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TGn Sync Proposal Technical Specification

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Author:

Name	Company	Address	Phone	email
Syed Aon Mujtaba	Agere Systems Inc.	555 Union Blvd., Allentown, PA 18109, U.S.A.	+1 610 712 6616	mujtaba@agere.com

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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Name	Company	Email
Adina Matache	Marvell Semiconductor	amatache@marvell.com
Adrian P Stephens	Intel Corporation	adrian.p.stephens@intel.com
Aleksandar Purkovic	Nortel Networks	apurkovi@nortelnetworks.com
Arnaud Meylan	Qualcomm Incorporated	ameylan@qualcomm.com
Bjorn Bjerke	Qualcomm Incorporated	bbjerke@qualcomm.com
Bo Xia	Intel Corporation	bo.xia@intel.com
Brian Hart	Cisco Systems Inc	brianh@cisco.com
Chiu Ngo	Samsung Electronics Co. Ltd.	cngo@sisa.samsung.com
Daisuke Takeda	Toshiba Corporation	daisuke.takeda@toshiba.co.jp
Darren McNamara	Toshiba Corporation	Darren.McNamara@toshiba-trel.com
Dongjun Lee	Samsung Electronics Co Ltd	djthekid.lee@samsung.com
Eldad Perahia	Cisco Systems Inc	eperahia@cisco.com
Eric Jacobsen	Intel Corporation	eric.a.jacobsen@intel.com
Gyubum Kyung	Samsung Electronics Co Ltd	gyubum.kyung@samsung.com
Huanchun Ye	Atheros Communications Inc	hcye@atheros.com
Huaning Niu	Samsung Electronic Co Ltd	Huaning.Niu@samsung.com
Hui-Ling Lou	Marvell Semiconductors	hlou@marvell.com
Irina Medvedev	Qualcomm Incorporated	irinam@qualcomm.com
Jan Boer	Agere Systems Inc	janboer@agere.com
Jeffrey Gilbert	Atheros Communications Inc	gilbertj@atheros.com
Jerry Kim	Samsung Electronic Co Ltd	kimjy@samsung.com
Job Oostveen	Royal Philips Electronics	job.oostveen@philips.com
Jörg Habetha	Royal Philips Electronics	joerg.habetha@philips.com
John Ketchum	Qualcomm, Incorporated	johnk@qualcomm.com
John Sadowsky	Intel Corporation	john.sadowsky@intel.com
Luke Qian	Cisco Systems Inc	lchia@cisco.com
Masahiro Takagi	Toshiba Corporation	masahiro3.takagi@toshiba.co.jp
Michael Livshitz	Nortel Networks	livshitz@nortelnetworks.com
Monisha Ghosh	Royal Philips Electronics	monisha.ghosh@philips.com
Nina Burns	Nortel Networks	nburns@nortelnetworks.com
Pen C. Li	Royal Philips Electronics	pen.li@philips.com
Pieter-Paul Giesberts	Agere Systems Inc	pgiesberts@agere.com
Richard van Leeuwen	Agere Systems Inc	rleeuwen@agere.com
Ronald Rietman	Royal Philips Electronics	ronald.rietman@philips.com
Sanjiv Nanda	Qualcomm, Incorporated	snanda@qualcomm.com
Santosh Abraham	Qualcomm Incorporated	sabraham@qualcomm.com
Seigo Nakao	SANYO Electric Co Ltd	snakao@gf.hm.rd.sanyo.co.jp
Sergey Sukobok	Nortel Networks	ssukobok@nortelnetworks.com
Sheung Li	Atheros Communications Inc.	sheung@atheros.com
Shravan Surenini	Qualcomm Incorporated	shravans@qualcomm.com
Stephen Shellhammer	Intel Corporation	Stephen.j.shellhammer@intel.com
Tomoko Adachi	Toshiba Corporation	tomo.adachi@toshiba.co.jp
Tomoya Yamaura	Sony Corporation	yamaura@wcs.sony.co.jp
Tsuguhide Aoki	Toshiba Corporation	tsuguhide.aoki@toshiba.co.jp
Won-Joon Choi	Atheros Communications Inc.	wjchoi@atheros.com
Xiaowen Wang	Agere Systems Inc	xiaowenw@agere.com
Yasuhiko Tanabe	Toshiba Corporation	yasuhiko.tanabe@toshiba.co.jp
Youngsoo Kim	Samsung Electronics Co., Ltd	KimYoungsoo@samsung.com
Yuichi Morioka	Sony Corporation	morioka@wcs.sony.co.jp

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1 Executive Summary

The TGn Sync team respectfully submits its complete proposal. The team is comprised of 802.11 WG participants whose companies represent a broad range of markets, including, PC, Enterprise, Consumer Electronics, Handset, Semiconductor and Public Access. Since these companies are based in the US, Europe and Asia Pacific, the team has had the benefit of a worldwide perspective, both in terms of perceived market demand as well as regulatory concerns (including channel bandwidth limitations, limited channel access, restricted transmission times, etc.).

Our goal has been to align (or "sync" with) 802.11n members to a single set of core positions prior to the TGn down selection phase. By aligning before entrenched positions form, we hope to increase the possibility of a more rapid introduction of an 802.11n standard.

The team has worked as a technical group for many months to develop a TGn proposal, recognizing that whatever decisions were made had to ultimately survive the TGn process and therefore be based solely on technical merit. There were no signed agreements involved in joining the TGn Sync team. There was no attempt to develop joint IP and each company was expected to abide by the same reasonable and non-discriminatory terms that the IEEE bylaws require.

The technical approach balances market expectations with design practicality. The solution is a robust, scalable architecture targeting the least amount of complexity. In fact, the basic configuration delivers a maximum rate of 243 Mbps using only two antennas. This rate is consistent with the historical trend of 5x with each generation of 802.11 (802.11/2Mbps, 802.11b/11Mbps, and finally 802.11a/ 54Mbps). The proposal also incorporates options for rates up to 720 Mbps. This choice of higher peak data rates was seen as critical for future proofing this next generation of WLAN.

The PHY techniques used to achieve the higher data rates involve a MIMO evolution of 802.11 OFDM PHY with spatial division multiplexing of spatial streams, wider bandwidth options (either 20MHz or 40MHz) and an optimized interleaver for both the 20 MHz and 40MHz channelizations. Additionally, optional enhancements include advanced FEC coding techniques (LDPC), transmit beamforming with negligible additional cost in the receiving client device and/or additional RF chains. These options provide extra scalability if additional robustness and/or throughput is required.

The TGn Sync proposal also offers seamless interoperability with 802.11 legacy devices. This interoperability is achieved with an enhanced 802.11 preamble design and efficient PHY and MAC level mechanisms, which also provide robustness and cost-effectiveness.

The features added to improve MAC efficiency – for higher throughput and overall system performance – include aggregation, bi-directional data flow, enhanced Block Ack, channel management (including a receiver assisted channel training protocol) and feedback mechanisms that enable rate adaptation. Protection mechanisms are also added to achieve the seamless

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interoperability and coexistence with legacy devices mentioned above. The approach supports 802.11e and proposes new features for further enhancement.

1.1 Proposal Structure

The TGn Sync complete proposal meets the IEEE 802.11n PAR, meets all functional requirements, and addresses all mandatory requirements of the comparison criteria.

This document contains a technical specification of the proposed MAC and PHY enhancements.

[5] contains the presentation of the proposal in powerpoint format. (Please note that the summary presentation [4] is no longer up to date).

[6] contains a statement of compliance to the IEEE 802.11 TGn FRCC requirements.

[7] and [8] contain FRCC results (and others) for the PHY and MAC respectively.

[9] and [10] are Excel spreadsheets containing detailed FRCC results from MAC simulations, and [11] describes the methodology used in these simulations.

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2 References

[1] IEEE Std 802.11®-1999 (Reaff 2003)
Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

[2] IEEE P802.11e/D8.0, February 2004
(Draft Amendment to IEEE Std 802.11, 1999 Edition (Reaff 2003))
Medium Access Control (MAC) Enhancements for Quality of Service (QoS)

[3] Project Authorization Request for IEEE 802.11n.
11-02-798r7-HT-SG-Draft-PAR.doc

[4] IEEE 802.11-04/887, "TGnSync Proposal Summary"

[5] IEEE 802.11-04/888, "TGnSync Proposal"

[6] IEEE 802.11-04/890, "TGnSync Proposal FRCC Compliance"

[7] IEEE 802.11-04/891, "TGnSync Proposal PHY Results"

[8] IEEE 802.11-04/892, "TGnSync Proposal MAC Results"

[9] IEEE 802.11-04/893, "TGnSync Proposal MAC1 Simulation Results"

[10] IEEE 802.11-04/894, "TGnSync Proposal MAC2 Simulation Results"

[11] IEEE 802.11-04/895, "TGnSync Proposal MAC Simulation Methodology"

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3 Definitions

Aggregate: A PSDU transported by the PHY with an aggregate attribute indicating that it contains multiple MPDUs.

Initiator: A STA that holds a TXOP and transmits the first frame in a frame exchange sequence including aggregate PPDUs and/or aggregate control frames (IAC/RAC/MRAD).

LongNAV: A MAC-layer protection mechanism that protects multiple PPDUs exchanged within a TXOP

Mixed Mode: A mode of operation of an HT BSS in which there are co-channel legacy devices present.

OFDM Format: Definition of subcarrier frequencies relative to the channel center frequency, and specification of data bearing and pilot subcarriers.

Originator: A QSTA that sends data using the Block ACK mechanism.

Pairwise Spoofing: A PHY layer protection mechanism described in 7.1.3.2.

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
ACK	Acknowledgement
AGC	Automatic Gain Control
AP	Access Point
ATOC	Aggregate Table Of Contents
BF-MIMO	Beamforming MIMO
CAP	Controlled Access Phase
CDD	Cyclic Delay Diversity
CRC	Cyclic Redundancy Check
CSI	Channel State Information
CSIT	Channel State Information at the Transmitter
CTS	Clear to Send
DLP	Direct Link Protocol
DCB	Decrease Channel Bandwidth MPDU
ERP	Extended Rate PHY
FCS	Frame Check Sequence
FPD	Following Packet Descriptor
HC	Hybrid Controller
HID	Header Identity
HT	High Throughput
HT-LTF	High Throughput Long Training Field
HT-SIG	High Throughput Signal Field
HT-STF	High Throughput Short Training Field
IAC	Initiator Aggregate Control
ICB	Increase Channel Bandwidth MPDU
IE	Information Element
LLC	Logical Link Control
L-LTF	Legacy Long Training Field
L-SIG	Legacy Signal Field
L-STF	Legacy Short Training Field
MAC	Medium Access Controller

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MCS	Modulation Coding Scheme – includes modulation order (BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM) and FEC code rate (1/2, 2/3, 3/4, 7/8)
MFB	MCS Feedback
MIMO	Multiple input, multiple output (Both transmitter and receiver have multiple antennas for signaling over a point-to-point link)
MISO	Multiple input, single output (transmitter has multiple antennas but receiver has a single antenna)
MPDU	MAC protocol data unit
MRA	Multiple Receiver Aggregate – an aggregate that contains MPDUs for multiple receiver addresses.
MRAD	Multiple Receiver Aggregate Descriptor
MRC	Maximum Ratio Combining (a technique to maximize received SNR using antenna signal combining).
MRMRA	Multi-response Aggregate – an MRA with multiple responses from its multiple receivers
MRQ	MCS Request
MSDU	MAC service data unit
NAV	Network Allocation Vector (a MAC-level carrier-sense)
N_{SD}	Number of Data Subcarriers
N_{SS}	Number of Spatial Streams
N_{RX}	Number of Receive Antennas
N_{TX}	Number of Transmit Antennas
OFDM	Orthogonal Frequency Division Multiplexing
PHY	Physical Layer
PLCP	PHY layer convergence protocol
PPDU	PHY protocol data unit
PSDU	PHY service data unit
Pure Mode	A mode of operation of a BSS in which there are no legacy devices
QAP	QoS access point
QoS	Quality of service
QSTA	QoS station
RAC	Royal Automobile Club
RDG	Reverse Direction Grant

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RDL	Reverse Direction Limit
RDR	Reverse Direction Request
RDTID	Reverse Direction Traffic Identifier
RPO	Response Period Offset
RR	Rate Recommendation
RSSI	Receive Signal Strength Indicator
RTS	Request to send
RX	Receiver
SAP	Service Access Point
SF	Signal Field
SIFS	Short inter-frame spacing
SIMO	Single input, multiple output (transmitter has a single antenna, receiver has multiple antennas)
SISO	Single input, single output (both transmitter and receiver have a single antenna)
SoP	Start of Packet (i.e. PPDU Packet)
SRA	Single Receiver Aggregate – an aggregate that contains MPDUs for a single receiver address.
STA	Station
SVD	Singular Value Decomposition: For an arbitrary matrix A = USV^H
TBD	To be determined
TC	Traffic Category
TGe	802.11 Task Group e - Quality of Service
TGn	802.11 Task Group n - Enhancements for Higher Throughput
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. Aggregation is suported at the MSDU level and at the MPDU level.

- 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.

- A receiver assisted channel training protocol.

- A reverse direction data protocol that allows efficient channel access for single and multiple responders within a frame exchange sequence.

- Protection of the new frame exchange sequences may be provided through one of two mechanisms: a MAC-level mechanism based on NAV reservations, and a PHY-level mechanism based on spoofing the legacy PLCP rate/length information.

- QoS enhancements for TSPEC renegotiation and prioritized discarding of QoS MSDUs according to an application-defined loss priority labeling.

- Mechanisms to manage coexistence of legacy and HT devices.

- Channel management and channel selection methods.

5.3 General description of PHY enhancements

With the aim to increase the maximum PHY layer data rate, we have introduced two primary techniques in our proposal:

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

- Extended Bandwidth signaling. 20MHz channelization shall be mandatory worldwide. Our recommendation is to support 40MHz channelization in regulatory domains that will permit wider bandwidth operation

We have also introduced several secondary techniques for increasing throughput. These include:

- Increasing the number of data tones to 52 in 20MHz.

- A reduced guard interval of 400ns (i.e. half-GI), channel dispersion permitting (e.g. TGn channel model B). Support for half-GI is optional.

- Higher channel coding rate of 5/6. Support for 5/6 is mandatory in 20MHz.

- Optional support for 256-QAM in the Transmit Beamforming mode.

Due to the susceptibility of a wireless link to multipath fading, especially in a MIMO channel, our proposal introduces two optional techniques for improving the robustness of the link between the transmitter and the receiver, with the aim to keep the client (station) configuration low-cost and low-power:

- Transmitter beamforming.

- Advanced channel coding. Our proposal includes LDPC as an option. LDPC codes exhibit a larger minimum free distance compared to the existing 802.11a convolutional code, and hence are able to better exploit the frequency and spatial diversity in the channel.

Our proposal support full backwards compatibility with existing 802.11a/b/g standards. Our preamble design support PHY layer interoperability with the OFDM preamble from 802.11a/g, while providing a robust mechanism for synchronization of the high throughput data.

6 Frame Formats

This clause specifies the format of new HT frames.

Reserved fields and subfields shall be transmitted as zeroes and shall be ignored by an HT receiver

6.1 Control frames

This section defines new control frame subtypes as listed below:

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Control Frame **Subtype**	**Name**
IAC	Initiator aggregate control
RAC	Responder aggregate control
MMP	Multiple receiver aggregate multi-poll
ICB	Increase channel bandwidth
DCB	Decrease channel bandwidth
Calibration Training	Calibration Training frame

6.1.1 Initiator Aggregation Control (IAC) MPDU

6.1.1.1 Introduction

This MPDU provides control of the MCS, size, duration, training and any reverse flow of aggregates in an exchange of aggregates between STAs. It is sent by the initiator STA of an aggregate exchange.

There are a number of groups of fields (IAC elements), which perform specific purposes within the MPDU as described below:

Element Name	**Purpose of item**
RTS – Request to Send	Detects collisions at the receiver 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	Request for MCS feedback
MFB – MCS Feedback	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

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	Used for Bi-directional frame transfer as defined in section 7.1.2
RDG – Reverse direction grant	Grants a specified duration to be used for a reverse direction PPDU Used for Bi-directional frame transfer as defined in section 7.1.2

Note, although described as "elements", the structure of the IAC MPDU containing these elements is fixed.

6.1.1.2 Format of IAC MPDU

This section defines the format of the IAC MPDU.

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

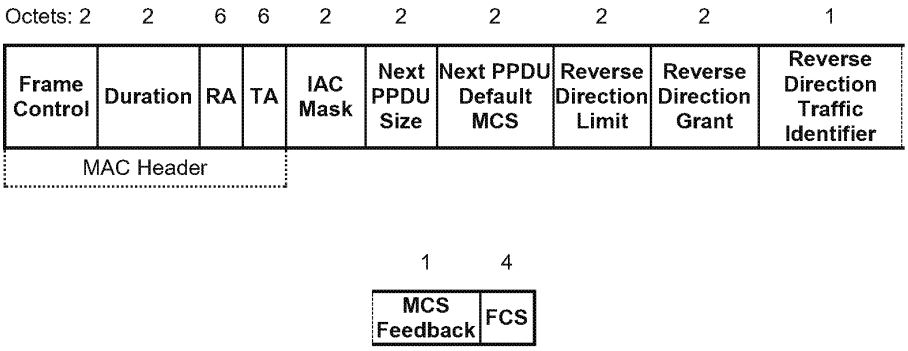


Figure 1 – IAC MPDU

Field	Size (bytes)	Purpose
Frame Control	2	Type is control, subtype is IAC
Duration	2	
Receiver Address	6	
Transmitter Address	6	
IAC Mask	2	A bitmask indicating which IAC elements are present in the packet.
Next PPDU Size	2	Size in bytes of following PPDU that will be sent by this STA (FPD). This is interpreted along with the Next PPDU default MCS to determine the duration of the next PPDU. Present when FPD is indicated, otherwise

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		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.
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.

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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.
RDL	B6	When set, indicates that a reverse direction limit is present

6.1.1.2.2 Format of MCS Feedback Field

This field contains an MCS value and a selection for the Short GI.

The least significant 7 bits carry the MCS TXVECTOR parameter.
The most significant bit (bit7) carries the SHORT-GI TXVECTOR parameter.

6.1.2 Responder Aggregation Control (RAC) MPDU

6.1.2.1 Introduction

This MPDU provides control of the MCS, size, duration, training and any reverse flow of aggregates in an exchange of aggregates between STAs. It is sent by the responder STA of an aggregate exchange.
There are a number of groups of fields (RAC elements), which perform specific purposes within the MPDU as described below:

RAC Element Name	**Purpose of item**
CTS – Clear-to-Send	Response to RTS indicates that the medium is clear
TRQ – MIMO training request	Request to train the channel Used for MIMO with implicit Feedback.
MRQ – MCS request	Indicates a request for MCS feedback
MFB –MCS Feedback	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 for a reverse direction data flow

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request	Contains requested total data MPDU length (bytes) and default MCS

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.

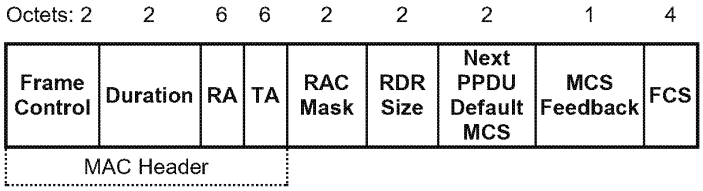


Figure 2 – RAC MPDU

Field	Size (bytes)	Purpose
Frame Control	2	Type is control, subtype is RAC
Duration	2	
Receiver Address	6	
Transmitter Address	6	
RAC Mask	2	A bitmask indicating which RAC elements are present in the packet.
RDR Size	2	Size in bytes of requested reverse direction flow. 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	

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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.

