access Control Layer (MAC) so that modes of operation can be enabled that are capable of much higher throughputs, with a maximum throughput of at least 100Mbps, as measured at the MAC data service access point (SAP).

13. Purpose of Proposed Project:

The purpose of the project is to improve the 802.11 wireless local area network (LAN) user experience by providing significantly higher throughput for current applications and to enable new applications and market segments.

14. Intellectual Property:

Sponsor has reviewed the IEEE patent policy with the working group?
Choose One **X Yes** ☐No

Sponsor is aware of copyrights relevant to this project?
Choose One ☐Yes **X No**

Sponsor is aware of trademarks relevant to this project?
Choose One ☐Yes **X No**

Sponsor is aware of possible registration of objects or numbers due to this project?
Choose One ☐Yes **X No**

15. Are there other standards or projects with a similar scope?

Choose One ☐Yes **X No**

Explanation:

If Yes, please answer the following:
Sponsor Organization:
Project Number:
Project Date:
Project Title:

16. International Sponsor Organization
Is there potential for this standard (in part or in whole) to be submitted to an international organization for review/adoption?
Choose One ?? {Yes/No/?? **if you don't know at this time**}

If Yes, please answer the following questions:
International Committee Name and Number:
International Organization Contact Information:
Contact First Name:
Contact Last Name:
Contact Telephone Number:
Contact FAX Number:
Contact E-mail address:

17. Will this project focus on health, safety or environmental issues? **No**

If Yes: Explanation?

18. **Additional Explanatory Notes:**

Item 12.
The scope of the MAC and PHY enhancements assume a baseline specification defined by 802.11 and its amendments and anticipated amendments a, b, d, e, g, h, i and j. The enhancements shall be to support higher throughput. The amendment shall not redefine mechanisms in the baseline that do not pertain to higher throughput.

Some of the modes of operation defined in the HT amendment shall be backwards compatible and interoperable with 802.11a and/or 802.11g.

Existing 802.11 standards are typically designated by their peak physical data rates. For example, 802.11a has a peak data rate of 54Mbps. This amendment has chosen to use a performance metric of throughput measured at the MAC data SAP. This amendment seeks to improve the peak throughput to at least 100Mbps, measured at the MAC data SAP. Depending on the scenario, this represents an improvement of at least 4 times the throughput obtainable using existing 802.11 systems.

In order to make efficient use of scarce spectral resources in unlicensed bands, the highest throughput mode defined by the HT amendment shall achieve a spectral efficiency of at least 3 bits per second per Hertz for the PSDU.

In the process of formulating this PAR, it was found that there are multiple user scenarios. Accordingly, the task group will undertake the following steps:

1. Identify and define usage models, channel models and related MAC and application assumptions. Initial usage models envisioned include hot-spot, enterprise and residential; others may be included.

2. Identify and define evaluation metrics that characterize the important aspects of a particular usage model. The evaluation metrics may include but are not limited to the items listed in Table 1, provided as an illustration of the format.

Table 1: Evaluation Metrics

Evaluation Parameter	Usage Model 1	Usage Model 2	Usage Model 3
Throughput at the MAC data SAP, Mbps#			

Range, meters			
Aggregate Network Capacity □			
Power Consumption (peak and average), mW			
Spectral Flexibility □□			
Cost / Complexity Flexibility			
Backward Compatibility**			
Coexistence *			

Notes:
□Definition includes a measure of spectral efficiency.
□□That is, agnostic to a particular frequency allocation and perhaps able to implement spectral agility.
*The ability of one system to perform a task in a given shared environment in which other systems have an ability to perform their tasks and may or may not be using the same set of rules.
**Backward compatibility with non-HT 802.11 device is desirable to the extent practicable. It is a comparison metric but is explicitly not mandated. The question of what possible tradeoffs exist between high effective throughput modes and backward compatibility mechanisms requires detailed technical information that is not now available to the HT Study Group.
It is intended that throughput will be a primary comparison metric, and at least 100Mbps is the mandatory minimum throughput for the highest throughput usage models. It is anticipated that the amended standard will contain a family of related modes, with different throughputs. It is anticipated that some of these modes will have throughputs that are substantially below 100Mbps, but that are still substantially higher, given similar operating conditions, than any modes in the existing 802.11 standard.

3. Develop a technical requirement specification.

4. Define a process for evaluations.

The impact of an HT device on the operation of a legacy network shall be comparable to that of any other legacy device identified in the baseline defined above.

Note: The PAR Copyright Release and Signature Page must be submitted either by FAX to 208-460-5300 or as an e-mail attachment in .pdf format to the NesCom Administrator before this PAR will be sent on for NesCom and Standards Board approval.