6.1.3 Multiple Receiver Aggregate Multi-Poll (MMP) MPDU

6.1.3.1 Introduction

The MMP frame is used to define multiple response periods, in combination with multiple-receiver aggregation.
The MMP frame may be transmitted in a separate PPDU, or may be aggregated with the first MRA of the MMP sequence. See section 7.1.4 (MMP exchange sequences).

6.1.3.2 Format of MMP MPDU

This section defines the format of the MRAD MPDU.

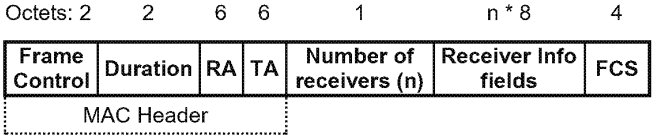


Figure 3 – MRAD MPDU

Field	Size (bytes)	Purpose
Frame Control	2	Frame type is Control, subtype MRAD
Duration	2	
Receiver Address	6	The RA field is the broadcast group address.
Transmitter Address	6	The TA field is the address of the STA

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		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 * 8	n Receiver Info fields, one for each Receiver Address in the MRA aggregate.
FCS	4	

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

Each receiver info field carries the following information

Subfield	Size	Purpose
AID	2 bytes	Contains an association identifier that identifies the STA addressed by this record
TID	4 bits	Defines the TID for transmissions by the STA
New PPDU Flag	1 bit	Indicates that the downlink for this STA occurs at the start of a PPDU.
Reserved	3 bits	
Rx Offset	10 bits	Defines the start of the first symbol containing downlink data for this STA, specified in units of 4us relative to the start of the PPDU carrying the MMP. Reserved if Rx Duration is zero.
Rx Duration	10 bits	Defines the length of the downlink data in units of 4 us. If there is no downlink data for this AID, contains a zero.
Tx Offset	10 bits	Defines the time when transmissions by this STA may start, in units of 4us relative to the end of the MMP PPDU. Reserved if Tx Duration is zero.
Tx Duration	10 bits	Defines the limit of transmission duration, in units of 4us. If no transmission is scheduled, contains a zero.

6.1.4 Increase Channel Bandwidth (ICB) MPDU

6.1.4.1 Format of ICB MPDU

The frame format for the ICB frame is defined as is in Figure 4.

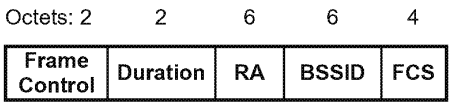


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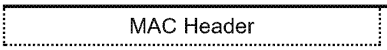


Figure 4 – ICB MPDU

Field	Size (bytes)	Purpose
Frame Control	2	Frame type is Control, subtype ICB
Duration	2	Duration of the 40MHz phase plus transition periods
Receiver Address	6	The RA field is the broadcast group address.
BSSID	6	
FCS	4	

Refer to section 8.1.3.4 describing how this MPDU is used.

6.1.5 Decrease Channel Bandwidth (DCB) MPDU

6.1.5.1 Format of DCB MPDU

The frame format for the DCB frame is defined as is in Figure 4.

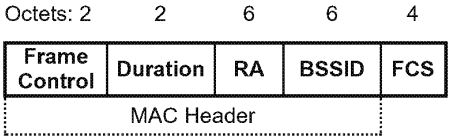


Figure 5 – DCB MPDU

Field	Size (bytes)	Purpose
Frame Control	2	Frame type is Control, subtype DCB
Duration	2	Duration of the 20MHz period, in TU.
Receiver Address	6	The RA field is the broadcast group address.
BSSID	6	The BSSID field is the address of the STA contained in the AP.
FCS	4	

Refer to section 8.1.3.4 describing how this is used.

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6.1.6 Block Ack (BA) MPDU

This section defines a compressed variant of the 802.11e BA MPDU. The variant is distinguished by setting the "Compressed" field of the BA Control field to 1.
Two compression mechanisms exist:

- Support for non-fragmented BA. This reduces the bitmap size to 1 bit per MSDU.
- Truncation of the bitmap to reduce the number of MSDUs acknowledged in the bitmap.

The use of these mechanisms is negotiated when the BA agreement is created through the exchange of ADDBA frames, and is constant for a BA agreement throughout its lifetime. This means that a BA for a particular BA agreement is always the same size.

6.1.6.1 Format of BA MPDU

The frame format for the BA frame is defined as in Figure 6.

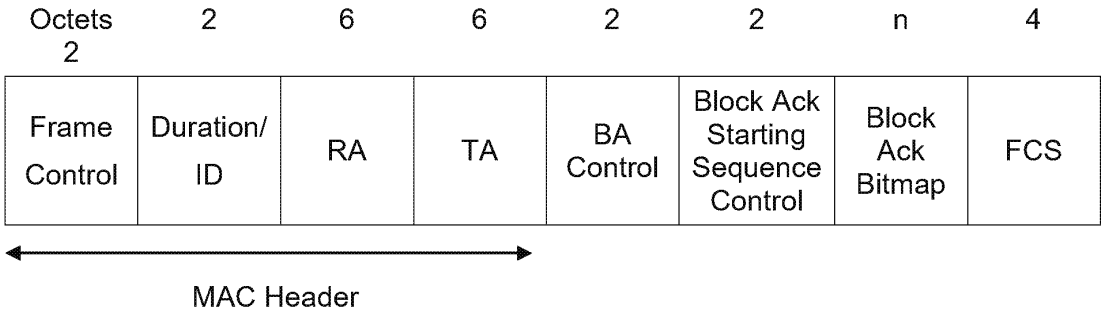


Figure 6 – Compressed BA MPDU

Only the BA control and Block Ack Bitmap fields are modified.

The BA Control Field is shown in Figure 7.

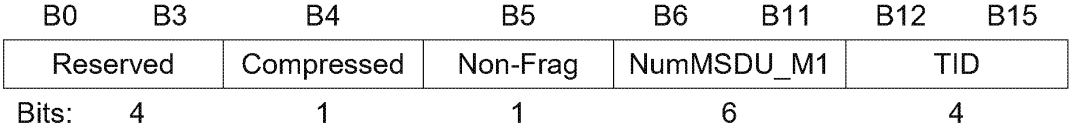


Figure 7 – BA Control field

The Compressed, Non-Frag and NumMSDU_M1 are new fields.

The Compressed field selects between legacy 802.11e format and compressed format. When Compressed is set to 0, the BA is interpreted according to legacy 802.11e. The Compressed field is always set to 1 when the BA is set up between HT STAs.

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The Non-Frag bit indicates whether acknowledgement is per MSDU or per MPDU. It affects the interpretation of the bitmap field as defined below.

The NumMSDU_M1 field defines the number of MSDUs that are acknowledged by the present bitmap, less one. The NumMSDU_M1 field set as 0 indicates 1 MSDU is acknowledged by the bitmap and when it is 63, 64 MSDUs are acknowledged.

The maximum value of NumMSDU_M1 and the length of the Block Ack Bitmap is defined by the BA agreement, and is fixed for the lifetime of the BA agreement. They are derived from the ADDBA parameters, Non-Frag and Buffer Size, as defined below

Table 1 – Interpretation of the ADDBA Parameters

Non-Frag subfield value	Maximum value of NumMSDU_M1	Bitmap length n (octets)
1	Buffer Size – 1	ceil (Buffer Size/8)
0	Min (Buffer Size, 64) – 1	Buffer Size x 2

The bitmap is interpreted according to the setting of the Compressed, Non-Frag and NumMSDU_M1 fields as defined in the following table.

Table 2 – Interpretation of the BA Bitmap

Compressed	Non-Frag	NumMSDU_M1	Bitmap interpretation
0	0	0	Legacy 802.11e interpretation
1	1	0 to 63	Each bit set acknowledges the successful reception of a single MSDU in order of sequence number
1	0	0 to 63	Each bit set acknowledges reception of a single MPDU. The bitmap is interpreted as in legacy 802.11e except that only the first (NumMSDU_M1+1) x 16 bits are significant.

Other combinations of these fields are reserved.

6.1.7 Calibration Training MPDU

The frame format of the Calibration Training MPDU is defined in Figure 8.

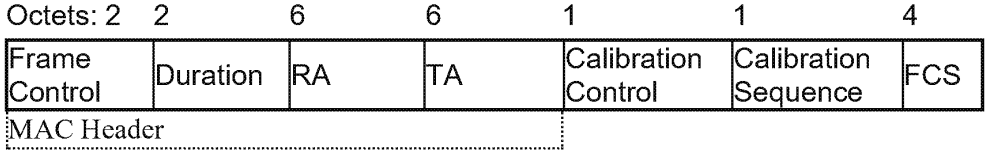


Figure 8 – Calibration Training MPDU

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The Calibration Control field contains:

- Number of antennas at the initiating STA *Ni* (2 bits)
- Number of antennas at the responding STA *Nr* (2 bits)
- Position (2 bits). This field is set to '0' by the STA transmitting the first frame that initiates the calibration training frame exchange sequence. The field is incremented in subsequent Calibration Training frame transmissions in the calibration training frame exchange sequence.
- *Reserved* (2 bits)

The Calibration Sequence field is incremented at the transmission of the Calibration Training frame that initiates the calibration procedure. The remaining frames in the same calibration procedure use the same Calibration Sequence value.

The Calibration Traning frame is carried in a PPDU with attributes defined according to the value of the position field.

Position Field	PPDU	TXVECTOR NLTF
0	Non-Aggregate	
1	Non-Aggregate, Sounding	*Ni*
2	Non-Aggregate, Sounding	*Nr*

Figure 9 – PPDU attributes for Calibration Training MPDUs

The Calibration Training frame shall be transmitted in a non-aggregate PPDU as part of the calibration training exchange defined in 8.3.

6.2 Management frame formats

6.2.1 HT Capabilities

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

Table 3 –HT Capabilities

Capability	Contents
HT Supported	Indicates that the device is an HT device, supporting all the mandatory features of this document. This capability is indicated by the presence of the HT capability element.
Number of Rx Antennas	Indicates the number of Rx Antennas
Max number of Rx spatial	Max number of spatial channels the device can

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channels	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 **11.2.1.7.2.2** 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.
Maximum Rx PSDU Length	Indicates the maximum PSDU size that can be received by the STA. See section 7.5
MMP Supported	When transmitted by a STA, indicates it is able to interpret the MMP frame and respond to a poll through the MMP mechanism (see section 7.1.4). When transmitted by an AP, indicates that it is able to transmit MMP frames.
Short GI Supported	Indicates that the STA can transmit and receive PPDUs using the SHORT GI Feature.
Calibration Supported	Indicates that the STA can participate in the calibration exchange defined in 8.3.

6.2.1.1 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 10.

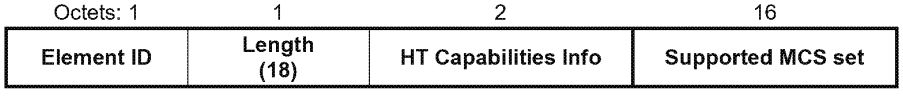


Figure 10 – HT Capability element format

The HT Capabilities Info field is 2 octets in length, and contains capability information bits as defined in Figure 11.

B0 B1	B2 B3	B4	B5	B6-B10	B11	B12	B13-B15

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Number of rx Antennas	Max number of Rx spatial channels	Advanced coding capability	Supported channel width set	Maximum Rx PSDU Length	MMP Supported	Calibration Supported	Reserved

Figure 11 – HT Capabilities Info field

The Number of rx antennas field contains the number of rx antennas supported, minus 1.
The max number of rx spatial channels filed contains the maximum number of rx spatial channels supported, minus 1.
The advanced coding capability field indicates support for advanced coding if its value is 1.
The supported channel width set indicates {20} if its value is 0, and {20, 40} if its value is 1.

The Maximum Rx PSDU length indicates the maximum length of PSDU that the STA can receive. The limit defined by this field is $2^{\text{Maximum Rx PSDU Length}}$ bytes, where Maximum Rx PSDU Length shall be between 15 and 18.

6.2.2 Additional HT Information Elements

The AP will signal information in new information elements to manage the BSS.
This information is defined in the table below.

Table 4 – Additional HT Information Elements

Name	Description	Use
Control Channel	Channel number of the control 20MHz channel	In a mixed mode, all broadcast and non-aggregated control frames are sent so that they can be received by a legacy device operating on the control channel.
Extension Channel Offset	Values: –1, 1 indicate offset of the extension channel from the control channel. 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.
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	Used to control the use of protection mechanisms (see section7.1.3). Also selects between legacy beacon and HT beacon generation in an IBSS network (see section 8.1.3.2).

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	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	
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.)
TSF Synchronization Precision Capability	Indicates that the AP reduces jitter in the on-the-air timing of beacons related to its TSF timer to the precision specified in the element.	Present in beacons, (re)association and probe response frames transmitted by an AP that supports this function.

1

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6.2.2.1 TSF Synchronization Precision Capability Element

The TSF synchronization precision capability transmitted by an AP indicates the precision of its beacon transmission start time at the output of AP to the media relative to TSF timer updates. This value represents the amount of jitter present in the timestamp in the beacon relative to TSF timer update timing. It includes all jitter introduced in the process of beacon generation through both MAC and PHY.

This element is present in Association, Reassociation and Probe Response frames.

This information is used to inform other stations of the ability of the AP to support synchronization within a communicated precision.

The TSF Synchronization Precision Capability Element is given in Figure 12.



Figure 12 – TSF Synchronization Precision Capability Element

The SyncPrecision field contains a non-negative integer in the range 0-20 representation that indicates the amount of synchronization of TSF at the output of AP is $2^{(-\text{SyncPrecision})}$ in units of μs.

6.2.3 Management Action Frames

These frames are defined to be action frames using the 802.11e Action frame format. They share a common category code "HT".

The frames using the "HT" category code are defined in Figure 13.

Action Code	Meaning
1	Calibration Measurement
2	Calibration Correction

Figure 13 – Action codes for the HT action category

6.2.3.1 Calibration Measurement Action Frame

Calibration Measurement frame is a management action frame of category Calibration. It contains the following fields.

Order	Information	Size
1	Calibration Control	1
2	Calibration Sequence	1
3	MCMR Segment Sequence	1
4	MIMO Channel Measurement Report	3 × *Ns* × *Ni* × *Nr*
Where:		

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- *Ns* = Number of subcarriers in the Calibration Training symbols
- *Ni* = Number of antennas at the STA that transmitted the Calibration Request
- *Nr* = Number of antennas at the STA that is transmitting the Calibration Response

All messages in the same calibration procedure use the same Calibration Sequence value. The Calibration Control field (1 octet) consists of:

- Number of antennas at the initiating STA *Ni* (2 bits)
- Number of antennas at the responding STA *Nr* (2 bits)
- Calibration Complete (1 bit). The Calibration Complete bit is set to '1' if the STA transmitting the Calibration Measurement frame declares the calibration procedure complete without requiring the other STA to transmit a Calibration Correction Vector frame.
- Reserved (3 bits)

The MCMR Segment Sequence (1 octet) contains the segment sequence number when the MIMO Channel Measurement Report has been segmented. The MCMR Segment Sequence of the first segment is 0. The complete MIMO Channel Measurement Report contains $Ns \times Ni \times Nr$ complex coefficients.

Each complex coefficient (3 octets) is represented by its 12-bit real and 12-bit imaginary parts. Hence the total length of the complete MIMO Channel Measurement Report is $3 \times Ns \times Ni \times Nr$ octets.

The complete MIMO Channel Measurement Report may need to be transmitted using more than one MAC frame. In the mandatory configuration with $Ns = 114$, $Ni = 2$, $Nr = 2$, there will be 1368 octets (456 coefficients) in a single MIMO Channel Measurement Report element. The maximum length of the MIMO Channel Measurement Report field is 5472 octets (1824 coefficients) for the case with $Ns = 114$, $Ni = 4$, and $Nr = 4$. If the MIMO Channel Measurement Report is longer than 1368 octets, the first 1368 octets are included in the first frame (MCMR Segment Sequence = 0) and the remaining octets are included in subsequent frames (MCMR Segment Sequence = 1, 2, etc.).

6.2.3.2 Calibration Correction Action Frame

Calibration Correction frame is a management action frame of category Calibration Correction. It contains the following fields.

Order	Information	Size
1	Calibration Control	1
2	Calibration Sequence	1
3	MIMO Correction Vector	$3 \times Ns \times Nr$

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Where:

- *Ns* = Number of subcarriers in the Calibration Training symbols
- *Nr* = Number of antennas at the STA that transmitted the Calibration Response

All frames in the same calibration procedure use the same Calibration Sequence value.
The Calibration Control field (1 octet) consists of:

- Number of antennas at the initiating STA *Ni* (2 bits)
- Number of antennas at the responding STA *Nr* (2 bits)
- Reserved (4 bits)

The MIMO Correction Vector contains $Ns \times Nr$ complex coefficients.
Each complex coefficient (3 octets) is represented by its 12-bit real and 12-bit imaginary parts.
Hence the total length of the MIMO Correction Vector field is $3 \times Ns \times Nr$ octets. The maximum length of the Correction Vector field corresponds to $Ns = 114$, $Nr = 4$ is 1368 octets.

6.2.4 Block Ack Parameter Set field

This section defines changes to the 802.11e Block Ack Parameter set field of the ADDBA frame.

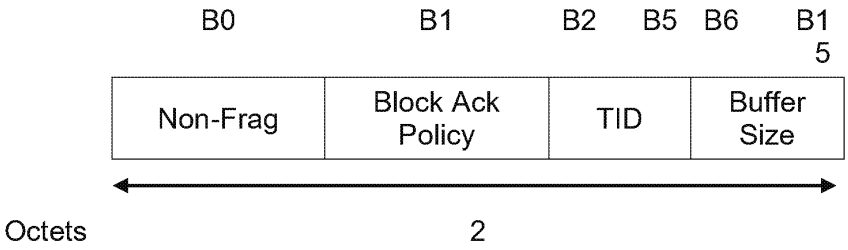


Figure 14 - Block Ack Parameter Set fixed field

The Non-Frag subfield is set to 1 if fragmentation is not used.
The compressed BA format is used whenever the Block Ack negotiation is set up between the HT STAs.
The Buffer Size subfield contains the number of buffers at the receiver. Its interpretation depends on the setting of the Non-Frag subfield. The maximum value of the NumMSDU_M1 parameter used in the compressed BA is also derived from the Buffer Size and Non-Frag fields as specified in the following table.

Table 5 - Interpretation of the Buffer Size parameter

Non-Frag subfield value	Buffer Size interpretation	NumMSDU_M1
1	Buffer size contains the maximum number of MSDUs that can be sent	NumMSDU_M1 = Buffer Size – 1

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	within the BA window. Maximum value is 64	
0	Buffer size contains the maximum number of MPDUs that can be sent within the BA window. Maximum value is 1024 (i.e., 64 x 16)	NumMSDU_M1 = min (Buffer Size, 64) - 1

In an ADDBA request frame, the Buffer Size subfield is advisory and the recipient selects a value equal to or smaller than the initial value.