IEEE-SA Standards Board

PAR Copyright Release and Signature Page

(Revised 2003)

1. Sponsor Date of Request: 2003-03-14

2. Assigned Project Number: P802.11n
   Title:

Draft Amendment to STANDARD [FOR] Information Technology-Telecommunications and information exchange between systems-Local and Metropolitan networks-Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Enhancements for Higher Effective Throughput

I hereby acknowledge my appointment as Official Reporter (usually the WG Chair) to the 802.11 Wireless LAN Working Group.

In consideration of my appointment and the publication of the Standards Publication identifying me, at my option, as an Official Reporter, I agree to avoid knowingly incorporating in the Standards Publication any copyrighted or proprietary material of another without such other's consent and acknowledge that the Standards Publication shall constitute a "work made for hire" as defined by the Copyright Act, and, that as to any work defined, I agree to and do hereby transfer any right or interest I may have in the copyright to said Standards Publication to IEEE.

I acknowledge having read and understood the **IEEE Code of Ethics** (http://www.ieee.org/portal/index.jsp?pageID=corp_level1&path=about/whatis&file=code.xml&xsl=generic.xsl). I agree to conduct myself in a manner, which adheres to the IEEE Code of Ethics when engaged in official IEEE business.

Signature of Official Reporter _____ Date _____
Name of Official Reporter (usually the WG Chair):

Title in WG:	Chairman	IEEE/SA/Affiliate Memb #:	
Company:	Philips	Telephone:	
Address:		FAX:	
City/State/Zip:		EMAIL:	

Submitted by: (This MUST be the Sponsor Chair or the Sponsor's Liaison Representative to the IEEE Standards Board) who MUST be an IEEE/Affiliate AND Standards Association (SA) member. If the Sponsor chair is the submitter of the PAR by EMAIL and verifiable by his sender's Email address, this form does not need to be signed by the sponsor. The submitter will be notified in writing when the PAR is received and when the PAR will be considered for approval by the Standards Board. After the Standards Board meeting, the submitter will be notified in writing of the action taken.

As submitter, I shall be responsible for the development and coordination of the standards project, for supervising the standards project from inception to completion, and for ensuring that the standards project operates according to a written set of policies and procedures (P&P) per subclause 5.1.1 of the IEEE-SA Standards Board Operations Manual.

I acknowledge having read and understood the **IEEE Code of Ethics** (http://www.ieee.org/portal/index.jsp?pageID=corp_level1&path=about/whatis&file=code.xml&xsl=generic.xsl). I agree to conduct myself in a manner, which adheres to the IEEE Code of Ethics when engaged in official IEEE business.
Signature of Submitter_____ Date _____

Name of Sponsor Committee Chair:	IEEE/SA/Affiliate Memb #:
Company:	Telephone:
Address:	FAX:
City/State/Zip:	EMAIL:

Do Not Write Below This Line

Signature by IEEE-SA Officer: _____

Title: _____

Date: _____

IEEE P802.11
Wireless LANs

CRITERIA FOR STANDARDS DEVELOPMENT

(FIVE CRITERIA)

Date: November 15, 2002

Author: Jon Rosdahl
Micro Linear
Draper, Utah
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e-Mail: jrosdahl@microlinear.com

Abstract

This is the proposed response to the 5 Criteria for creating a new Task Group.

CRITERIA FOR STANDARDS DEVELOPMENT

(FIVE CRITERIA)

6.1 Broad Market Potential
A standards project authorized by IEEE 802 shall have a broad market potential. Specifically, it shall have the potential for:
a) Broad sets of applicability.
b) Multiple vendors and numerous users.
c) Balanced costs (LAN versus attached stations).

Demand for WLANs is expected to grow at a 50% Compounded Annual Growth Rate (CAGR) over the next five years. Over 50% of all home networking connections and over 40% of all mobile PC network connections will be over WLAN by 2005. New usages such as simultaneous transmission of multiple HDTV signals, audio, on-line gaming, etc. will drive the need for higher throughput in the home. As usage increases in the corporate and other high density environments, bandwidth restrictions of a shared media will begin to be realized. This is very similar to what happened in the wired Ethernet market. The need for higher throughput drove switching and 100Base-TX adoption. While a switching technology would ultimately be desired for WLAN, this is not technically feasible. The next logical step is to increase the data throughput of each WLAN Connection.

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IEEE 802 defines a family of standards. All standards shall be in conformance with the IEEE 802.1 Architecture, Management and Interworking documents as follows: 802. Overview and Architecture, 802.1D, 802.1Q and parts of 802.1f. If any variances in conformance emerge, they shall be thoroughly disclosed and reviewed with 802. Each standard in the IEEE 802 family of standards shall include a definition of managed objects which are compatible with systems management standards.

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This project will result in a wireless LAN with higher throughput than provided by 802.11a, 802.11b and 802.11g. The goal is to increase the overall system throughput by considering both PHY and MAC layer enhancements.

IEEE P802.15 study group SG3*a* will support higher-rates than those currently defined by P802.15 task group 3, and similar to those targeted by this proposal. However, the applications of 802.11 and 802.15 are different. 802.15 defines standards for *wireless* personal area networks, 802.11 defines standards for wireless local area networks. The different requirements of each group may result in different standards that satisfy the purpose and scope defined in each project's PAR.

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There are no other wireless LAN standards providing significantly higher throughput than either 802.11a or 802.11g.

c) Easy for the document reader to select the relevant specification.

The high throughput standard will be introduced as an amendment to the 802.11 specification.

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For a project to be authorized, it shall be able to show its technical feasibility. At a minimum, the proposed project shall show:
a) Demonstrated system feasibility.

b) Proven technology, reasonable testing.
c) Confidence in reliability.

Simulations are available that demonstrate the feasibility and performance of new MAC and PHY layer techniques that result in significant throughput improvement.

6.5 Economic Feasibility
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a) Known cost factors, reliable data.
b) Reasonable cost for performance.
c) Consideration of installation costs.

Support of the proposed standard may require the development of modified MAC and PHY implementations. This is similar in principal to the transition between 802.11b and 802.11g. The new standard will provide manufacturers the option of supporting higher throughput. Competition between manufacturers will ensure that costs are reasonable.

IEEE P802.11
Wireless LANs
CRITERIA FOR STANDARDS DEVELOPMENT
(FIVE CRITERIA)

Date: November 15, 2002

Revision 1: January 16, 2003

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b) **The technologies referenced in some of the documents above have been in use in other fields for some time. Until the full extent of the user models referenced in the HTSG PAR is understood, the study group cannot completely assess the extent of reasonable testing for those technologies. However, the increased capabilities envisioned for the baseband and RF parts necessary to implement the proposed amendment are in line with the current progress in ASIC technology.**

c) **Analysis of current WLAN products and of proposals of potential candidate approaches provides confidence in the reliability of the proposed solutions.**

There are currently reliable WLAN solutions. The study group envisions that the proposed amendment will result in no less reliability.

6.5 Economic Feasibility
For a project to be authorized, it shall be able to show economic feasibility (so far as can reasonably be estimated), for its intended applications. At a minimum, the proposed project shall show:
a) Known cost factors, reliable data.
b) Reasonable cost for performance.
c) Consideration of installation costs.

a) Support of the proposed standard will probably require a manufacturer to develop a modified radio, modem and firmware. This is similar in principle to the transition between 802.11b and 802.11g or between 802.11b and 802.11a. The cost factors for these transitions are well known and the data for this is well understood.

b) The new standard will provide manufacturers the option of supporting higher throughput. In general, the cost factor changes needed to implement the extensions envisioned by the study group are well within the capabilities of existing technology. Competition between manufacturers will ensure that costs remain reasonable.

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IEEE P802.11
Wireless LANs

CRITERIA FOR STANDARDS DEVELOPMENT

(FIVE CRITERIA)

Date: November 15, 2002

Revision 1: January 16, 2003

Author: Jon Rosdahl
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b) A wide variety of vendors currently build numerous products for the WLAN marketplace. It is expected that the majority of those vendors, and others, will participate in the standards development process and subsequent commercialization activities.

c) WLAN equipment is accepted as having balanced costs. The addition of High Throughput capabilities will not disrupt the established balance.

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IEEE 802 defines a family of standards. All standards shall be in conformance with the IEEE 802.1 Architecture, Management and Interworking documents as follows: 802. Overview and Architecture, 802.1D, 802.1Q and parts of 802.1f. If any variances in conformance emerge, they shall be thoroughly disclosed and reviewed with 802. Each standard in the IEEE 802 family of standards shall include a definition of managed objects which are compatible with systems management standards.