6.3 A-MPDU and A-MSDU aggregation formats

6.3.1 Introduction to Aggregation (Informative)

There are two types of aggregation defined in this specification: A-MSDU aggregation and A-MPDU aggregation.

A-MSDU aggregation joins together multiple MSDUs and creates a single larger MSDU that is transported in Data MPDUs.

A-MPDU aggregation joins multiple MPDUs together and transports them in a single PSDU.

Note, the term "aggregate" used elsewhere in this document refers to A-MPDU aggregation, unless specifically referring to A-MSDU aggregation.

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

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

6.3.2 Aggregated MPDU format (A-MPDU)

An A-MPDU consists of a number of MPDU delimiters each followed by an MPDU.
Except when it is the last MPDU, padding octets are appended (if needed) to make each section a multiple of 4 octets in length.

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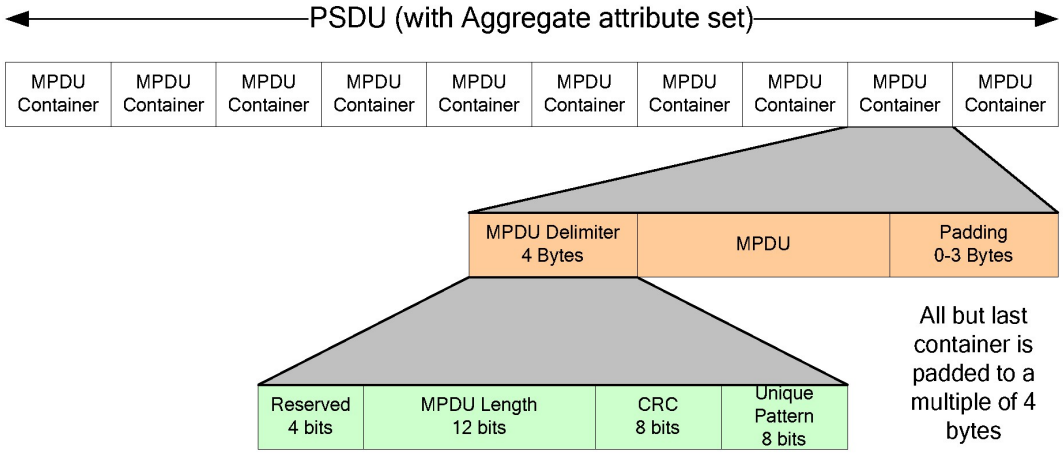


Figure 15 – A-MPDU format

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

Table 6 – MPDU delimiter Fields

MPDU delimiter Field	Size (bits)	Description
Reserved	4	-
MPDU length	12	Length of the MPDU in octets
CRC	8	8-bit CRC of the preceding 16-bits. 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. The unique pattern is set to the ASCII value for character 'N'.

The purpose of the MPDU delimiter is to robustly delimit the MPDUs within the aggregate. Robust in this case means that the structure of the aggregate can usually be recovered when one or more MPDU delimiters are received with errors. Individual delimiters have the same BER as the surrounding MPDUs, and so can be lost.

Note, a delimiter with MPDU length zero is valid. This can be used to introduce padding between MPDUs, or at the end of the A-MPDU.

6.3.3 Single receiver frame aggregation format

An aggregate is a sequence of MPDUs carried in a single PPDU with the TXVECTOR AGGREGATE field set to 1.
In a single-receiver aggregate, all MPDUs are addressed to the same receiver address.
The aggregate contains MPDUs in the order defined below.

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Table 7 Single Receiver Aggregation MPDUs

MPDU	Multiplicity	Description
IAC or RAC	At most one	Initiator or responder aggregate control. Used when it is necessary to include a logical element as described in sections 6.1.1 and 6.1.2
ACK	At most one	Contains an acknowledgement of at most one MPDU in the previous aggregate that required immediate acknowledgement.
BA	At most one per Block ACK agreement in the appropriate direction	Block ACK MPDUs
QoS Data	No limit, except as constrained by Block ACK protocol and TXOP duration	Data MPDUs sent under Block-ACK policy. These MPDUs can come from multiple TCs, provided that they comply with the TC policy of the current TXOP.
BAR	At most one per Block ACK agreement (immediate Block ACK policy).	Immediate Block ACK Requests
Any MPDU requiring an immediate response	At most one	At most one MPDU that requires an Ack MPDU response may be transmitted. 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.

6.3.4 Multiple receiver frame aggregation format

A multiple-receiver aggregate (MRA) contains MPDUs that are addressed to multiple receivers.

An MRA may be transmitted in one of two contexts distinguished by whether it is transmitted during an MMP sequence (as defined in section 7.1.4) or not.

	Normal Context	MMP Sequence Context
Receiver Addresses	Any	Only those listed in the prior MMP
Responses	None	Scheduled by the prior MMP

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		transmission

If multiple responses are required, they are scheduled by transmission of an MMP frame before transmission of any other MPDUs that comprise the downlink. The MMP frame may be transmitted in as a non-aggregate, or may be aggregated with downlink MPDUs.

In the MRA, frames for each receiver address are grouped together.

The MRA contains any frames addressed to broadcast/multicast RA (known as broadcast/multicast groups) followed by frames addressed to unicast RA, grouped together (known as unicast group).

A Broadcast/Multicast Data Group contains MPDUs in the order defined below.

Table 8 - Broadcast/Multicast Receiver Group MPDUs

MPDU	Multiplicity	Description
Data or management MPDU	No limit, except as constrained TXOP duration	Data or management MPDUs with the broadcast or the same multicast destination address.

In MMP context, a Unicast Group shall contain the same MPDUs as a Single Receiver Aggregate (see section 6.3.3), addressed to the same receiver, in the order defined in Table 7. An IAC frame may be present, but it shall not contain an RDG, because the response duration has been defined in the MMP.

In Normal context, a Unicast Group shall contain the same MPDUs as a Single Receiver Aggregate, except that frames requiring an immediate response shall not be transmitted.

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

Table 9 - MRA Aggregate MPDUs

MPDU	Multiplicity
MMP	At most one if this MRA is a the start of an MMP sequence (see section 7.1.4)
Broadcast/Multicast Data Group	One group of frames per broadcast or multicast destination address. Only permitted when the BSS is operating in pure mode.
Unicast Group	One group of frames per receiver address.

Data MPDUs can come from multiple TCs, provided that they comply with the TC policy of the current TXOP.

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Data MPDUs with the same receiver address are included in consecutive locations in the MRA aggregate. In MMP context, the order of (groups of) Data MPDUs for different receiver addresses is equal to the order of the matching Receiver Info fields in the previous MMP MPDU.

6.3.5 Aggregated MSDU Format (A-MSDU)

This section describes the format of Aggregated MSDU (A-MSDU). The purpose of the A-MSDU is to allow multiple MSDUs being sent to the same receiver to be aggregated and sent in a single MPDU, which improves the efficiency of the MAC layer, particularly when there are many small MSDUs such as TCP acks. Support for A-MSDU is mandatory at the receiver. However, the transmitter is free to use A-MSDU or not based on information such as traffic characteristics and link conditions. The maximum length of an A-MSDU shall be 3800 bytes.[1]

Figure 16 shows the structure of a Data MPDU containing an A-MSDU, which is a sequence of *n* MSDU sub-frames. Each sub-frame consists of a sub-frame header followed by an MSDU and 0-3 bytes of padding. The MSDU shall not exceed 2304 byes in length. A sub-frame (except the last) is padded so that its length is a multiple of 4 bytes. The last sub-frame has no padding.

The sub-frame header contains three fields: Destination Address (DA), Source Address (SA), and Length. [2] The DA and SA fields are interpreted as described in Table 10 below. The length field contains the length in bytes of the MSDU.

[1] This figure is chosen so that the length of an MPDU containing an (unfragmented) A-MSDU does not exceed 3839 bytes. The figure of 3839 is chosen so that the maximum length MPDU containing an A-MSDU is 256B shorter than a common physical memory page size of 4KB, thereby allowing room for status and control information to be stored with the MPDU without forcing the use of multiple physical pages.

[2] Note, these fields are arranged in the same order as the 802.3 frame format.

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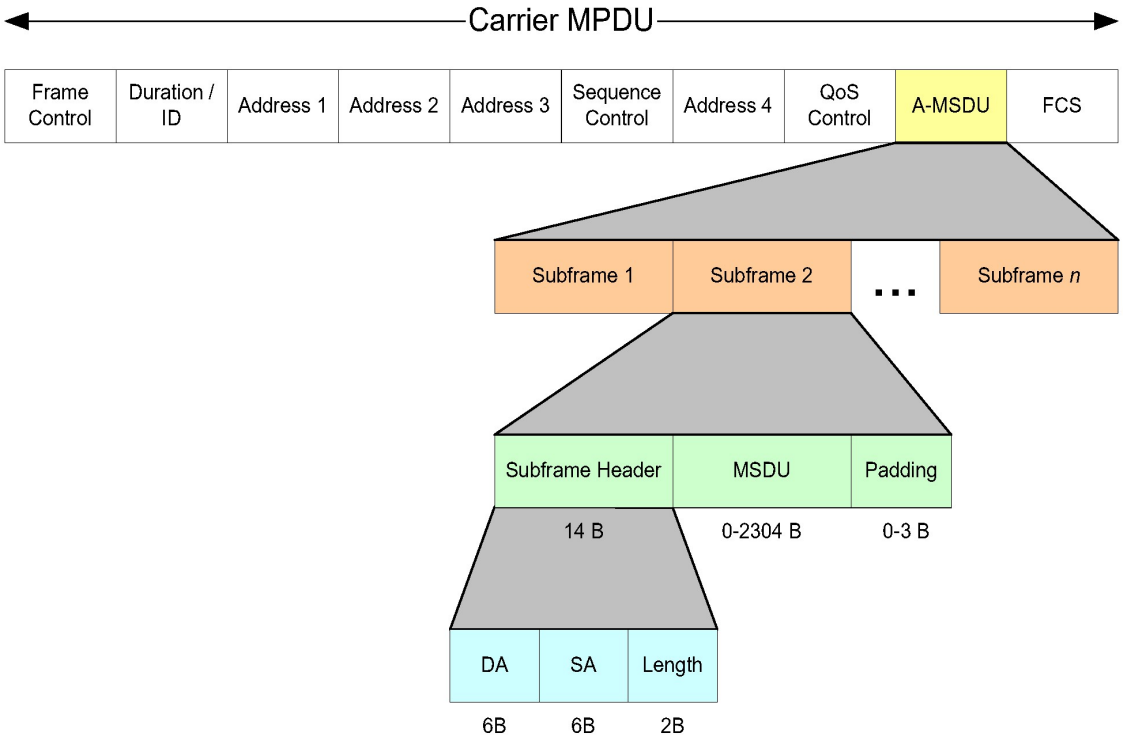


Figure 16 – A-MSDU Structure

The MPDU containing the A-MSDU is one of the QoS data subtypes. The presence of the A-MSDU is signaled by setting bit 7 of the QoS control field to a 1.

The DA and SA are passed between the MAC and its service client in the MAC service primitives. The mapping of DA, SA to the addresses in the MPDU header is described by the following tables. It is possible to have different DA and SA in the same A-MSDU as long as they all map to the same receiver address.

Table 10 – Address field contents

To DS	From DS	Address 1	Address 2	Address 3	Address 4	DA	SA
0	0	DA	SA	BSSID	X	-	-
0	1	DA	BSSID	-	X	-	SA
1	0	BSSID	SA	-	X	DA	-
1	1	RA	TA	-	-	DA	SA

Notes:

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X = not present

- = reserved

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7 MAC sublayer functional description

7.1 Aggregation Exchange Sequences and related rules

7.1.1 Aggregation Exchanges

A STA that owns the TXOP may start an exchange of PPDUs. This STA is called the initiator.

The STA may transmit PPDUs and obtain response PPDUs from one or more STA during the exchange. These STA are called responders.

This section defines the rules relating to these exchange sequences.

A response PPDU may be transmitted according to the PPDU received previously from the initiator as follows:

- Reception of an unaggregated IAC (RDG=0) at a basic rate generates an unaggregated RAC response at a basic rate (See 7.2 for a definition of basic rate). The response is transmitted after a SIFS interval. If the IAC contains an RTS element, the responder shall generate no response if its NAV is non-zero at the start of the response period, otherwise the responder shall respond with an RAC containing a CTS element.
- Reception of an aggregated IAC (RDG > 0) in a SRA permits a response PPDU to be transmitted a SIFS after the PPDU containing the IAC, and of at most the specified duration.
- Reception of an SRA aggregate not containing a IAC permits a response PPDU containing at most RAC and BA responses to the contents of the aggregate. The response is transmitted after a SIFS interval.
- Reception of an MMP frame permits a response PPDU at the responder's tx offset contained in the MMP frame and for the responder's tx duration contained in the MMP frame.

In the case of an MMP sequence, the AP shall ensure that the first response period shall start no less than a SIFS after the end of the MMP PPDU. Typically the initiator will arrange that response periods are separated by SIFS, but there is no normative requirement for this to be the case.

The initiator shall ensure that its PPDU transmission and any responses fit entirely within the current TXOP.

7.1.2 Bi-Directional Data Exchange Rules

A STA that is an initiator may advertise willingness to provide reverse direction data flow by including a RDL element in its IAC.

A STA that is a responder may request a reverse direction allocation from the initiator using an RDR element. The RDR element contains the length of data in the PPDU it would like to send, plus a default MCS. An MFB element may accompany the RDR, and the initiator may determine an updated MCS based on their contents.

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The initiator receiving the RDR information (and possibly augmented by the MFB) calculates a grant duration. The RDG element in the next IAC contains the allocation for reverse direction data, plus any additional grants for RAC and BA response frames and retries. The initiator is free to grant any RDG it wishes (compliant with the TXOP rules) including: no duration, the exact duration implied by the RDR, or any other duration determined by the implementation.

When transmitting an MRA containing periodic RDR, or when transmitting a SRA under the Pairwise Spoofing rules, the initiator shall allocate in its next RDG sent to a responder during the current frame exchange sequence, a grant for MPDUs transmitted by the responder that were not received successfully at the initiator.

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

- When the RDTID contains a TSID, only MPDUs of this traffic stream may be transmitted. This is typically used with a periodic TSPEC to gather uplink MPDUs for that TSPEC.

- When the RDTID contains an AC, only MPDUs of the specified access category may be transmitted. This is typically used by an initiator that gained access to the channel using EDCA to ensure that only MPDUs of that AC are sent by a responder.

- When the RDTID contains the value "unconstrained", MPDUs of any traffic stream or user priority may be transmitted. This may be used by an initiator during a TXOP gained through HCCA.

7.1.3 Protection mechanisms

7.1.3.1 LongNAV protection

When a STA has a TXOP, it may set a long NAV to protect multiple PPDUs using a single protection MAC layer protection exchange, e.g., RTS/CTS.

LongNAV protection is defined as selecting a duration value, limited by the remaining duration in the current TXOP and setting the NAV to this value using one of the MAC layer protection techniques.

In the case that a STA gains access to the channel using EDCA and uses LongNAV to protect a duration value, and then runs out of MPDUs to transmit, the STA may transmit a CF-End provided that the remaining duration is long enough to transmit this MPDU.
This shall be interpreted by HT STAs and is interpreted by legacy STAs as a NAV reset – i.e. they reset their NAV timer to zero at the end of the PPDU containing this MPDU.

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7.1.3.2 PHY layer protection – Spoofing

With spoofing, the NAV Duration is virtually set in the PHY Header by using the Length and Rate values of the legacy SIGNAL Field.
In a legacy packet, the Rate field declares the rate that the packet is coded in after the PHY Header, and the Length field declares the length of the packet (after the PHY header) in Bytes. When a legacy node receives this SIGNAL Field, it starts to decode the rest of the packet in the specified rate and will continue to do so until the end of Length / Rate time.
The Spoofed NAV uses this characteristic of the Length and Rate Fields, so that the (Length / Rate) is equivalent to the intended NAV Duration – (EIFS – DIFS). A legacy node that is spoofed by these two fields will continue reception for that (Length / Rate) time, preventing it to start transmission during that period. This way protection can be achieved without requiring legacy nodes to receive the MPDU contents. HT nodes will interpret the spoofed values of the legacy SIGNAL Field according to the rules in Section 7.1.3.3..
Because spoofed duration is carried in the PHY Header which is decode able in both halves of the 40MHz channel, it can provide protection from 20MHz-only capable STAs in both channels.

7.1.3.2.1 Pairwise Spoofing

A STA may use pairwise spoofing to protect an exchange sequence to a single responder. Pairwise spoofing is indicated by an FPD element in the IAC frame. This shall be set to the length and rate that will be used to send the next PPDU.

The initiator shall set the spoofed duration of its PPDU to the actual duration of the PPDU, plus SIFS, plus the duration contained in the RDG element of the IAC minus (EIFS – DIFS).

The responder, on receiving a IAC with an FPD element shall generate a response PPDU with the legacy SF set to a duration equal to the RDG, plus SIFS, plus the expected duration of the following PPDU sent by the initiator minus (EIFS – DIFS). This expected duration is based on the indicated length and either the default rate (if the RAC contains no MFB element), or the rate indicated in the MFB element.

7.1.3.2.2 Single Ended Spoofing

A STA may use single-ended spoofing to protect an exchange sequence to multiple responders.

The initiator shall set the spoofed duration of the PPDU so that it protects to the end of the last scheduled response minus (EIFS – DIFS).

7.1.3.3 HT Device NAV and EIFS Rules

An HT device that receives a PPDU examines the legacy and HT rate and length fields from which it calculates legacy and HT durations.
It determines that spoofing is in operation if the legacy duration is not equal to the HT duration.
If spoofing is in operation, it shall set its NAV to the value of legacy duration + (EIFS – DIFS) – HT duration at the end of the received PPDU, unless the NAV has been set by reception of a duration field value within the PPDU.

The following rule defines EIFS selection for an HT STA:

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An HT STA that receives an MPDU with a bad CRC shall only use EIFS if its NAV is zero at the start of the PPDU containing the MPDU. The condition is never true during an aggregate exchange, but is true for isolated Data/ACK.

7.1.3.4 Protection Rules for MRA

An MRA exchange may be protected using either LongNAV or single-ended spoofing.

In the LongNAV case the NAV of all devices that can hear the initiator has already been set by transmission of a previous MPDU, such as a CTS-to-self. 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 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.

7.1.4 MMP Sequences

7.1.4.1 Introduction (Informative)

The MMP sequence is provided in response to two classes of comments on an earlier version of this proposal. One comment regarded the complexity of the response generation using the "reverse direction offset", which was mandatory in all STA, but there primarily to serve VoIP and similar applications. The second regarded the need to more effectively support power-saving in VoIP STA.

The MMP sequence addresses these commentsachieves this by removing the general-purpose multiple response mechanism from the IAC into the MMP frame, and by making the ability to receive an MMP optional. The MMP frame contains addressing and timing information that allows a VoIP client to spend the minimum time awake during the MMP sequence. 3rd party STA, not participating in the sequence, or supporting the mechanism, can sleep through the entire sequence.

The existing 802.11e TSPEC mechanism is used to negotiate the creation of a periodic TSPEC. It is an option of the AP whether and how to group service intervals of STA into MMP sequences. It may use the MMP capability to determine that it can group STA together to service the TSPEC as part of an MMP sequence.

7.1.4.2 Definitions

An MMP sequence starts with the transmission of an MMP frame, and ends when the last scheduled response contained in the MMP ends.