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IEEE P802.11
Wireless LANs

CRITERIA FOR STANDARDS DEVELOPMENT

(FIVE CRITERIA)

Date: November 15, 2002

Revision 4: March 11, 2003

Author: Jon Rosdahl
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Draper, Utah
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Abstract

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Rev 2 sent to WG to be part of LB55 – Letter Ballot failed.
Rev 3 Apply Edits requested by LB55 and ExCom Chair
Rev 4 Edits approved by SG through Tuesday 3-11-3 Evening

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ICE 1002
p. 590

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TCL 1002
p. 591

IEEE P802.11
Wireless LANs

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Date: November 15, 2002

Revision 5: March 13, 2003

Author: Jon Rosdahl
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IPR 1002
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IEEE Std 802®-2001
(Revision of IEEE Std 802-1990)

IEEE Standards

802®

IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

IEEE

Published by
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IEEE Std 802®-2001
(Revision of IEEE Std 802-1990)

IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture

Sponsor

LAN/MAN Standards Committee
of the
IEEE Computer Society

Approved 6 December 2001

IEEE-SA Standards Board

Abstract: IEEE Std 802-2001, IEEE Standards for Local and Metropolitan Area Networks: Overview and Architecture, provides an overview to the family of IEEE 802 Standards. It defines compliance with the family of IEEE 802 Standards; it describes the relationship of the IEEE 802 Standards to the Open Systems Interconnection Basic Reference Model [ISO/IEC 7498-1:1994] and explains the relationship of these standards to the higher layer protocols; it provides a standard for the structure of LAN MAC addresses; and it provides a standard for identification of public, private, and standard protocols.
Keywords: IEEE 802 standards compliance, Local Area Networks (LANs), LAN/MAN architecture, LAN/MAN reference model, Metropolitan Area Networks (MANs).

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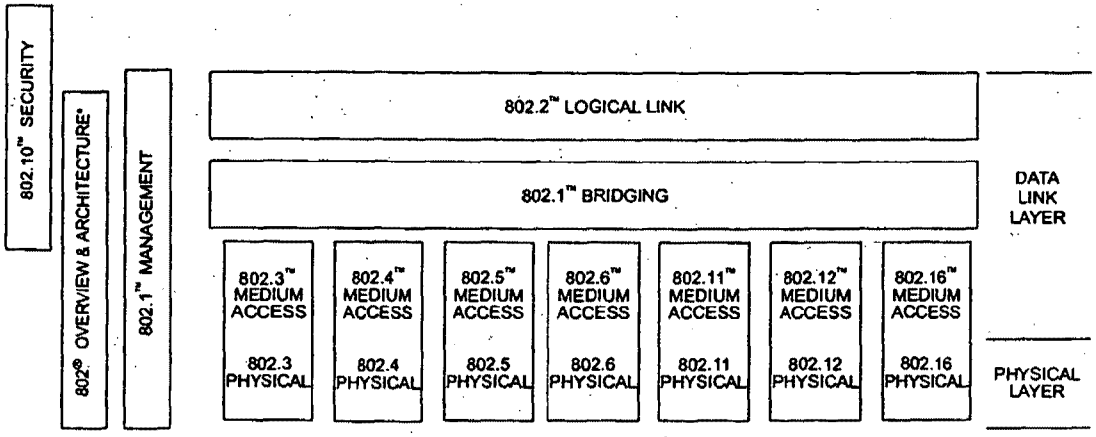
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Introduction

(This introduction is not part of IEEE Std 802-2001, IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture.)

IEEE Std 802-2001 provides an overview to the family of IEEE 802 Standards. It defines compliance with the family of IEEE 802 Standards; it describes the relationship of the IEEE 802 Standards to the Open Systems Interconnection Basic Reference Model [ISO/IEC 7498-1: 1994] and explains the relationship of these standards to higher layer protocols; it provides a standard for the structure of LAN MAC addresses; and it provides a standard for the identification of public, private, and standard protocols.

This standard is part of a family of standards for local and metropolitan area networks. The relationship between the standard and other members of the family is shown below. (The numbers in the figure refer to IEEE standard numbers.[1])



* Formerly IEEE Std 802.1A.

This family of standards deals with the Physical and Data Link Layers as defined by the International Organization for Standardization (ISO) Open Systems Interconnection Basic Reference Model (ISO/IEC 7498-1:1994). The access standards define several types of medium access technologies and associated physical media, each appropriate for particular applications or system objectives. Other types are under investigation.

The standards defining the technologies noted above are as follows:

- IEEE Std 802:[2] — *Overview and Architecture.* This standard provides an overview to the family of IEEE 802 Standards. This document forms part of the IEEE Std 802.1 scope of work.
- IEEE Std 802.1B™ and 802.1K™ [ISO/IEC 15802-2]: — *LAN/MAN Management.* Defines an Open Systems Interconnection (OSI) management-compatible architecture, and services and protocol elements for use in a LAN/MAN environment for performing remote management.

[1]The IEEE Standards referred to in the above figure and list are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

[2]The IEEE 802 Architecture and Overview Specification, originally known as IEEE Std 802.1A, has been renumbered as IEEE Std 802. This has been done to accommodate recognition of the base standard in a family of standards. References to IEEE Std 802.1A should be considered as references to IEEE Std 802.

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• IEEE Std 802.1D™	*Media Access Control (MAC) Bridges*: Specifies an architecture and protocol for the [ISO/IEC 15802-3]: interconnection of IEEE 802 LANs below the MAC service boundary.
• IEEE Std 802.1E™ [ISO/IEC 15802-4]:	*System Load Protocol*. Specifies a set of services and protocol for those aspects of management concerned with the loading of systems on IEEE 802 LANs.
• IEEE Std 802.1F™	*Common Definitions and Procedures for IEEE 802 Management Information*.
• IEEE Std 802.1G™ [ISO/IEC 15802-5]:	*Remote Media Access Control (MAC) Bridging*. Specifies extensions for the interconnection, using non-LAN systems communication technologies, of geographically separated IEEE 802 LANs below the level of the logical link control protocol.
• IEEE Std 802.1H™ [ISO/IEC TR 11802-5]	*Recommended Practice for Media Access Control (MAC) Bridging of Ethernet V2.0 in IEEE 802 Local Area Networks*.
• IEEE Std 802.1Q™	*Virtual Bridged Local Area Networks*. Defines an architecture for Virtual Bridged LANs, the services provided in Virtual Bridged LANs, and the protocols and algorithms involved in the provision of those services.
• IEEE Std 802.2 [ISO/IEC 8802-2]:	*Logical Link Control*.
• IEEE Std 802.3 [ISO/IEC 8802-3]:	*CSMA/CD Access Method and Physical Layer Specifications*.
• IEEE Std 802.4 [ISO/IEC 8802-4]:	*Token Bus Access Method and Physical Layer Specifications*.
• IEEE Std 802.5 [ISO/IEC 8802-5]:	*Token Ring Access Method and Physical Layer Specifications*.
• IEEE Std 802.6 [ISO/IEC 8802-6]:	*Distributed Queue Dual Bus Access Method and Physical Layer Specifications*.
• IEEE Std 802.10:	*Interoperable LAN/MAN Security*. Currently approved: Secure Data Exchange (SDE).
• IEEE Std 802.11: [ISO/IEC 8802-11]	*Wireless LAN Medium Access Control (MAC) Sublayer and Physical Layer Specifications*.
• IEEE Std 802.12: [ISO/IEC 8802-12]	*Demand Priority Access Method, Physical Layer and Repeater Specification*.
• IEEE Std 802.15™:	*Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for: Wireless Personal Area Networks*.
• IEEE Std 802.16:	*Standard Air Interface for Fixed Broadband Wireless Access Systems*.
• IEEE Std 802.17™:	*Resilient Packet Ring Access Method and Physical Layer Specifications*.

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In addition to the family of standards, the following is a recommended practice for a common physical layer technology:

• IEEE Std 802.7™:	*IEEE Recommended Practice for Broadband Local Area Networks.*

The reader of this standard is urged to become familiar with the complete family of standards.

Conformance test methodology

An additional standards series, identified by the number 1802™, has been established to identify the conformance test methodology documents for the IEEE 802 family of standards. Thus the conformance test documents for IEEE 802.3 are numbered 1802.3™, the conformance test documents for IEEE 802.5 will be 1802.5™, and so on. Similarly, ISO will use 18802 to number conformance test standards for 8802 standards.

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IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture

1. Scope

1.1 General

This document serves as the foundation for the family of IEEE 802®[1] Standards published by IEEE for Local Area Networks (LANs) and Metropolitan Area Networks (MANs). It contains descriptions of the networks considered as well as a reference model (RM) for protocol standards. Compliance with the family of IEEE 802 Standards is defined, and a standard for the identification of public, private, and standard protocols is included.

1.2 Key concepts

The LANs described herein are distinguished from other types of data networks in that they are optimized for a moderate-sized geographic area, such as a single office building, a warehouse, or a campus. An IEEE 802 LAN is a peer-to-peer communication network that enables stations to communicate directly on a point-to-point, or point-to-multipoint, basis without requiring them to communicate with any intermediate switching nodes. LAN communication takes place at moderate-to-high data rates, and with short transit delays, on the order of a few milliseconds or less.

A LAN is generally owned, used, and operated by a single organization. This is in contrast to Wide Area Networks (WANs) that interconnect communication facilities in different parts of a country or are used as a public utility.

A MAN is optimized for a larger geographical area than is a LAN, ranging from several blocks of buildings to entire cities. As with local networks, MANs can also depend on communications channels of moderate-to-high data rates. A MAN might be owned and operated by a single organization, but it usually will be used by many individuals and organizations. MANs might also be owned and operated as public utilities. They will often provide means for internetworking of local networks.