7.1.4.3 Rules at the AP

An AP shall only include a STA in an MMP if that STA declares support for MMP.

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If the AP has grouped multiple STA to service under the MMP sequence, it shall transmit an MMP frame at the start of the service interval containing a record for each STA that is to be serviced during the current service interval.

The MMP shall any contain records for STA that have declared support for MMP, at most one record per AID/TID combination.

During an MMP sequence, the AP shall only transmit frames addressed to STA identified in the MMP frame according to the schedule defined in the MMP frame.

7.1.4.4 Rules at the STA

A STA receiving an MMP shall be enabled to receive during its indicated Rx period, and may transmit only during its indicated Tx period. With the exception of control frames relating to acknowledgement, it may transmit only data frames of the specified TID.

If it transmitted any frames for which an immediate response is required, it shall wake to receive responses at the end of the current MMP exchange.

7.1.4.5 Power-saving at the receiver of an MMP frame (informative)

Once it has decoded the MMP frame at the start of the service interval, the STA knows when it needs to be able to receive and when it can transmit. This may enable it to reduce power during some or all of the 3rd-party downlink and uplink.

The downlink may be contained in one or more PPDUs. The STA can locate the start of the PPDU containing its downlink by scanning backwards in the receiver info fields until a receiver info field with the "new PPDU" flag set is found. This receiver info field locates the start of the PPDU containing its downlink.

After acquisition, if the STA is able to save power by disabling some of its receive mechanism, it can do so up to the first symbol containing its downlink data (MPDU). From that point, it decodes the data and scans for a valid MPDU delimiter. After it has received the indicated number of symbols of data defined in its receiver info record, it may sleep.

It also wakes to transmit at the time indicated in its receiver info field.

If it transmitted any frames requiring an immediate response, it shall wake at the end of the current MMP exchange to receive any responses.

7.1.4.6 Power-saving at the 3rd-party receiver of an MMP frame (informative)

An HT STA that receives an MMP may sleep through the remaining duration of the MMP sequence on the following conditions:

- It does not support MMP
- It does support MMP, and the MMP does not contain its AID

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7.1.5 MAC support for closed loop modes

7.1.5.1 Closed-loop MCS training

Support for closed-loop MCS adaptation is provided by the exchange of MRQ (MCS Request) and MFB (MCS Feedback) elements carried in IAC/RAC control frames.
An MCS Request may be included in any IAC or RAC.
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.

The MFB response is sent when it is available. That means that a device that can evaluate the MFB quickly may send it in the following PPDU. Other devices that evaluate it more slowly may send it in a later PPDU of the same sequence, or in a later sequence.

7.1.5.2 Closed-loop MIMO training

Support for closed-loop MIMO adaptation is provided by the exchange of a TRQ (MIMO Training Request) element carried in 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.

7.2 MCS selection rules

The Supported MCS Set (6.2.1) and Basic MCS Set (6.2.2) indicate MCS values for HT format PPDUs only.
The existing basic rate and supported rate sets indicate rate selections for legacy format PPDUs only.

7.2.1 MAC Protection Frames

Any frame that is used to set or reset the NAV shall be sent at a basic rate, as defined here.
When legacy devices are present, only rates in the legacy basic rate set and the legacy PPDU format may be used. Then no legacy devices are present, rates in the Basic MCS Set may be used.

7.2.2 Multicast

Multicast/broadcast frames in pure mode and control frames that need to be received by HT devices only shall be selected from the Basic MCS set.

7.2.3 MRA MCS Selection Rules

When a STA transmits a MRA to multiple receivers, it shall ensure that the MRA is sent using transmit parameters that should make the PPDU receivable by all receivers in the aggregate.

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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 to a rate in the basic MCS set.

7.2.4 Short GI

The SHORT GI TXVECTOR attribute shall only be set to 1 in unicast frames addressed to a peer that declares support of the Short GI in the HT capabilities element.

The SHORT GI TXVECTOR attribute shall be set to 0 in all broadcast frames, and all MAC protection frames.

7.3 Quality of Service (QoS)

7.3.1 802.11e Requirements

An HT device shall support the mandatory features of an 802.11e QSTA.
An HT device shall support the use of the Block ACK mechanism introduced in 802.11e.

Note: this document extends the 802.11e Block Ack by defining a compressed Block Ack frame format, and rules for implicit Block Ack request in an aggregate. These are defined in section 6.1.6 and 6.2.4.

7.4 Enhanced Block acknowledgment

7.4.1 Introduction (Informative)

The 802.11e Block Ack mechanism is enhanced with the usage of implicit Block Ack Request when using frame aggregation.
An aggregated frame need not include a BAR frame and the recipient interprets the receiving aggregation frame as though it includes a BAR frame. This is the Implicit BAR mechanism.
A compressed variant of the 802.11e Block Ack frame is also defined. The compression parameters are defined during the Block Ack set up by an ADDBA request/response frame exchange based on whether to use fragmentation or not and the maximum number of MSDUs in the Block Ack window.
The size of the compressed BA frame is defined by the BA agreement, and is constant throughout the lifetime of the BA agreement.

7.4.2 Implicit BAR mechanism

The originator may omit the inclusion of a BAR frame in an aggregated frame.

An HT STA that receives directed data frames for a particular TID sent under BA acknowledgement policy without a matching BAR interprets this as an implicit BAR, and shall prepare a BA for the TID for transmission in its response PPDU.

On receiving an aggregate, the receiver buffer and starting sequence number are updated as defined below:

Condition	Receive Buffer Update	BAR starting sequence number
Aggregate received and	Update according to the	Use this MPDU's

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the first data MPDU for this TID is received correctly	first data MPDU's sequence number	sequence number
Aggregate received and the first data MPDU for this TID is not received correctly	Do not update the receive buffer	Use the seqence number of the first data MPDU received correctly. In an aggregate MPDUs are strictly ordered by sequence number
A BAR MPDU is received	Update according to the starting sequence number contained in the BAR	Use the starting sequence number in the BAR MPDU

For the multiple TID aggregate, the first data MPDU of a TID is identifiable if the last data MPDU of the previous TID has no error. The first data MPDU for the directed part in the MRA case can be also identified in the same way.

When the originator does not receive the BA frame after the transmission of an aggregated MPDU, it shall transmit a BAR frame and obtain a BA response before transmitting any more data frames using this BA agreement. The recipient then transmits a BA frame according to the Starting Sequence number indicated by the BAR frame and the buffer status.

When all the MPDUs in the aggregate fail at the recipient, the recipient does not send a BA frame. From the originator's point of view, this is indistinguishable from the lost BA case described above, and is handled in the same way.

7.4.3 Maintaining Acknowledgement State for a BA agreement

The recipient shall maintain the acknowledgement bitmap of size defined by the combination of Non-Frag and NumMSDU_M1 defined in section 6.1.6.1 for each BA agreement.

This bitmap for the matching agreement shall be reset whenever a first data frame for that agreement is received in an aggregate. A STA retains this acknowledgement state in case its BA is not received by the originator, and the originator has to retry. However, once the originator has successfully received the BA, it may transmit data in an aggregate, and the receipt of a new aggregate indicates to the recipient that the previous acknowledgement state is no longer required for the matching TID.

7.4.4 Compressed BA

A compressed variant of the 802.11e legacy BA frame may be used according to parameters negotiated during the Block Ack setup.

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The Non-Frag and NumMSDU_M1 parameters define the use of fragmentation and the maximum number of MSDUs acknowledged in the BA bitmap.
The compressed BA frame format is defined in section 6.1.6.

A STA transmitting an ADDBA MPDU shall first determine if its peer is a HT STA from an exchange of capabilities and shall not set the Non-Frag field to 1 if its peer is not a HT STA.

A HT STA shall always transmit a compressed format BA MPDU to a HT STA. A HT STA shall never transmit a compressed format BA MPDU to a non-HT STA.

The maximum value of the NumMSDU_M1 subfield is determined from the BA agreement as defined in 6.2.4. The number of MSDUs whose acknowledgment status is reported in the current BA MPDU is equal to (NumMSDU_M1+1).

The value of the Non-Frag subfield shall match the BA agreement. This same value is present in all BA MPDUs transmitted for this agreement.

The length of the BA bitmap is determined from the ADDBA Buffer Size subfield and the Non-Frag subfield as defined in 6.2.4, and is constant for the lifetime of the BA agreement.

An HT STA shall not transmit fragmented MSDUs on a BA agreement for which Non-Frag has the value 1.

7.5 PSDU Length Limit Rules

A STA shall declare the maximum PSDU size that it can receive using the Maximum Rx PDSU Length capability field. The STA shall be able to receive PSDUs of length less than the indicated limit. When it receives a PSDU of length greater than the limit, it shall receive the first $2^{\text{Maximum Rx PSDU Length}}$ bytes and discard any remainder.

A STA shall form an aggregate for transmission such that all the MPDUs within the aggregate that are intended to be received by a particular STA shall be within the first $2^{\text{Maximum Rx PSDU Length}}$ bytes of the PSDU, using the limit declared by that STA.

8 MAC sublayer management

8.1 Coexistence management

8.1.1 Operating Modes

The operating modes of an HT BSS are defined in the following table. These modes determine the format of beacon transmission and the kind of protection used for HT transmissions.

Topology	BSS Mode Name	Definition of Mode
Infrastructure	Pure	No co-channel legacy devices are present

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	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: In this mode, time is divided between contention periods for HT and legacy stations (by selectively setting the NAV)
	Unmanaged Mixed	BSS contains both legacy and HT devices or there are co-channel legacy devices of a different BSS present
	20 MHz-Base Managed Mixed	BSS contains both legacy and HT devices. There may be legacy devices of overlapping BSS in either or both of the channels. Legacy and HT devices associate to the AP's BSS in the control channel. The AP manages the generation of 40 MHz mode periods, during which 40 MHz HT devices are allowed to access in 40 MHz.
Independent (ad-hoc)	Discoverable IBSS	No co-channel legacy devices are present. The IBSS may be discovered by a legacy device.
	Mixed IBSS	There are legacy devices co-channel

8.1.2 Receiver capabilities regarding legacy operation in the extension channel

An HT AP or IBSS STA should be able to detect activity in the extension channel without being able to receive legacy MPDUs in it. On detecting a possible legacy MPDU, the STA should enable itself to receive in that extension channel in order to determine if a legacy BSS has arrived on the extension channel. It is not necessary that this capability be available simultaneous with operation on the control channel.

8.1.3 Infrastructure BSS Operation

8.1.3.1 At the AP

Table 11 – AP Mode Definitions

AP Mode	Beacon Transmission	Indicated STA operation
Pure	Pure	Pure
Mixed Capable	Legacy	Mixed
Managed Mixed	Dual (see below)	Pure
Unmanaged	Legacy	Mixed

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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 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 [3]. Its STA operate in pure mode, and are unaware of any difference between pure mode and mixed capable mode.

In the mixed-capable mode, the AP may receive association and probe requests from legacy STAs. It shall respond to a legacy probe request with a legacy probe response. It shall respond to a legacy association request with a legacy association response. The AP may choose to accept or deny the association request. If the AP sends an association response with status = OK, it shall enter either managed, unmanaged or 20 MHz-base managed mixed mode operation, and stay there while it has any associated legacy STA. The AP monitors its channel for a legacy co-channel BSS, and if it detects one, transitions into mixed mode, or attempts to find an alternative channel using the procedures defined in section 8.2.

In the unmanaged mixed mode, the AP transmits its beacon using the legacy PPDU type. The beacon contains an HT management element that requires mixed mode operation of its STAs. STAs in an unmanaged mixed mode BSS may use legacy or HT transmissions.

In the 20 MHz-base managed mixed mode, the AP transmits its beacon using the legacy PPDU type. The beacon is transmitted on the control channel but for the purpose of reserving the extension channel, an AP may send beacons also in the extension channel. Beacons in the extension channel may cause legacy STAs to attempt association but the HT AP shall deny association or may ignore those requests. The beacon contains an HT management element that requires mixed mode operation of its STAs.

8.1.3.2 At the STA

An infrastructure HT STA supports three possible modes of operation: legacy, mixed and pure. [4] In pure mode, there are no overlapping legacy STAs. Protection of HT frames from legacy devices is not required.

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

[4] The STA cannot distinguish between the AP's managed mixed mode and pure mode.

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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, a legacy protection mechanism is required (see section 0).

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.

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.

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.

8.1.3.4 20 MHz-Base Managed Operation

This section describes a coexistence mechanism where a BSS operates in 20 MHz mode and switches to a 40 MHz capable phase under the control of an HT AP. Due to the protection of the 40 MHz period in both channels, it is tolerant of overlapping BSSs.

8.1.3.4.1 Assumptions

Legacy STAs and 20 MHz HT STAs may coexist with the 40 MHz capable HT STAs. An HT AP provides legacy protection against legacy STAs and 20 MHz HT STAs.

8.1.3.4.2 Description of 20MHz-Base Managed Operation

The 40 MHz capable HT AP divides time into 20 MHz and 40 MHz phases. In a 20 MHz phase, it ensures that the NAV of 40 MHz mode operation in 40 MHz capable HT STAs is set and STAs associated with the HT AP operate on the control channel. In the 40 MHz phase, the NAV of legacy STAs and 20 MHz HT STAs is set and the 40 MHz capable HT STAs associated with the HT AP operate in 40 MHz mode.The transition between 20 and 40 MHz phases is as follows:

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Transition to 40 MHz phase

To start a 40 MHz phase, 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 CFP of the Beacon sent or the Duration/ID field of the ICB frame will be set to cover the 40 MHz phase plus the transition periods between 20 and 40 MHz operation. If the HT AP intends to continue the CFP after the 40 MHz phase, it may do so by setting longer values for the Duration/ID field. The transmission rate of the ICB frame shall be selected from the BSSBasicRateSet.

A 40 MHz capable HT STA associated with the HT AP extends its channel bandwidth to 40 MHz when it receives a Beacon frame including the channel extension indication information element or an ICB frame.

Then the AP may switch to 40 MHz analogue and 20 MHz digital mode and transmits a CTS-to-self or legacy Beacon in the extension channel by performing carrier sense across both control channel and extension channel.[5] The NAV shall cover the intended duration of the 40 MHz phase and the transition time back to 20 MHz phase.

After setting the NAV in the extension channel, the HT AP resets the NAV of 40 MHz capable HT STAs by sending a CF-end frame and thereby the 40 MHz phase is started.

Transition to 20 MHz phase

To end the 40 MHz phase, the HT AP first sets the NAV of 40 MHz mode operation in 40 MHz capable HT STAs by transmitting an DCB frame. The transmission rate of the DCB frame shall be selected from the Basic MCS set, considering only the 40MHz PPDU types. The 40 MHz capable HT STAs may 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 CF-End frame may be transmitted in 40 MHz analogue and 20 MHz digital mode. The AP may then reset the NAV in the control channel by a CF-End frame in 20 MHz analogue mode but it may also continue the CFP that was set in the last Beacon frame or the ICB frame on the control channel.

The AP has to wait at least aMax40MhzAnalogueSwitchingTime before starting the 40 MHz phase or ending the 40 MHz phase in order to account for the STA with the slowest possible switching time.

The recovery from unexpectedly long channel access delay to the 40 MHz phase is avoided by the extension channel access timeout value in Beacon and Probe Response frames. When the HT AP transmits the Beacon frame or ICB frame on the control channel to transit to the 40 MHz phase, it starts a timer with a timeout value equal to the extension channel access timeout minus the duration of the Beacon or ICB frame. A 40 MHz capable HT STA shall also start this timer when it receives this transmission. If the timer at the AP expires while attempting to transmit CTS-to-self or Beacon, the AP shall abandon switching to the 40 MHz bandwidth and may try again at a later time. The AP shall 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. 40 MHz capable HT STAs will also switch back to 20 MHz mode on the control channel by the expiry of the associated timer.

To avoid the influence of missing the DCB frame, a 40 MHz capable HT STA shall extract the NAV value from the ICB frame or from the Beacon frame at the start of the transition to a 40 MHz phase. In case of NAV extracted from these frames expires before the 40 MHz capable HT

[5] Transmission of the Beacon on the extension channel may avoid other BSSs being created, since other STAs will detect the presence of the HT BSS. Furthermore, NAV can be set longer by a Beacon than by a CTS-to-self.

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STA receives the DCB frame, it shall set the NAV by the maximum duration value of a DCB frame for 40 MHz mode operation and may switch back to 20 MHz mode on the control channel.

One cycle of the process is illustrated in Figure 17. The ratio between the 40 MHz and 20 MHz phase may be adjusted according to types of traffic and priority.

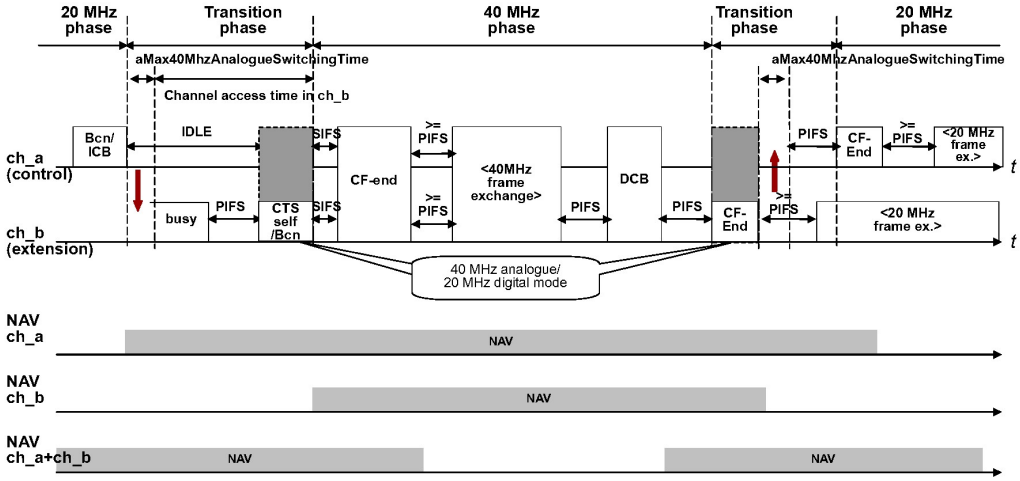


Figure 17 – 20 MHz-Base Managed Mixed Mode

8.1.3.4.3 Rules for Operation at HT AP

A HT AP exchanges frames with 40 MHz capable HT STAs using 40 MHz HT MCS in a 40 MHz phase. In a 20 MHz phase, it exchanges frames with legacy STAs using legacy rate and with both 20 MHz HT STAs and 40 MHz capable HT STAs using 20 MHz HT MCS. Frame exchanges may be in EDCA or HCCA in both phases.

8.1.3.4.4 Rules for Operation at 40 MHz capable HT STAs

A 40 MHz capable HT STA shall only operate on the control channel in 20 MHz mode .

A 40 MHz capable HT STA that obtains a TXOP shall only transmit frames during the 40MHz phase using 40 MHz HT MCS and shall only transmit frames during the 20MHz phase using a 20MHz (HT or legacy) PPDU type.

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 HT STA may send frames not only in EDCA but also in HCCA, which is enabled by QoS CF-Poll to it.

By the reception of a DCB frame, a 40 MHz capable HT STA may switch back to 20 MHz mode if it wishes to communicate in the 20 MHz phase when receiving the DCB frame.