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Although primarily aimed at deployment on the scale of a large building or a campus, LANs are also frequently applied in smaller areas, such as small offices or single laboratories, and increasingly in homes. At the small-scale application level, a LAN is different from the type of network, such as a data bus or backplane bus, that is optimized for the interconnection of devices on a desktop or of components within a single piece of equipment. However, desktop-scale applications of LANs are also possible, particularly where the nature of the application is more suited to peer-to-peer communication among autonomous components, as opposed to a system structure with more centralized control.

The original IEEE 802 LAN technologies used shared-medium communication, with information broadcast for all stations to receive. That approach has been varied and augmented subsequently, but in ways that preserve the appearance of simple peer-to-peer communications behavior for end stations. In particular, the use of bridges (see 6.3.2) for interconnecting LANs is now widespread. These devices allow the construction of networks with much larger numbers of LAN end stations, and much higher aggregate throughput, than would be achievable with a single shared-medium LAN. End stations attached to such a bridged LAN can communicate with each other just as though they were attached to a single shared-medium LAN (however, the ability to communicate with other stations can be limited by use of management facilities in the bridges, particularly where broadcast or multicast transmissions are involved). A further stage in this evolution has led to the use of point-to-point full duplex communication in LANs, either between an end station and a bridge or as a typically high-speed link between a pair of bridges.

The basic communications capabilities provided by all LANs and MANs are packet-based, as opposed to either cell-based or isochronous. That is, the basic unit of transmission is a sequence of data octets, which can be of any length within a range that is dependent on the type of LAN; for all LAN types, the maximum length is in excess of 1000 octets. (By contrast, cell-based communication transmits data in shorter, fixed-length units; isochronous communication transmits data as a steady stream of octets, or groups of octets, at equal time intervals.)

An optional function that may be offered by a LAN or a MAN is the provision of local networking of isochronous bearer services that are compatible with, or higher speed versions of, Integrated Services Digital Networks (ISDN) as defined by the ITU-T I-series Recommendations, to support voice, video, and data devices and terminals. These services are based on the use of end-user to end-user isochronous bearers that will span the supporting Integrated Services LAN (ISLAN) or MAN and an intervening ISDN-conformant WAN. Typically, the information streams for packet and isochronous services are multiplexed over the same physical media. In addition, capabilities are specified for a single integrated management of these various streams.

1.3 Application and support

The networks are intended to have wide applicability in many environments. The primary aim is to provide for moderate-cost devices and networks, suitable for commercial, educational, governmental, and industrial applications. Low-cost alternatives are possible for some networks, and application in other environments is not precluded. The following lists are intended to show some applications and devices and, as such, are not intended to be exhaustive, nor do they constitute a set of required items:

- File transfer
- Graphics
- Text processing
- Desktop publishing
- Electronic mail
- Database access
- Transaction processing

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— Multimedia
— Office automation
— Process control
— Robotics
— Integrated Services (voice, video and data) applications
— Client/server applications

The networks are intended to support various data devices, such as the following:

— Computers
— Terminals
— Mass storage devices
— Printers and plotters
— Photocopiers and facsimile machines
— Image and video monitors
— Wireless terminals
— Monitoring and control equipment
— Bridges, routers, and gateways
— Integrated Services devices, including ISDN terminals and end systems supporting combined voice, video, and data applications

1.4 An international family of standards

The terms LAN and MAN encompass a number of data communications technologies and applications of these technologies. So it is with the IEEE 802 Standards. In order to provide a balance between the proliferation of a very large number of different and incompatible local and metropolitan networks, on the one hand, and the need to accommodate rapidly changing technology and to satisfy certain applications or cost goals, on the other hand, several types of medium access technologies are currently defined in the family of IEEE 802 Standards. In turn, these medium access control (MAC) standards are defined for a variety of physical media. A logical link control (LLC) standard, a secure data exchange standard, and MAC bridging standards are intended to be used in conjunction with the MAC standards. In some ISLAN and MAN standards, provisions are made for optionally conveying isochronous bearer services in support of continuous voice, video, and synchronous data applications. An architecture and protocols for the management of IEEE 802 LANs are also defined.

The IEEE 802 Standards have been developed and applied in the context of an increasingly global data communications industry. This global context is recognized in that most IEEE 802 Standards are progressed to become also international standards, within ISO/IEC JTC 1 (Joint Technical Committee 1, Information Technology, of the International Organization for Standardization and the International Electrotechnical Commission); see Clause 2 and Annex A.

2. References

The following publications contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to

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revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below.