A 40 MHz capable HT STA including a HT AP that is attempting an EDCA channel access during a 40MHz phase either freezes the backoff counter during 20MHz operation and resumes the interrupted backoff during the next 40MHz phase or selects a new random backoff at the start

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of the 40 MHz phase. Likewise, if it is attempting a channel access during a 20MHz phase, it either freezes the backoff counter during 40MHz operation and resumes the interrupted backoff during the next 20MHz phase or it selects a new random backoff at the start of the 20 MHz phase.

8.1.4 Ad-hoc (IBSS) Operation

Each STA maintains a table for STAs it can see according to the mode of operation of the STA. Stale entries in this table are removed by a timeout process. A STA can be classified as legacy if it is seen to transmit a legacy beacon without the HT elements (note, this also includes legacy APs). 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 12 – 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

When operating in Mixed IBSS mode, basic rates include only legacy rates and PPDU types as defined in section 7.2.

8.2 Channel management

8.2.1 Channel Management at the AP

The AP transmits a beacon containing the following elements:

Table 13 – 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.

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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.

8.2.3 Channel Selection Rules for HT AP

The HT AP shall either be configured manually or configure itself automatically as described in this section.
The HT AP shall scan its environment before selecting channel parameters. If the 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.

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

8.3 Calibration

8.3.1 Introduction

Transmit beamforming can operate with or without calibration assistance from the receiver. Support for calibration is optional.

Differences in transmit and receive chains in a STA or AP destroy the inherent reciprocity of the over-the-air TDD channel. Calibration is helpful in order to remove differences in transmit and receive chains and enforce reciprocity in the observed baseband-to-baseband channels. A simple over-the-air calibration procedure effectively corrects for these differences. The calibration procedure ensures that the observed channel matrices in the two directions of the link are transposes of each other and thus renders the resultant channel reciprocal. Thus, if they are able to do so, STAs calibrate upon association. Calibration works for any square or non-square dimensionality, i.e., N_{Tx} and N_{Rx} greater than one and less than five.

[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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8.3.2 Procedure

A STA shall only initiate a calibration training frame exchange sequence with a device that has the "Calibration Supported" HT Capability set to 1.

The Calibration Training frame exchange sequence, illustrated in Figure 18 operates as follows:

- STA A transmits a Calibration Training MPDU (Position field = 0).
- In response, STA B transmits a Calibration Training MPDU (Position field = 1) after a SIFS interval, which includes the HT-LTF that allows STA A to estimate the channel matrices.
- In response, STA A transmits a Calibration Training MPDU (Position field = 2) after a SIFS interval, which includes the HT-LTF that allows a receiving STA B to estimate the channel matrices.

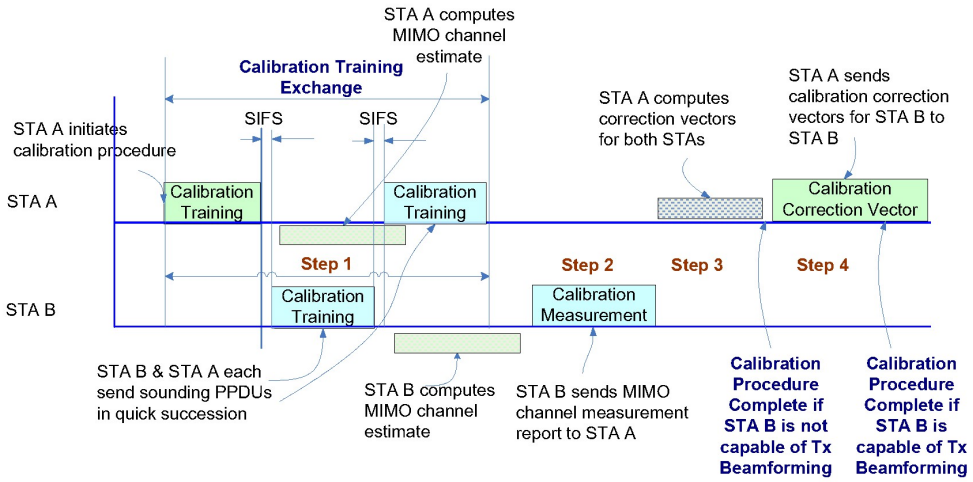


Figure 18 - Calibration Procedure

The Calibration Training MPDUs are carried in non-aggregated sounding PPDUs. The last two steps must occur over a sufficiently short time interval so that the channel does not change over the interval. When used in a mixed BSS, this frame exchange sequence must be protected with an appropriate protection mechanism.

The remaining message exchange in the calibration procedure is not time critical.
When the channel measurements become available at STA B, STA B sends one or more Calibration Measurement action frames that contains the MIMO Channel Measurement Report. STA B sets the Calibration Complete bit to '1' in case it is not capable of transmit beamforming. In this case STA A will not send Calibration Correction frame.

In case that both STAs are capable of transmit beamforming, once STA A has the MIMO Channel Measurement Report from STA B, along with its local channel measurement measured from the Calibration Training frame transmitted by STA B, STA A can compute the correction vectors required for both itself and STA B. The Calibration Correction frame is transmitted to complete the calibration procedure by STA A. The message includes the MIMO Correction Vector for STA B.

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8.4 Precise TSF synchronization

8.4.1 Precise TSF synchronization support at the AP

Jitter of the beacon transmission time relative to its timestamp is created by its passage through both MAC and PHY.

The optional "Precise TSF synchronization" function provides a means to improve the precision of synchronization of timestamps at a non-AP STA with those transmitted by the AP.

This is achieved by synchronizing the timing of the generation of PHY-TXSTART.request primitive used to transmit a beacon with the update events ("clock edge") of the TSF timer, and by minimizing the variation of PHY processing delay.

The amount of jitter between the TSF timer update and the on-the-air transmission time is assumed to be a constant, which is a characteristic of the AP design. It is signaled in the SyncPrecision field of the TSF Synchronization Precision Capability Element.

If Precise TSF synchronization is not supported, the AP shall not transmit the TSF synchronization precision capability element.

If Precise TSF synchronization is supported, the AP shall transmit a TSF synchronization precision capability element with the SyncPrecision field set to a non-zero value that is no less than the actual precision available.

8.4.2 Precise TSF synchronization support at the non-AP STA

The precision of oscillators used for the TSF timers in both AP and STA, the variation of multipath delay, as well as the transmission path jitter described in 8.4.1 are sources of jitter for synchronizing TSF timers.

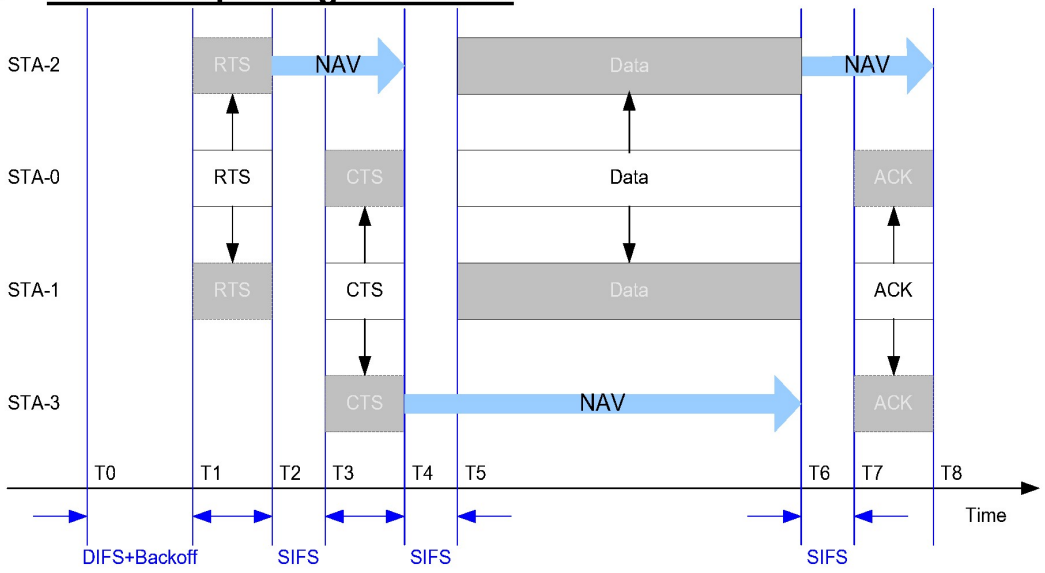
Transmission path jitter can be reduced at AP as described in 8.4.1. The Non-AP STA may maintain a precise TSF timer by filtering out the above jitters using a PLL.

The implementation detail of the PLL is out of a scope of this standard.

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9 Background information and Examples (Informative)

9.1 Pairwise Spoofing Protection



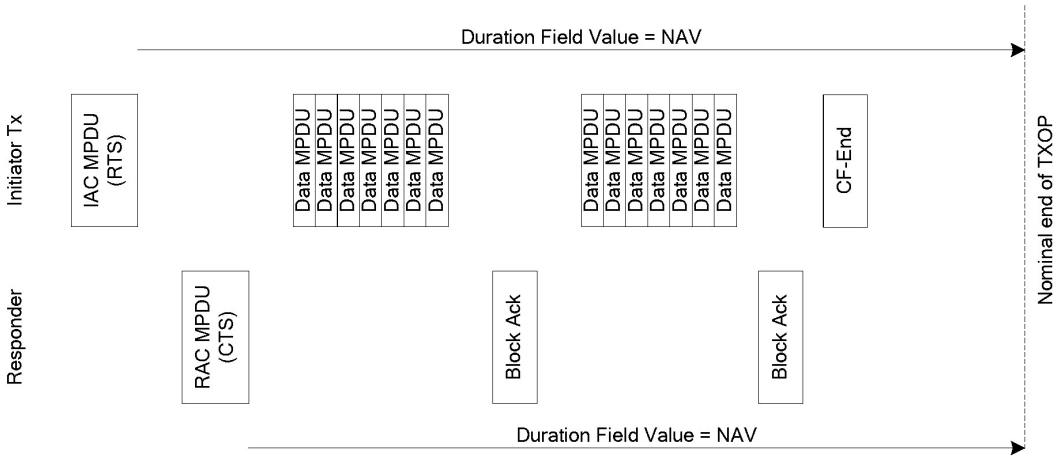
Under legacy 802.11 operation, when using RTS / CTS, the duration fields in the RTS / CTS / DATA packets point at the end of the ACK. Therefore the Duration of data must be fixed when sending RTS implying the mode and rate in which the data packet would be sent at must be fixed before sending RTS.

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 protection 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 timely rate adaptation, without sacrificing protection from hidden nodes. The use of shorter protection durations can reduce channel idle time when the RTS / CTS packets are not correctly received.

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9.2 Example Aggregation Exchanges

9.2.1 Simple Aggregation Exchange



The initiator transmits a non-aggregate IAC (RTS) using a basic rate, and with a NAV value set to the nominal end of the TXOP (this is LongNAV protection).

The responder transmits a non-aggregate RAC (CTS) after a SIFS interval using a basic rate.

The initiator transmits an A-MPDU containing a burst of Data MPDUs addressed to the responder.

The responder determines this is an SRA (no IAC) and transmits a response after SIFS carrying only mandatory response frames. In this case only a single BA is required, which is sent in an unaggregated MPDU.

This sequence of Data burst / BA continues until the initiator has run out of data, or the TXOP expires. In this case, the initiator runs out of data, and transmits a CF-End at a basic rate.

9.2.2 Aggregation Exchange with Reverse-Direction Data

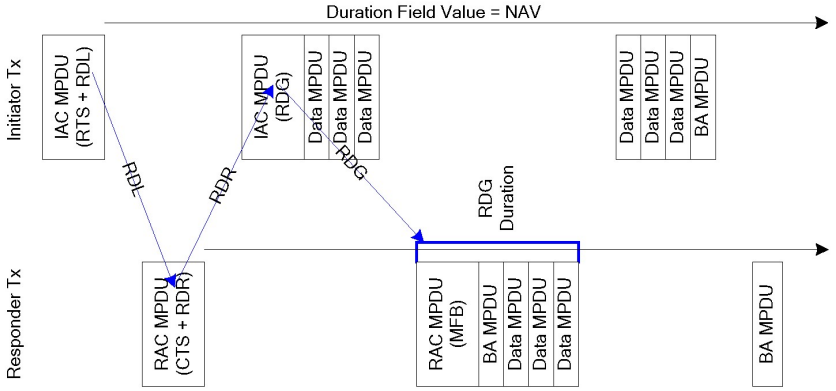


Figure 19 – LongNAV Bi-Directional Example

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Initiator sets the granted RDG duration long enough to include the duration of reverse data plus any expected responses (RAC + BAs). The duration granted by the RDG for reverse data may be less than the requested duration, in which case the responder must reduce the amount of data it sends. The responder can also itself reduce the amount of reverse data it sends. Any response PPDU duration no longer than the RDG duration is valid.

9.2.3 MMP Sequence

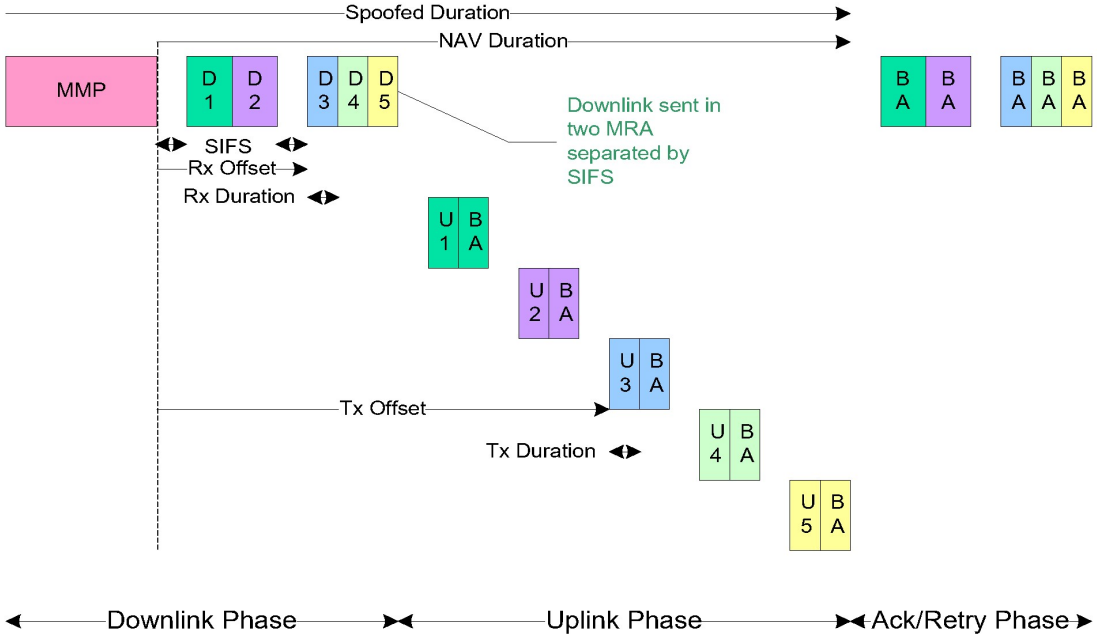


Figure 20 – Example MMP Sequence

Figure 20 shows an example of the use of MMP, such as in support of VoIP handsets.

In this example, the AP has grouped together five handsets into one service interval. The five handsets all wake from sleep according to 802.11e periodic APSD. The AP transmits an MMP frame at the start of the service interval that locates the downlink (receive) and uplink (transmit) periods for each STA, identified through its association identifer.

In this case the downlink is split into two PPDUs containing five data MPDUs. STA with similar rates are grouped together to optimize the duration of the downlink. Each STA wakes to receive its downlink, and then wakes to transmit its uplink.

In this example, we show the use of data sent under a block ack agreement. So the transmitted data results in an implicit BAR, causing the uplink to contain data and acknowledgement to the downlink. It's also possible, in this example, to use normal ack policy because we are only transmitting at most one data frame for each receiver in each aggregate.

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The five STA all awake at the end of the MMP sequence to receive the acknowledgements they are expecting to their uplink data (again, through the operation of the implicit BAR in this example). They stay awake until they receive their acknowledgements, or the service interval expires.

10 PHY-SAP service specification

The PHY service is provided to the MAC entry at an STA through the PHY service access point (PHY-SAP), as shown in Figure 11 of [1] and described in Clause 12 of that reference.

The amendments to the PHY-SAP parameters TXVECTOR and RXVECTOR are described in Sections 10.1.1 and 10.1.2 respectively.

10.1 PHY Specific Service Parameter List

The architecture of the IEEE 802.11 MAC is intended to be PHY independent. Some PHY implementations require PHY-dependent MAC state machines running in the MAC sublayer in order to meet certain PMD requirements. The PHY-dependent MAC state machine resides in a sublayer defined as the MAC sublayer management entity (MLME). In certain PMD implementations, the MLME may need to interact with the PLME as part of the normal PHY SAP primitives. These interactions are defined by the PLME parameter list currently defined in the PHY service primitives as TXVECTOR and RXVECTOR. The list of these parameters, and the values they may represent, are defined in the specific PHY specifications for each PMD. This subclause addresses the TXVECTOR and RXVECTOR for the MIMO-OFDM High Throughput (HT) PHY. The service parameters for TXVECTOR and RXVECTOR shall follow subclause 10.1.1 and 10.1.2.

10.1.1 TXVECTOR

The TXVECTOR is an array of fields sent from the MAC to the PHY instructing the PHY how to transmit the PPDU.

Parameter	Associated Primitive	Value
PPDU FORMAT	PHY-TXSTART.request (TXVECTOR)	Legacy 20 in 20 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

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		reserved null bits
TX_PWR_LEVEL	PHY-TXSTART.request (TXVECTOR)	1 – 8
HT-LENGTH	PHY-TXSTART.request (TXVECTOR)	1 – 262143
MCS	PHY-TXSTART.request (TXVECTOR)	0 – 126
ADV CODING	PHY-TXSTART.request (TXVECTOR)	0, 1
SOUNDING	PHY-TXSTART.request (TXVECTOR)	0, 1
NLTF	PHY-TXSTART.request (TXVECTOR)	1 – 4
AGGREGATE	PHY-TXSTART.request (TXVECTOR)	0, 1
SCRAMBLER-INIT	PHY-TXSTART.request (TXVECTOR)	0, 1, 2, 3
SHORT-GI	PHY-TXSTART.request (TXVECTOR)	0, 1
BEAMFORMED	PHY-TXSTART.request (TXVECTOR)	0, 1
BEAMFORM MATRIX	PHY-TXSTART.request (TXVECTOR)	$N_{TX} \times N_{SS} \times N_{SD}$ complex matrices

Table 14: Table of parameters for the TX Vector

10.1.1.1 TXVECTOR PPDU FORMAT

The PPDU FORMAT field specifies whether the PPDU is to be sent using a legacy PPDU format or using a high-throughput format. Legacy is interpreted to be 802.11g if operating in the 2.4 GHz band and 802.11a if operating in the 5 GHz band. Furthermore, it specifies the channel (i.e, the full 20MHz channel, the upper 20MHz sub-channel in the 40MHz channel, the lower 20MHz sub-channel in the 40MHz channel, or the full 40MHz channel) at which the PPDU is to be sent.

The value of this field affects the interpretation of several other TXVECTOR fields.

10.1.1.2 TXVECTOR L-LENGTH

The allowed values for the L-LENGTH parameter are in the range of 1–4095.