ISO/IEC 7498-1:1994, Information technology—Open Systems Interconnection—Basic Reference Model: The basic model.[2]

ISO/IEC 8802-2:1998 (IEEE Std 802.2™-1998), Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 2: Logical Link Control.[3]

ISO/IEC TR 11802-1:1997, Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Technical reports and guidelines—Part 1: The structure and coding of Logical Link Control addresses in Local Area Networks.

ISO/IEC TR 11802-2:1999, Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Technical reports and guidelines—Part 2: Standard Group MAC Addresses.

ISO/IEC 15802-1:1995, Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Common specifications—Part 1: Medium access control (MAC) service definition.

ISO/IEC 15802-3:1998 (IEEE Std 802.1D™-1998), Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Common specifications—Part 3: Media Access Control (MAC) Bridges.

NOTE—Annex A lists, for information, the other LAN/MAN and related standards. Unlike those listed above, they do not contain detailed provisions that are used, by reference, by this standard.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this standard, the following definitions apply. *The Authoritative Dictionary of IEEE Standards Terms,* Seventh Edition [B2],[4] should be referenced for terms not defined in this clause.

3.1.1 access domain: A set of LAN or MAN stations together with interconnecting data transmission media and related equipment (e.g., connectors, repeaters), in which the LAN or MAN stations use the same MAC protocol to establish the sequence of stations that are in temporary control of the shared transmission media.

3.1.2 bit-reversed representation: The representation of a sequence of octet values in which the values of the individual octets are displayed in order from left to right, with each octet value represented as a two-digit hexadecimal numeral, and with the resulting pairs of hexadecimal digits separated by colons. The order of the hexadecimal digits in each pair, and the mapping between the hexadecimal digits and the bits of the octet value, are derived by reversing the order of the bits in the octet value and interpreting the resulting bit sequence as a binary numeral using the normal mathematical rules for digit significance.

[2]ISO/IEC publications are available from the ISO Central Secretariat, Case Postale 56, 1 rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iso.ch/). ISO/IEC publications are also available in the United States from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/). Electronic copies are available in the United States from the American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

[3]The IEEE standards referred to in Clause 2 are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

[4]The numbers in brackets correspond to those of the bibliography in Annex A.

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NOTE—The bit-reversed representation is applicable to LAN MAC addresses for use in a Token Ring (IEEE 802.5™) or FDDI environment. See Figure 8 for a comparative example of bit-reversed and hexadecimal representation.

3.1.3 bridge, MAC bridge: A functional unit that interconnects two or more LANs or MANs that use the same Data Link layer protocols above the MAC sublayer, but can use different MAC protocols.

3.1.4 canonical format: The format of a MAC data frame in which the octets of any MAC addresses conveyed in the MAC user data field have the same bit ordering as in the Hexadecimal Representation.

3.1.5 end station: A device attached to a LAN or MAN, which acts as a source of, and/or destination for, data traffic carried on the LAN or MAN.

3.1.6 Ethernet frame: A MAC data frame structured in accordance with ISO/IEC 8802-3 and containing an Ethernet type value in the LENGTH / TYPE field.

3.1.7 fibre distributed data interface (FDDI) frame: A MAC data frame structured in accordance with ISO/IEC 9314-2.

3.1.8 hexadecimal representation: The representation of a sequence of octet values in which the values of the individual octets are displayed in order from left to right, with each octet value represented as a two-digit hexadecimal numeral, and with the resulting pairs of hexadecimal digits separated by hyphens. The order of the hexadecimal digits in each pair, and the mapping between the hexadecimal digits and the bits of the octet value, are derived by interpreting the bits of the octet value as a binary numeral using the normal mathematical rules for digit significance.

NOTE—See Figure 8 for a comparative example of bit-reversed and hexadecimal representation.

3.1.9 IEEE 802.3™ frame, 802.3 frame: A MAC data frame structured in accordance with ISO/IEC 8802-3 and containing a length value in the LENGTH / TYPE field.

3.1.10 IEEE 802.5 frame, 802.5 frame: A MAC data frame structured in accordance with ISO/IEC 8802-5.

3.1.11 IEEE 802.n frame, 802.n frame: A MAC data frame structured in accordance with ISO/IEC 8802-n.

NOTES

1—At the time of publication of this standard, relevant specifications, in addition to those cited explicitly in 3.1.9 and 3.1.10, are for n = 4, 6, 9, and 11.

2—ISO/IEC 8802-12 also defines a MAC protocol, but it does not specify its own MAC data frame format; instead, it uses the IEEE 802.3 and IEEE 802.5 frame formats.

3.1.12 IEEE 802 LAN, 802 LAN: A LAN consisting of an access domain using either a MAC protocol specified in one of the IEEE 802.n and ISO/IEC 8802-n Standards or the FDDI MAC protocol.

3.1.13 IEEE 802 MAN, 802 MAN: A MAN consisting of one or more interconnected subnetworks each using a MAC protocol specified in an IEEE 802 or ISO/IEC 8802 MAN Standard.

NOTE—Part of the data communication capability of an IEEE 802 MAN is the provision of a data service equivalent to that provided by an IEEE 802 LAN, over the extended geographical area of the MAN.

3.1.14 interconnection: The provision of data communication paths between LAN or MAN stations.

3.1.15 interworking: The use of interconnected LAN or MAN stations for the exchange of data, by means of protocols operating over the underlying data transmission paths.

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3.1.16 LAN: A computer network, located on a user's premises, within a limited geographical area.

3.1.17 MAC control frame: A data structure consisting of fields in accordance with a MAC protocol, for the communication of control information, only, in a LAN or MAN.

NOTE—ISO/IEC 8802-5 uses the term "MAC frame" in this sense.

3.1.18 MAC data frame: A data structure consisting of fields in accordance with a MAC protocol, for the communication of user data and control information in a LAN or MAN; one of the fields contains a sequence of octets of user data.

3.1.19 MAC protocol: The protocol that governs access to the transmission medium in a LAN or MAN, to enable the exchange of data between LAN or MAN stations.

3.1.20 MAN: A computer network, extending over a large geographical area such as an urban area and providing integrated communication services such as data, voice, and video.

3.1.21 noncanonical format: The format of a MAC data frame in which the octets of MAC addresses conveyed in the MAC user data field have the same bit ordering as in the Bit-reversed representation.

3.1.22 octet: A sequence of eight bits, the ends of the sequence being identified as the most significant bit (MSB) and the least significant bit (LSB).

NOTE—This identification of the ends of the sequence defines an unambiguous mapping from octet values, via binary numerals, to the integers 0–255, and hence a mapping also from octet values to the expressions of those integers as numerals in hexadecimal notation. See: Hexadecimal Representation.

3.1.23 station: An end station or bridge.

4. Abbreviations and acronyms

CMIP	common management information protocol (ISO/IEC 9596-1)
CSMA/CD	carrier sense multiple access with collision detection (ISO/IEC 8802-3)
DQDB	distributed queue dual bus
FDDI	fibre distributed data interface (ISO/IEC 9314)
IM	implementation model
I/G	individual/group
ISDN	integrated services digital network
ISLAN	integrated services LAN (ISO/IEC 8802-9)
LAN	local area network
LLC	logical link control (ISO/IEC 8802-2)
LSAP	link service access point (ISO/IEC 8802-2)
LSB	least significant bit
MAC	medium access control, media access control[5]
MAN	metropolitan area network

[5]Both forms are used, with the same meaning. This standard uses "medium."

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MIB	management information base
MOCS	managed object conformance statement
MSAP	MAC service access point
MSB	most significant bit
PDU	protocol data unit
PhSAP	physical service access point
PICS	protocol implementation conformance statement
RM	reference model
OSI	open systems interconnection (ISO/IEC 7498-1)
OUI	organizationally unique identifier
SNAP	subnetwork access protocol
SNMP	simple network management protocol (RFC 1157[6])
U/L	universally or locally administered
WAN	wide area network

5. Compliance

NOTE—IEEE policy with respect to claims of compliance, conformance, or compatibility with IEEE standards can be found in the Trademark Policy statement in the front matter. This clause will be deleted in the next revision of this standard.

6. Reference and implementation models

6.1 Introduction

This clause defines the IEEE 802 LAN and MAN RM (LAN&MAN/RM) and implementation model (LAN&MAN/IM). The intent of presenting these models is as follows:

a) To provide an overview of the standard

b) To serve as a guide to reading other IEEE 802 Standards

The IEEE 802 LAN&MAN/RM is patterned after the Open Systems Interconnection (OSI) Basic Reference Model (OSI/RM), ISO/IEC 7498-1. It is assumed that the reader has some familiarity with the OSI/RM and its terminology. The IEEE 802 Standards encompass the functionality of the lowest two layers of the OSI/RM (i.e., Physical layer and Data Link layer) and the higher layers as they relate to LAN management. The LAN&MAN/RM is similar to the OSI/RM in terms of its layers and the placement of its service boundaries.

For the mandatory packet services supported by all LANs and MANs, the Data Link layer is structured as two sublayers, with the LLC sublayer operating over a MAC sublayer. In addition, some IEEE 802 LAN technologies provide direct support by the MAC sublayer for an alternative Ethernet sublayer operating at the same place in the architecture as does LLC; for the other IEEE 802 LAN technologies, the equivalent

[6]See A.1 for information on obtaining RFCs.

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