In legacy format this parameter is used to indicate the number of octets in the MPDU which the MAC is currently requesting the PHY to transmit. This value is used by the PHY to determine the number of octet transfers that will occur between the MAC and the PHY after receiving a request to start the transmission. In high-throughput format this parameter (along with L-DATARATE) is used to spoof the length of the current PPDU and possibly additional PPDUs.

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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 – 126. In HT format this parameter indicates the modulation and coding scheme. The number is an index into the MCS table given in Table 21 and Table 22. In legacy format this parameter is Null.

10.1.1.8 TXVECTOR ADV CODING

In HT format this parameter indicates whether advanced coding is used. A value of 0 indicates that advanced coding is not used. In legacy format this parameter is Null. A value of 1 indicates LDPC coding is used.

10.1.1.9 TXVECTOR SOUNDING

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

10.1.1.10 TXVECTOR NLTF

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

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10.1.1.11 TXVECTOR AGGREGATE

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

10.1.1.12 TXVECTOR SCRAMBLER-INIT

In high-throughout format this is the scrambler initialization field. It is a two-bit field, which serves as a pointer to one of four 7-bit long scrambler initialization sequences. In legacy format this parameter is Null.

The 2 bits are mapped to the following four scrambler initialization sequences:

b'00 → step 15 b'0111100
b'01 → step 84 b'0111101
b'10 → step 103 b'0111110
b'11 → step 127 b'0111111

Table 15: Scrambler Initialization Sequence

10.1.1.13 TXVECTOR SHORT-GI

In high-throughout format this parameter indicates whether the data is sent with a short guard interval (400 ns). A value of zero indicates a full GI (i.e. 800ns) and a value of 1 indicates a short GI (i.e. 400 ns). In legacy format this parameter is Null.

10.1.1.14 TXVECTOR BEAMFORMED

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

10.1.1.15 TXVECTOR BEAMFORM MATRIX

In high-throughout format this field specifies the complex matrix $N_{TX} \times N_{SS} \times N_{SD}$ which is used to beamform the PPDU. This field is only valid when the BEAMFORMED parameter is 1. In legacy format this parameter is Null.

10.1.2 RXVECTOR

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

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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 – 262143
MCS	PHY-RXSTART.indicate (RXVECTOR)	0 – 126
ADV CODING	PHY-RXSTART.indicate (RXVECTOR)	0, 1
SOUNDING	PHY-RXSTART.indicate (RXVECTOR)	0, 1
NLTF	PHY-RXSTART.indicate (RXVECTOR)	1 – 4
AGGREGATE	PHY-RXSTART.indicate (RXVECTOR)	0, 1
SHORT-GI	PHY-RXSTART.indicate (RXVECTOR)	0, 1

Table 16: Table of parameters for the RX Vector

10.1.2.1 RXVECTOR PPDU FORMAT

The PPDU FORMAT field specifies whether the received PPDU has a legacy PPDU format or a high-throughput format. Legacy is interpreted to be 802.11g if operating in the 2.4 GHz band and 802.11a if operating in the 5 GHz band. Furthermore, it specifies the channel (i.e, the full 20MHz channel, the upper 20MHz sub-channel in the 40MHz channel, the lower 20MHz sub-channel in the 40MHz channel, or the full 40MHz channel) at which the received PPDU was sent.

10.1.2.2 RXVECTOR L-LENGTH

The allowed values for the L-LENGTH parameter are in the range of 1–4095. This parameter is used to indicate the value of the L-LENGTH field in received PPDU. If this was a legacy PPDU

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then this parameter is the actual length of the PPDU. If this is a HT PPDU then this parameter, along with the L-DATARATE parameter, is used to calculate the spoofed duration.

10.1.2.3 RXVECTOR RSSI

The allowed values for the receive signal strength indicator (RSSI) parameter are in the range from 0 through RSSI maximum. This parameter is a measure by the PHY sub-layer of the energy observed at the antenna used to receive the current PPDU. RSSI shall be measured during the reception of the PLCP preamble. RSSI is intended to be used in a relative manner, and it shall be a monotonically increasing function of the received power. The value of RSSI is the maximum of the RSSI values from each receive antenna.

10.1.2.4 RXVECTOR L-DATARATE

The allowed values for L-DATARATE are: 6, 9, 12, 18, 24, 36, 48, and 54. This parameter is used to indicate the value of the L-DATARATE field in the received PPDU. If this is a legacy PPDU this is the data rate at which the data was transmitted. If this is an HT PPDU then this parameter, along with L-LENGTH, is used to calculate the spoof duration.

10.1.2.5 RXVECTOR BW

In high-throughput format this parameter specifies whether the received PPDU is a 20 MHz bandwidth or 40 MHz bandwidth HT PPDU. In legacy format this parameter is Null.

10.1.2.6 RXVECTOR HT-LENGTH

The allowed values for this parameter are 1 – 264143. In HT format this parameter indicates the value contained in the HT-LENGTH field. This parameter specifies the number of octets to be transferred from the PHY to the MAC sub-layer. In legacy format this parameter is Null.

10.1.2.7 RXVECTOR MCS

The allowed values for this parameter are 0 – 126. The number is an index into the MCS table given in Table 21 and Table 22. In high-throughput format this parameter indicates the value of the MCS field in the PPDU HT-SIG. In legacy format this parameter is Null.

10.1.2.8 RXVECTOR ADV CODING

In HT format this parameter indicates whether advanced coding was used in the PPDU. A value of 0 indicates that advanced coding is not used. In legacy format this parameter is Null. A value of 1 indicates that LDPC coding is used.

10.1.2.9 RXVECTOR SOUNDING

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

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10.1.2.10 RXVECTOR NLTF

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

10.1.2.11 RXVECTOR AGGREGATE

In high-throughout format this parameter indicates whether the PPDU contains an aggregate PSDU. A value of 0 indicates that the PSDU is not an aggregate and a value of 1 indicates that the PSDU is an aggregate. This value is used by the MAC sub-layer to indicate whether de-aggregation is required. In legacy format this parameter is Null.

10.1.2.12 RXVECTOR SHORT-GI

In high-throughout format this parameter indicates whether the data was sent with a short guard interval (400 ns). A value of zero indicates a full GI (800 ns) and a value of 1 indicates a short GI (400 ns). In legacy format this parameter is Null.

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11 MIMO-OFDM HT PHY specification

11.1 Overview

11.1.1 Introduction (Informative)

The PHY layer introduces several techniques for increasing the rate and reliability of the wireless link, as shown in Table 17:

Feature	Mandatory	Optional
Number of Spatial Streams	1 and 2	3 and 4
Number of Transmit Antennas	2	Greater than 2
Channelization bandwidth	20MHz	40MHz
Number of Occupied Subcarriers	56 in 20MHz	114 in 40MHz
Number of Data Subcarriers	52	108
Number of Pilot Subcarriers	4	6
Modulation Order	BPSK, QPSK, 16-QAM, 64-QAM	256-QAM
Code Rate	1/2, 2/3, 3/4, 5/6	
Guard Interval	800ns	400ns
Convolutional Coding	R=1/2, K=7, ($g_1=133_8$, $g_2=171_8$)	
LDPC		TX and RX Optional
TX Beamforming		TX and RX Optional

Table 17: PHY Feature Set

11.1.1.1 Frequency Bands of Operation

Our proposal supports operation of devices in 2.4GHz, 5GHz, and 4.9GHz. Operation in 4.9GHz shall conform to 802.11j rules.

11.1.1.2 MIMO Data Path Overview

The general data path for MIMO transmission is shown in Figure 21.

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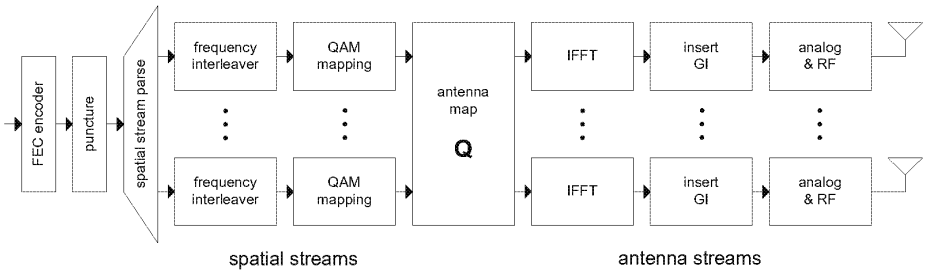


Figure 21: MIMO datapath.

The FEC architecture has a single encoder. For the convolutional code (CC), the mother code is rate 1/2. Encoded bits may be punctured to produce code rates 2/3, 3/4 or 5/6. For the LDPC code different code rates are produced within the encoder and external puncturing is not applied. Processing of bits following encoding/puncturing is identical for both CC and LDPC.

The punctured bits are then distributed to N_{SS} spatial streams via the spatial stream parser. For each spatial stream, blocks of bits that map to a single OFDM symbol are interleaved. This interleaving step is called "frequency interleaving" because it results in bit interleaving across subcarriers. The frequency interleaver is similar to the 802.11a interleaver. The combination of the spatial stream parser and the frequency interleavers results in space-time interleaving.

Interleaved bits are then mapped to QAM constellation points. The mapping may be BPSK, QPSK, 16 QAM, 64 QAM or 256 QAM.

The next step is the antenna map transformation. This transformation maps N_{SS} spatial streams to N_{Tx} transmit antenna streams. Note that MIMO transmission requires $N_{SS} \le \min\{N_{Tx}, N_{Rx}\}$ where N_{Rx} is the number of active receiving antennas. In particular, we must always have $N_{SS} \le N_{Tx}$ in the transmit datapath. This transformation is generically represented by the matrix **Q**. In general, there may be a different $N_{Tx} \times N_{SS}$ transformation for each subcarrier. There are three standard types Q-transformations, which are described in the subsections below.

After the antenna map, antenna streams are transformed to the time domain via the IFFT. The cyclically extended GI (guard interval) is added. Finally, time domain windowing (not shown) is applied to create a continuous time-domain signal, and analog and RF processing yields the signals that are applied to transmit antennas.

Table 14 summarizes the OFDM parameters for 20 and 40 MHz channels in comparison to the legacy 802.11 a/g formats.

	802.11a/g (20 MHz)	20 MHz Channel (Mandatory)	40 MHz Channel (Optional)
FFT size	64	64	128
Number of data subcarriers	48	52	108
Number of pilot subcarriers	4	4	6

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Subcarrier separation	312.5 kHz	312.5 kHz	312.5 kHz
Approx. Bandwidth	16.25 MHz	17.5 MHz	36.6 MHz

Table 18: Summary of OFDM parameters

11.1.1.2.1 Direct Map MIMO Overview

Direct map MIMO is the simplest antenna mapping transformation. The Q-matrix is simply the identity mapping, i.e. each spatial stream maps to one antenna. Hence, there is a one-to-one correspondence between spatial streams and transmit antennas. Figure 22 illustrates the simplified datapath for direct map MIMO.

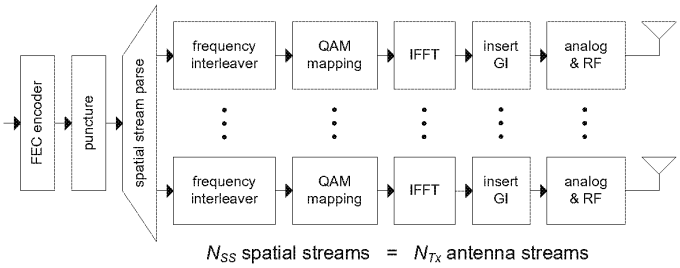


Figure 22: Direct Map MIMO.

11.1.1.2.2 Spatial Spreading

Direct map MIMO only utilizes as many antennas as there are spatial streams; that is $N_{SS} = N_{Tx}$. Spatial spreading is one way to map spatial streams when the number of spatial streams is less than the number of transmitting antennas; that is $N_{SS} \le N_{Tx}$.

The basic spatial spreading function is achieved using the first N_{SS} columns of a fixed $N_{Tx} \times N_{Tx}$ unitary matrix **W**. The same matrix **W** is used for all subcarriers. Typically one uses the Walsh matrix for $N_{Tx} = 2$ and 4, or the Fourier matrix for $N_{Tx} = 3$. A problem with this basic spatial spreading function is that it can result in undesired beamforming effects. To mitigate this effect, time-domain cyclic delays are applied to OFDM symbols prior to GI insertion. The first antenna is not delayed. Linearly increasing cyclic delays are then applied to the remaining antennas. In addition to mitigating undesired beamforming, the cyclic delays can also yield some performance improvement via transmit diversity. Thus, the method is referred to as Cyclic Delay Diversity (CDD). Since the unitary spatial spreading matrix is typically the Walsh matrix, this method is often called "Walsh+CDD."

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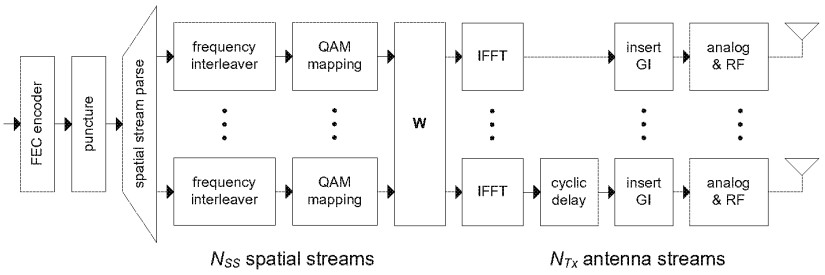


Figure 23: Time domain implementation of spatial spreading cyclic delay.

It is noted that since the **W** matrix is constant across subcarriers, yet another equivalent implementation would be to interchange the **W** matrix and the IFFT blocks.

At first, the spatial spreading method described above may seem to be a deviation to the general structure of Figure 21. However, there is a mathematical equivalence. The time domain cyclic delays are equivalent to a frequency dependent phase shift in the frequency domain. Each antenna has a different phasing due to the different cyclic delays. The result is that spatial spreading with time domain cyclic delays is mathematically equivalent to Figure 21 with **Q** = **ΦW** where **Φ** is a frequency dependent diagonal phasing matrix.

11.1.1.2.3 Transmit Beamforming

In this case, the Q-transformation is designed specifically to pre-emphasize the dominant modes of transmission of the random MIMO channel. The optimal beamforming transformation is created from the right singular vectors of the SVD (singular value decomposition) of the observed channel. Our proposal provides full capability to implement SVD beamforming, as well as other types of beamforming such as constant amplitude phasing or constant beamforming matrices across all subcarriers. In these cases, the optimized beamforming matrix is the Q-transformation.

11.1.1.3 PPDU Format for Basic MIMO Transmission

The generic PPDU format is shown in Figure 24:



Figure 24: PPDU Format

The L-STF (Legacy Short Training Field), the L-LTF (Legacy Long Training Field), L-SIG (Legacy Signal Field) and HT-SIG (High Throughput Signal Field) comprise the legacy compatible part of the PPDU preamble. HT-STF, the HT-STFs and HT-Data symbols comprise the HT-Part of the PPDU.

In the 40MHz bandwidth, there are two 20MHz wide sub-channels. The upper sub-channel spans from 0 to +63, and the lower sub-channel spans from -64 to -1, as shown in Figure 25. A

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40MHz-HT device receiving a 20MHz-only transmission shall indicate to the MAC which sub-channel is currently active.

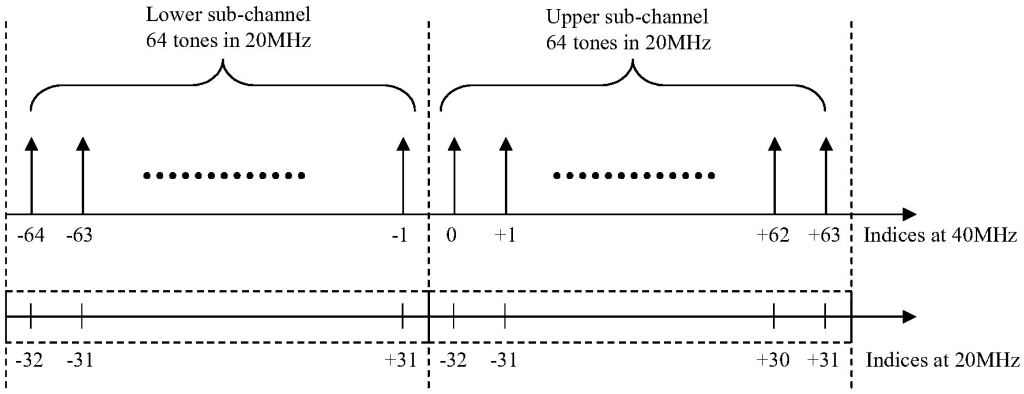


Figure 25: Upper and Lower sub-channel specification in 40MHz

The PPDU format from two transmit antennas, each 40MHz wide, is shown in Figure 26.

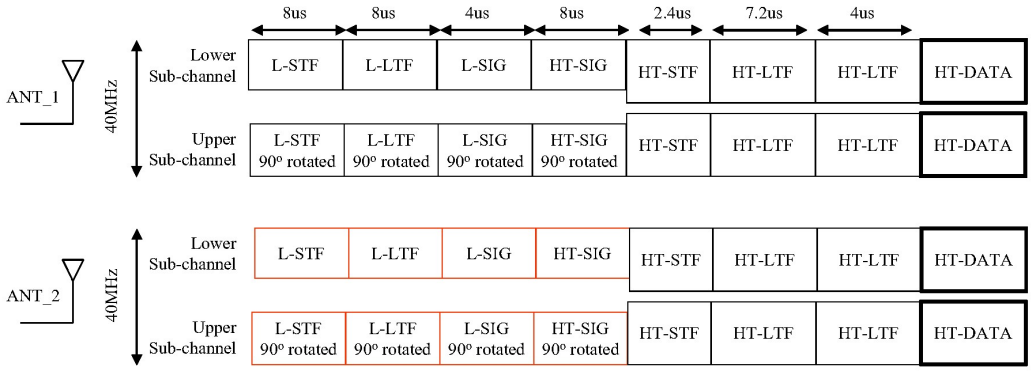


Figure 26: PPDU Format for 2x40 Basic MIMO Transmission[7]

The legacy part of the HT preamble (i.e. L-STF to L-SIG) and HT-SIG may either be transmitted from one antenna or both antennas. If transmitted from both antennas, the mapping of this single spatial stream to two antennas has to be such that beamforming in the far-field is mitigated. One method for achieving this is to use a cyclical delay diversity (CDD) mapping, as mentioned in 11.1.1.2.2. The optional part of the PPDU, corresponding to the CDD format, is shown in red color in Figure 26.

11.1.1.4 HT PCLP Preamble for Synchronization and Legacy Interoperability

The functions performed by the preamble include:

1. Start-of-Packet (SoP) detection
2. AGC
3. Coarse Frequency Offset Estimation

[7] 40MHz operation by an HT device shall only be permitted in those regulatory domain that allow it.

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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 27:

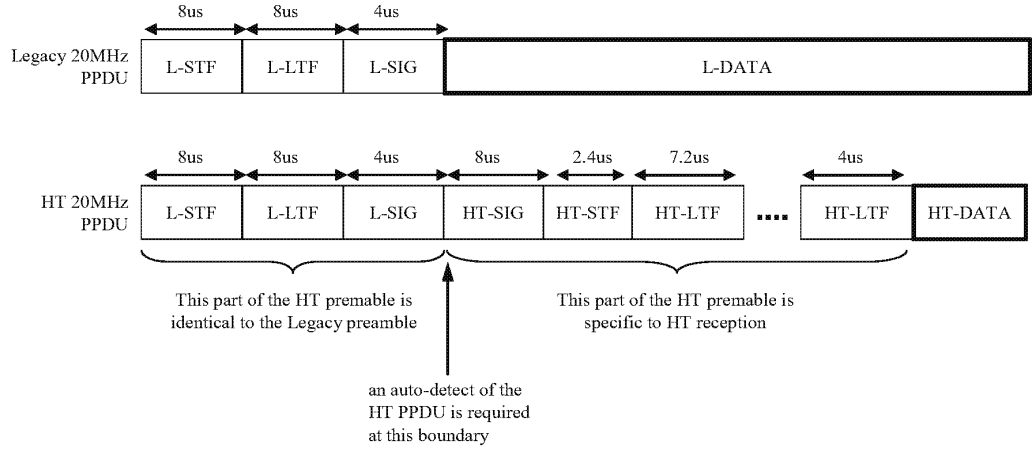


Figure 27: HT Preamble format

Concatenation of the legacy preamble allows PHY layer interoperability with 802.11a and ERP-802.11g modems.

A HT receiver does not know *a priori* whether it is receiving a legacy PPDU or a HT PPDU. Hence, a HT receiver has to perform an auto-detect after the legacy signal field (L-SIG) as to whether a HT-SIG is being received or legacy data (L-DATA). Our preamble format includes two provisions for auto-detecting the HT-SIG: (a) transmitting the HT-SIG as a BPSK signal on the quadrature axis instead of the in-phase axis, and (b) inverting the pilot polarity in going from the L-SIG to the HT-SIG.

The legacy part of the HT preamble allows a legacy receiver to properly decode the L-SIG. A HT receiver shall also perform functions 1 through 7 (SoP to Channel Estimation) to successfully decode the HT-SIG. It is anticipated that functions 1 through 4 (and perhaps function 5) are performed by the legacy short training field (L-STF), and functions 5 through 7 are performed by the legacy long training field (L-LTF).

Since a HT device (in our proposal) shall support multiple transmit antennas, the legacy part of the preamble can either be transmitted from one antenna or from multiple antennas. If more than one antenna is used for transmission, it is recommended that the signal be shifted in a cyclical fashion across the transmit antenna array. This technique introduces cyclical delay diversity (CDD), and it tends to reduce the "effective" length of the guard interval, as seen by a legacy device. Hence, the total shift across the transmit antenna array should be limited to 50ns.

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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 25 and Figure 26)

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 in 20MHz (L-STF uses 12 tones in a 20 MHz channel). The choice of 24 tones permits accurate AGC measurements across 4 transmit antennas. In the 40 MHz channel, 48 tones are used in the HT-STF. The 24 (48) tones are interleaved across the antennas, i.e., 6 (12) tones are used per antenna if there are 4 transmitter antennas, and likewise 12 (24) are used per antenna if there are 2 transmitter antennas. The length of the HT-STS is 1.6μs. Since, the purpose of HT-STF is purely for AGC purposes, only one STS is needed. Together with the 0.8μs guard interval, the total length of the HT-STF is 2.4μs. The GI of the HT-STF, i.e. the first 0.8us, would contain echoes from the previous symbol. Hence, a clean measurement of power is made in the 1.6us portion of the HT-STF. It is anticipated that the RF transient settling after the AGC switch would occur in the GI of the HT-LTF that follows the HT-STF.

After the AGC has been "fine-tuned" for HT reception, channel estimation and fine frequency offset estimation are performed using the HT Long Training Symbols. In the basic MIMO modes, as in beamforming mode, the number of HT-LTFs sent must be at least equal to the number of streams sent, and at most equal to the number of transmit antennas. For example, when one spatial stream is transmitted using two transmit antennas, at least one HT-LTF must be sent, and under some conditions two HT-LTFs may be sent. However, if two spatial streams are sent using two transmit antennas, two HT-LTFs must be sent.

When the number of HT-LTFs that are sent is greater than the number of data streams, the resulting set of HT-LTFs is referred to as a segmented HT-LTF, and the additional HT-LTFs are referred to as extension HT-LTFs. In this case the tone interleaving is arranged so that the first N_{SS} HT-LTFs sound the MIMO channel used by the N_{SS} data streams, and the extension HT-LTFs sound the remaining dimensions of the MIMO channel. This is covered in more detail in 11.2.1.6.4.

The HT-LTF is also tone interleaved to minimize the power fluctuation with respect to the AGC setting (obtained via the HT-STF). Therefore, one HT-LTF would cover half of the tones in the two antenna case. Remaining tones are covered in the second HT-LTF. The first HT-LTF consists of two Long Training Symbols (LTS) as in 802.11a/g and a regular guard interval of 0.8 μs, giving a total length of 7.2μs. When present, the second, third and fourth HT-LTFs each consist of a single HT-LTS with a regular guard interval of 0.8 μs, giving a total length of 4μs.

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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 28.

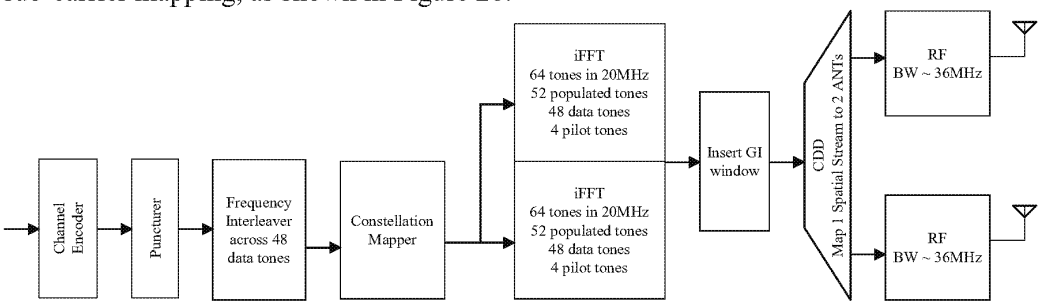


Figure 28: Transmitter configuration for 6Mbps in 40MHz[8]

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 26. The PPDU format for the 6Mbps duplicate mode is shown in Figure 29:

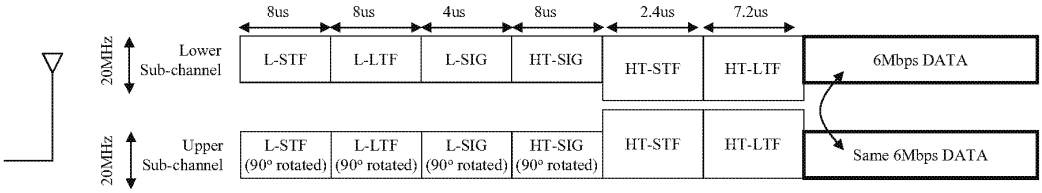


Figure 29: PPDU format for 6Mbps duplicate mode

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 21).

11.1.1.6 Feedback Mechanisms

Our proposal consists of several feedback mechanisms, supported at the MAC layer, as shown in Table 19.

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

[8] 40MHz operation by an HT device shall only be permitted in those regulatory domain that allow it.

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Implicit Feedback	Optional	Binary Response packet sent as a sounding packet	• Allows the Initiator to estimate the physical channel in the reverse link. If reciprocity can be assumed, and if the number of TX and RX antennas are identical at the recipient, the TX can use the derived CSI to perform spatial shaping (e.g. in the style of BF-MIMO)
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 19: Feedback Mechanisms

11.1.1.7 Comparison among MIMO transmission modes

Our proposal supports three classes of MIMO Transmissions Modes, as outlined in Table 20:

MIMO Modes	Characteristic	Extent of TX adaptation
Basic MIMO (mandatory)	• Antenna mapping: direct map or spatial spreading	• No adaptation is performed in the spatial domain • MCS selection (adaptation) is based upon either: (1) binary feedback (i.e. ACK/noACK), or (2) recommendation from the RX, or (3) availability of CSI at the TX
TX Beamforming (Optional)	• All spatial streams are spatially shaped via a beamforming matrix that may be different for each subcarrier. • The basic MCS set and extended MCS set is used, which would support different data rates across spatial streams.	• 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 at treansmitter side is required since reciprocity is used to perform TX beamforming • It is not mandated at devices which don't support Tx BF that they should be involved in calibration sequence.

Table 20: MIMO Transmission options

11.1.1.8 "Modulation-Coding Scheme" (MCS) Sets

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Our proposal augments the 802.11a MCS set through the use of multiple spatial streams and bandwidth extension. A basic MCS set and an extended MCS set are defined. The complete set is shown in Table 21. Our proposal recommends a mandatory data rate of 130 Mbps using two spatial streams in 20MHz channelizations. And, with an eye towards the future, our proposal supports scalability to 4 spatial streams, offering data rates in excess of 600Mbps.

11.1.1.8.1 Basic MCS Set

The basic MCS set is shown in Table 21. It consists of 8 modulation/code rate combinations supporting 1, 2, 3, and 4 spatial streams, plus a 6 Mbps duplicate mode for 40 MHz operation. Support of MCS 0 through MCS 15 (the basic MCSs supporting single-stream and two-stream operation) is mandatory. Support of MCS 16 through MCS 32 is optional.

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	6.50	13.50	7.22	15.00
1	1	QPSK	1/2	13.00	27.00	14.44	30.00
2	1	QPSK	3/4	19.50	40.50	21.67	45.00
3	1	16-QAM	1/2	26.00	54.00	28.89	60.00
4	1	16-QAM	3/4	39.00	81.00	43.33	90.00
5	1	64-QAM	2/3	52.00	108.00	57.78	120.00
6	1	64-QAM	3/4	58.50	121.50	65.00	135.00
7	1	64-QAM	5/6	65.00	135.00	72.22	150.00
8	2	BPSK	1/2	13.00	27.00	14.44	30.00
9	2	QPSK	1/2	26.00	54.00	28.89	60.00
10	2	QPSK	3/4	39.00	81.00	43.33	90.00
11	2	16-QAM	1/2	52.00	108.00	57.78	120.00
12	2	16-QAM	3/4	78.00	162.00	86.67	180.00
13	2	64-QAM	2/3	104.00	216.00	115.56	240.00
14	2	64-QAM	3/4	117.00	243.00	130.00	270.00
15	2	64-QAM	5/6	130.00	270.00	144.44	300.00
16	3	BPSK	1/2	19.50	40.50	21.67	45.00
17	3	QPSK	1/2	39.00	81.00	43.33	90.00
18	3	QPSK	3/4	58.50	121.50	65.00	135.00

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19	3	16-QAM	1/2	78.00	162.00	86.67	180.00
20	3	16-QAM	3/4	117.00	243.00	130.00	270.00
21	3	64-QAM	2/3	156.00	324.00	173.33	360.00
22	3	64-QAM	3/4	175.50	364.50	195.00	405.00
23	3	64-QAM	5/6	195.00	405.00	216.67	450.00
24	4	BPSK	1/2	26.00	54.00	28.89	60.00
25	4	QPSK	1/2	52.00	108.00	57.78	120.00
26	4	QPSK	3/4	78.00	162.00	86.67	180.00
27	4	16-QAM	1/2	104.00	216.00	115.56	240.00
28	4	16-QAM	3/4	156.00	324.00	173.33	360.00
29	4	64-QAM	2/3	208.00	432.00	231.11	480.00
30	4	64-QAM	3/4	234.00	486.00	260.00	540.00
31	4	64-QAM	5/6	260.00	540.00	288.89	600.00
32	1	BPSK	1/2		6.00		6.67

Table 21: MCS field content for the basic mode

11.1.1.8.2 Extended MCS Set (optional)

In order to match per stream code rates and modulations as closely as possible to channel conditions on each spatial stream in BF MIMO, it is necessary to include an extended MCS set that has MCSs with different rates and/or modulations on each stream. The extended MCS set may also be useful for basic MIMO. In order to simplify the coding and spatial parsing necessary to support this operation, each MCS in the extended MCS set uses a single code rate across all streams, and varies the modulation used per stream. The extended MCS set is shown in Table 22.

The extended MCS set is optional.

Table 22: Extended MCS set

MCS Index	Code Rate	Stream Modulations				20 MHz Rates		40 MHz Rates	
		M0	M1	M2	M3	Full GI	Half GI	Full GI	Half GI
33	3/4	256-QAM	OFF	OFF	OFF	78.00	86.67	162.00	180.00
34	1/2	16-QAM	QPSK	OFF	OFF	52.00	57.78	108.00	120.00
35	1/2	64-QAM	QPSK	OFF	OFF	52.00	57.78	108.00	120.00
36	1/2	64-QAM	16-QAM	OFF	OFF	65.00	72.22	135.00	150.00
37	3/4	16-QAM	QPSK	OFF	OFF	58.50	65.00	121.50	135.00

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MCS Index	Code Rate	Stream Modulations				20 MHz Rates		40 MHz Rates	
		M0	M1	M2	M3	Full GI	Half GI	Full GI	Half GI
38	3/4	64-QAM	QPSK	**OFF**	**OFF**	78.00	86.67	162.00	180.00
39	3/4	64-QAM	16-QAM	**OFF**	**OFF**	97.50	108.33	202.50	225.00
40	3/4	256-QAM	QPSK	**OFF**	**OFF**	97.50	108.33	202.50	225.00
41	3/4	256-QAM	16-QAM	**OFF**	**OFF**	117.00	130.00	243.00	270.00
42	3/4	256-QAM	64-QAM	**OFF**	**OFF**	136.50	151.67	283.50	315.00
43	3/4	256-QAM	256-QAM	**OFF**	**OFF**	156.00	173.33	324.00	360.00
44	1/2	16-QAM	QPSK	QPSK	**OFF**	52.00	57.78	108.00	120.00
45	1/2	16-QAM	16-QAM	QPSK	**OFF**	65.00	72.22	135.00	150.00
46	1/2	64-QAM	QPSK	QPSK	**OFF**	65.00	72.22	135.00	150.00
47	1/2	64-QAM	16-QAM	QPSK	**OFF**	78.00	86.67	162.00	180.00
48	1/2	64-QAM	16-QAM	16-QAM	**OFF**	91.00	101.11	189.00	210.00
49	1/2	64-QAM	64-QAM	QPSK	**OFF**	91.00	101.11	189.00	210.00
50	1/2	64-QAM	64-QAM	16-QAM	**OFF**	104.00	115.56	216.00	240.00
51	1/2	256-QAM	QPSK	QPSK	**OFF**	78.00	86.67	162.00	180.00
52	1/2	256-QAM	16-QAM	QPSK	**OFF**	91.00	101.11	189.00	210.00
53	1/2	256-QAM	16-QAM	16-QAM	**OFF**	104.00	115.56	216.00	240.00
54	1/2	256-QAM	64-QAM	QPSK	**OFF**	104.00	115.56	216.00	240.00
55	3/4	16-QAM	QPSK	QPSK	**OFF**	78.00	86.67	162.00	180.00
56	3/4	16-QAM	16-QAM	QPSK	**OFF**	97.50	108.33	202.50	225.00
57	3/4	64-QAM	QPSK	QPSK	**OFF**	97.50	108.33	202.50	225.00
58	3/4	64-QAM	16-QAM	QPSK	**OFF**	117.00	130.00	243.00	270.00
59	3/4	64-QAM	16-QAM	16-QAM	**OFF**	136.50	151.67	283.50	315.00
60	3/4	64-QAM	64-QAM	QPSK	**OFF**	136.50	151.67	283.50	315.00
61	3/4	64-QAM	64-QAM	16-QAM	**OFF**	156.00	173.33	324.00	360.00
62	3/4	256-QAM	QPSK	QPSK	**OFF**	117.00	130.00	243.00	270.00
63	3/4	256-QAM	16-QAM	QPSK	**OFF**	136.50	151.67	283.50	315.00
64	3/4	256-QAM	16-QAM	16-QAM	**OFF**	156.00	173.33	324.00	360.00
65	3/4	256-QAM	64-QAM	QPSK	**OFF**	156.00	173.33	324.00	360.00
66	3/4	256-QAM	64-QAM	16-QAM	**OFF**	175.50	195.00	364.50	405.00
67	3/4	256-QAM	64-QAM	64-QAM	**OFF**	195.00	216.67	405.00	450.00
68	3/4	256-QAM	256-QAM	QPSK	**OFF**	175.50	195.00	364.50	405.00
69	3/4	256-QAM	256-QAM	16-QAM	**OFF**	195.00	216.67	405.00	450.00
70	3/4	256-QAM	256-QAM	64-QAM	**OFF**	214.50	238.33	445.50	495.00
71	3/4	256-QAM	256-QAM	256-QAM	**OFF**	234.00	260.00	486.00	540.00
72	1/2	16-QAM	QPSK	QPSK	QPSK	65.00	72.22	135.00	150.00
73	1/2	16-QAM	16-QAM	QPSK	QPSK	78.00	86.67	162.00	180.00
74	1/2	16-QAM	16-QAM	16-QAM	QPSK	91.00	101.11	189.00	210.00
75	1/2	64-QAM	QPSK	QPSK	QPSK	78.00	86.67	162.00	180.00
76	1/2	64-QAM	16-QAM	QPSK	QPSK	91.00	101.11	189.00	210.00
77	1/2	64-QAM	16-QAM	16-QAM	QPSK	104.00	115.56	216.00	240.00
78	1/2	64-QAM	16-QAM	16-QAM	16-QAM	117.00	130.00	243.00	270.00
79	1/2	64-QAM	64-QAM	QPSK	QPSK	104.00	115.56	216.00	240.00
80	1/2	64-QAM	64-QAM	16-QAM	QPSK	117.00	130.00	243.00	270.00

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MCS Index	Code Rate	Stream Modulations				20 MHz Rates		40 MHz Rates	
		M0	M1	M2	M3	Full GI	Half GI	Full GI	Half GI
81	1/2	64-QAM	64-QAM	16-QAM	16-QAM	130.00	144.44	270.00	300.00
82	1/2	64-QAM	64-QAM	64-QAM	QPSK	130.00	144.44	270.00	300.00
83	1/2	64-QAM	64-QAM	64-QAM	16-QAM	143.00	158.89	297.00	330.00
84	1/2	256-QAM	QPSK	QPSK	QPSK	91.00	101.11	189.00	210.00
85	1/2	256-QAM	16-QAM	QPSK	QPSK	104.00	115.56	216.00	240.00
86	1/2	256-QAM	16-QAM	16-QAM	QPSK	117.00	130.00	243.00	270.00
87	1/2	256-QAM	16-QAM	16-QAM	16-QAM	130.00	144.44	270.00	300.00
88	1/2	256-QAM	64-QAM	QPSK	QPSK	117.00	130.00	243.00	270.00
89	1/2	256-QAM	64-QAM	16-QAM	QPSK	130.00	144.44	270.00	300.00
90	1/2	256-QAM	64-QAM	16-QAM	16-QAM	143.00	158.89	297.00	330.00
91	1/2	256-QAM	64-QAM	64-QAM	QPSK	143.00	158.89	297.00	330.00
92	1/2	256-QAM	256-QAM	16-QAM	QPSK	143.00	158.89	297.00	330.00
93	1/2	256-QAM	256-QAM	64-QAM	QPSK	156.00	173.33	324.00	360.00
94	1/2	256-QAM	256-QAM	256-QAM	QPSK	169.00	187.78	351.00	390.00
95	3/4	16-QAM	QPSK	QPSK	QPSK	97.50	108.33	202.50	225.00
96	3/4	16-QAM	16-QAM	QPSK	QPSK	117.00	130.00	243.00	270.00
97	3/4	16-QAM	16-QAM	16-QAM	QPSK	136.50	151.67	283.50	315.00
98	3/4	64-QAM	QPSK	QPSK	QPSK	117.00	130.00	243.00	270.00
99	3/4	64-QAM	16-QAM	QPSK	QPSK	136.50	151.67	283.50	315.00
100	3/4	64-QAM	16-QAM	16-QAM	QPSK	156.00	173.33	324.00	360.00
101	3/4	64-QAM	16-QAM	16-QAM	16-QAM	175.50	195.00	364.50	405.00
102	3/4	64-QAM	64-QAM	QPSK	QPSK	156.00	173.33	324.00	360.00
103	3/4	64-QAM	64-QAM	16-QAM	QPSK	175.50	195.00	364.50	405.00
104	3/4	64-QAM	64-QAM	16-QAM	16-QAM	195.00	216.67	405.00	450.00
105	3/4	64-QAM	64-QAM	64-QAM	QPSK	195.00	216.67	405.00	450.00
106	3/4	64-QAM	64-QAM	64-QAM	16-QAM	214.50	238.33	445.50	495.00
107	3/4	256-QAM	QPSK	QPSK	QPSK	136.50	151.67	283.50	315.00
108	3/4	256-QAM	16-QAM	QPSK	QPSK	156.00	173.33	324.00	360.00
109	3/4	256-QAM	16-QAM	16-QAM	QPSK	175.50	195.00	364.50	405.00
110	3/4	256-QAM	16-QAM	16-QAM	16-QAM	195.00	216.67	405.00	450.00
111	3/4	256-QAM	64-QAM	QPSK	QPSK	175.50	195.00	364.50	405.00
112	3/4	256-QAM	64-QAM	16-QAM	QPSK	195.00	216.67	405.00	450.00
113	3/4	256-QAM	64-QAM	16-QAM	16-QAM	214.50	238.33	445.50	495.00
114	3/4	256-QAM	64-QAM	64-QAM	QPSK	214.50	238.33	445.50	495.00
115	3/4	256-QAM	64-QAM	64-QAM	16-QAM	234.00	260.00	486.00	540.00
116	3/4	256-QAM	64-QAM	64-QAM	64-QAM	253.50	281.67	526.50	585.00
117	3/4	256-QAM	256-QAM	QPSK	QPSK	195.00	216.67	405.00	450.00
118	3/4	256-QAM	256-QAM	16-QAM	QPSK	214.50	238.33	445.50	495.00
119	3/4	256-QAM	256-QAM	16-QAM	16-QAM	234.00	260.00	486.00	540.00
120	3/4	256-QAM	256-QAM	64-QAM	QPSK	234.00	260.00	486.00	540.00
121	3/4	256-QAM	256-QAM	64-QAM	16-QAM	253.50	281.67	526.50	585.00
122	3/4	256-QAM	256-QAM	64-QAM	64-QAM	273.00	303.33	567.00	630.00
123	3/4	256-QAM	256-QAM	256-QAM	QPSK	253.50	281.67	526.50	585.00
124	3/4	256-QAM	256-QAM	256-QAM	16-QAM	273.00	303.33	567.00	630.00
125	3/4	256-QAM	256-QAM	256-QAM	64-QAM	292.50	325.00	607.50	675.00

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MCS Index	Code Rate	Stream Modulations				20 MHz Rates		40 MHz Rates	
		M0	M1	M2	M3	Full GI	Half GI	Full GI	Half GI
126	3/4	256-QAM	256-QAM	256-QAM	256-QAM	312.00	346.67	648.00	720.00

11.2 PLCP Sublayer

11.2.1 Basic MIMO Mode

As described in Table 20, 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 30 shows the PPDU format for the basic MIMO mode:

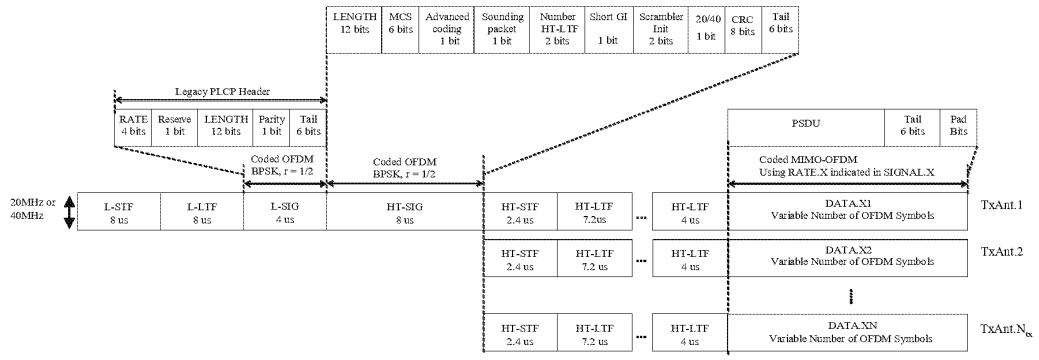


Figure 30: PPDU Format for N_{TX} antennas

L-STF is the Legacy Short Training Field. Details of the L-STF symbols can be found in clause 11.2.1.6.1. The HT-STF is specific for HT. Details can be found in 11.2.1.6.3

L-LTF stands for Legacy Long Training Field. Details of the L-LTF symbols can be found in clause 11.2.1.6.2. The HT-LTFs are specific for HT and the details can be found in clause 11.2.1.6.4

L-SIG is based on the Legacy SIGNAL field as defined in clause 17.3.4 in [1]. The modulation and coding procedure also follows the steps of 17.3.4 in [1]. The RATE and LENGTH fields in L-SIG are defined in accordance with "spoofing" procedures described in 11.2.1.7.1.

The HT-SIG field is the signal field dedicated to the HT mode. The structure of this field is the same as the L-SIG. Since our proposal supports interoperability between HT devices and legacy OFDM devices at the PHY layer, a HT receiver will not know *a priori* whether a legacy packet or an HT packet is being received. That determination can only be made after the L-SIG. Our proposal supports two mechanisms for signaling a HT transmission: (a) send the HT-SIG as a BPSK signal on the quadrature axis, instead of on the in-phase axis, and (b) invert the polarity of

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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 11.2.1.7.2.

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 31:

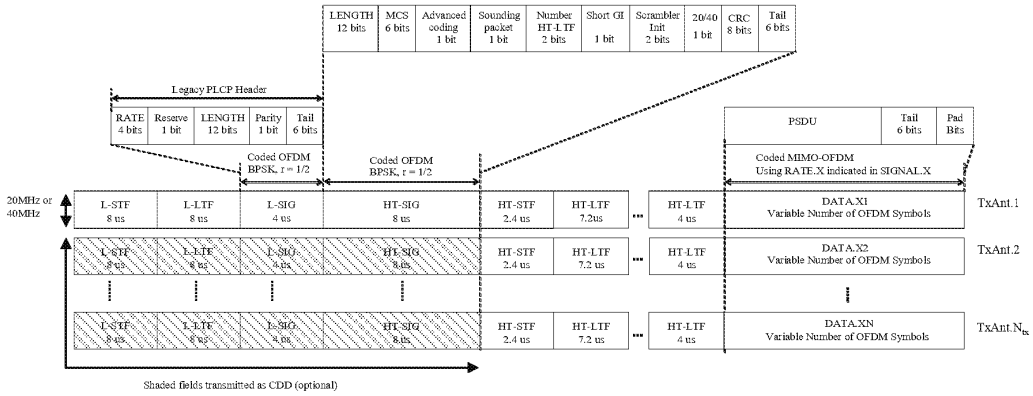


Figure 31: PPDU format leveraging CDD transmission

11.2.1.2 Antenna Map Transformations

The antenna map transformation maps spatial streams to antenna streams. This section provides some mathematical notation for the antenna map transformations first described in the overview of Section 11.1.1.2.

Let $\mathbf{Q}^{(k)}$ denote the $N_{Tx} \times N_{SS}$ matrix that defines the antenna map for subcarrier k. We shall use the notation $\mathbf{q}_j^{(k)}$ to denote the jth column of $\mathbf{Q}^{(k)}$, and $q_{i,j}^{(k)}$ to denote the i,j^{th} element of $\mathbf{Q}^{(k)}$. When convenient and when it is clear in context we shall often drop the subcarrier index superscript.

For an $N \times N$ matrix $\mathbf{A}$, the notation $[\mathbf{A}]_M$ shall denote the $N \times M$ matrix consisting of the first M columns of $\mathbf{A}$.

Steering matrices are orthonormal matrices. This means that the columns $\mathbf{q}_0 \cdots \mathbf{q}_{N_{SS}-1}$ have Euclidean norm 1 and are orthogonal to each other. Mathematically, the orthonormal property is

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equivalent to $\mathbf{Q}^H\mathbf{Q} = \mathbf{I}_{N_{SS}\times N_{SS}}$. In the case $N_{Tx} = N_{SS}$ an orthonormal matrix is said to be unitary, in which case we also have $\mathbf{Q}\mathbf{Q}^H = \mathbf{I}_{N_{Tx}\times N_{Tx}}$.

It is noted that non-singular MIMO transmission requires $N_{SS} \le \min\{N_{Tx}, N_{Rx}\}$ where N_{Rx} is the number of receive antennas.

We refer three generic types of steering transformations: direct map, spatial spreading and beamforming.

The PPDU has two parts. The legacy compatible part includes the L-STF, L-LTS, L-SIG and HT-SIG. The HT part includes the HT-STF, the HT-LTFs and the HT-Data. The antenna mapping for these two parts may be different. For example, the legacy compatible part may be direct map MIMO, while the HT part may employ spatial spreading or Tx beamforming. Indeed, both parts may employ spatial spreading, but with different cyclic delays.

To distinguish between different antenna map transformations, the notation $\mathbf{Q}^{(k)}$ shall always denote the antenna map used during the HT part. The legacy compatible part always has only one spatial stream. Thus, we use a column vector $\mathbf{q}^{L(k)}$ to denote the antenna mapping for the legacy compatible part, and $q_{i_{Tx}}^{L(k)}$ is the element that defines the mapping to antenna i_{Tx} (= 0, …, N_{Tx}).

11.2.1.2.1 Direct Map MIMO

The direct map case is simply $\mathbf{Q}^{(k)} = \left[\mathbf{I}_{N_{Tx}\times N_{Tx}}\right]_{N_{SS}}$; that is, we use that first N_{SS} columns of the $N_{Tx} \times N_{Tx}$ identity matrix. Notice that for $N_{SS} < N_{Tx}$, the bottom $N_{Tx} - N_{SS}$ rows of $\mathbf{Q}^{(k)}$ are all zero, which means that $N_{Tx} - N_{SS}$ transmit chains are not active.

For the legacy compatible part, the direct map antenna map vector is just $\mathbf{q}^{L(k)} = \left[1\,0\cdots 0\right]^T$, which simply means the entire legacy compatible part is transmitted on the first antenna.

11.2.1.2.2 Spatial Spreading

Direct map MIMO can reduce the number of spatial steams only by turning off transmit antennas. For power efficiency it is often desired to operate all PAs, hence we describe here the spatial spreading technique to achieve this.

The frequency domain representation of the spatial spreading antenna map is

$$\mathbf{Q}^{(k)} = \mathbf{\Phi}^{(k)}\left[\mathbf{W}_{N_{Tx}\times N_{Tx}}\right]_{N_{SS}} \quad (1)$$

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The matrix $\mathbf{\Phi}^{(k)}$ is an $N_{Tx} \times N_{Tx}$ diagonal unitary matrix that captures the frequency domain equivalent of cyclic delays in the time domain. Let D denote the per antenna cyclic delay. The delay applied to antenna i_{Tx} is $(i_{Tx} - 1)D$. Then

$$\mathbf{\Phi}^{(k)} = \text{diag}\left(1, \exp(-j2\pi k\Delta_F D), \ldots, \exp(-j2\pi k(N_{Tx}-1)\Delta_F D)\right). \quad (2)$$

The matrix $\mathbf{W}_{N_{Tx}\times N_{Tx}}$ is the unitary spreading matrix. For $N_{Tx} = 2$ or 4 these are Walsh-Hadamard matrices:

$$\mathbf{W}_{2\times 2} = \frac{1}{\sqrt{2}}\begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix} \text{ and } \mathbf{W}_{4\times 4} = \frac{1}{2}\begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{bmatrix}. \quad (3)$$

For $N_{Tx} = 3$ we use the Fourier matrix

$$\mathbf{W}_{3\times 3} = \frac{1}{\sqrt{3}}\begin{bmatrix} +1 & +1 & +1 \\ +1 & e^{j2\pi/3} & e^{-j2\pi/3} \\ +1 & e^{-j2\pi/3} & e^{j2\pi/3} \end{bmatrix}. \quad (4)$$

The unitary matrices in (3) and (4) are presented as typical solutions for construction of spatial spreading antenna map. In theory, any unitary matrix is sufficient. However, a significant advantage of these matrices is that each element has the constant complex modulous (= $1/\sqrt{N_{Tx}}$). This significance of this property is that each spatial stream maps equal energy to each antenna. Thus equal power is delivered to each antenna.

For the legacy compatible part, the spatial spreading antenna map vector is

$$\mathbf{q}^{L(k)} = \Phi^{(k)}(D)\,\frac{1}{\sqrt{N_{Tx}}}\begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix} = \frac{1}{\sqrt{N_{Tx}}}\begin{bmatrix} 1 \\ \vdots \\ \exp(-j2\pi k(N_{Tx}-1)\Delta_F D) \end{bmatrix}. \quad (5)$$

This corresponds to a cyclic delay of $i_{Tx}D$ applied to antennas $i_{Tx} = 0, \ldots, N_{Tx} - 1$.

11.2.1.2.3 Transmit Beamforming

Transmit beamforming is a technique that attempts to adjust the antenna map transformation to maximize the received energy at the receiver of each transmitted spatial stream. There are many ways to calculate beamforming matrices, which is largely left as an implementation option in this proposal. For informative purposes we briefly describe the optimal method based on the singular value decomposition (SVD) of the channel.

Let $\mathbf{H}^{(k)}$, which is an $N_{Rx} \times N_{Tx}$ matrix, denote the equivalent frequency domain channel for subcarrier k. Define $N = \min\{N_{Tx}, N_{Rx}\}$. Then the SVD is

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$$\mathbf{H}^{(k)} = \mathbf{U}^{(k)} \mathbf{\Sigma}^{(k)} \mathbf{V}^{(k)H} \quad (6)$$

where $\mathbf{\Sigma}^{(k)} = \mathrm{diag}\left(\sigma_0, \ldots, \sigma_{N-1}\right)$ is a diagonal matrix of "singular values," $\mathbf{U}^{(k)}$ is an $N_{Rx} \times N$ orthonormal matrix, and $\mathbf{V}^{(k)}$ is an $N_{Tx} \times N$ orthonormal matrix. (Thus, $\mathbf{U}^{(k)}$ is unitary if $N_{Rx} = N$, and likewise $\mathbf{V}^{(k)}$ is unitary if $N_{Tx} = N$.) The singular values are non-negative real numbers. We may always assume (by permutation of columns of $\mathbf{U}^{(k)}$ and $\mathbf{V}^{(k)}$) that $\sigma_0 \geq \sigma_1 \geq \ldots \geq \sigma_{N-1}$. Given this ordering, the optimal beamforming transformation for $N_{SS} \leq N$ spatial streams is

$$\mathbf{Q}^{(k)} = \left[\mathbf{V}^{(k)}\right]_{N_{SS}}. \quad (7)$$

11.2.1.3 Legacy Protection

All MIMO transmissions are protected against legacy OFDM devices at the physical layer, and protected against legacy CCK/DSSS devices at the MAC layer.
The legacy short training field, the legacy long training field and the legacy signal field are transmitted such that a legacy OFDM receiver (802.11g or 802.11a) is able to "understand" these fields. In the basic MIMO mode, the transmitter selects the Modulation Coding Scheme either based on conventional rate selection heuristics or via implicit or explicit feedback. Thus, the RATE and LENGTH fields in the legacy signal field can be "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.

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11.2.1.4 Timing related parameters

Parameter	Value for 20 MHz Channel	Value for 40 MHz Channel
N_{SD} : Number of data subcarriers	52	108
N_{SP} : Number of pilot subcarriers	4	6
N_{SN} : Number of center null subcarriers	1 (tone = 0)	3 (tones = -1,0,+1)
N_{SR} : Subcarrier range (index range)	28 (-28 … +28)	58 (-58 … +58)
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	0.8 µsec	0.8 µsec
$T_{ShortGI}$: Short GI duration	0.4 µsec	0.4 µsec
T_{GI2} : Legacy LongTraining symbol GI duration	1.6 µsec	1.6 µsec
T_{SYM} : Symbol interval	4 µsec	4 µsec
T_{L-STF} : Legacy STF duration	8 µsec	8 µsec
T_{L-LTF} : Legacy LTF duration	8 µsec	8 µsec
T_{L-SIG} : Legacy Signal Field duration	4 µsec	4 µsec
T_{HT-SIG} : HT Signal Field duration	8 µsec	8 µsec
T_{HT-STF} : HT Short training field duration	2.4µsec	2.4µsec
$T_{HT-LTF1}$: HT Long training field duration	7.2µsec	7.2 µsec
$T_{HT-LTF2}$: HT Long training field duration	4 µsec	4 µsec
T_S : Nyquist sampling interval	50nsec	25nsec

Table 23: Timing Related Parameters

11.2.1.5 Mathematical Representation of Time Domain Signals

The transmitted signals will be described using the complex baseband signal notation. The transmitted signal at RF, $r_{RF}(t)$, is related to the complex baseband signal by the following relationship:

$$r_{RF}(t) = \mathrm{Re}\left\{ r(t)\exp\left(j2\pi f_c t\right)\right\} \quad (8)$$

where

$\mathrm{Re}\{\cdot\}$ represents the real part of a complex variable;

f_c denotes the center frequency of the carrier.

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The transmitted baseband signal consists of several subframes. The timing boundaries for the various subframes are shown in Figure 32.

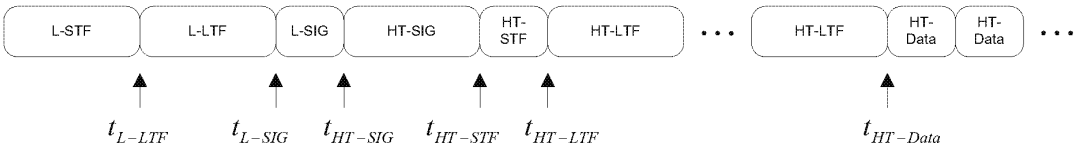


Figure 32: Timing boundaries for PPDU Fields

The signal transmitted on antenna i_{Tx} is

$$\begin{aligned} r_{PPDU}^{(i_{Tx})}(t) &= r_{L-STF}^{(i_{Tx})}(t) + r_{L-LTF}^{(i_{Tx})}\left(t - t_{L-LTF}\right) \\ &+ r_{L-SIG}^{(i_{Tx})}\left(t - t_{L-SIG}\right) \\ &+ r_{HT-SIG}^{(i_{Tx})}\left(t - t_{HT-SIG}\right) \\ &+ r_{HT-STF}^{(i_{Tx})}\left(t - t_{HT-STF}\right) \\ &+ r_{HT-LTF1}^{(i_{Tx})}(t - t_{HT-LTF1}) \\ &+ \sum_{i_{LTF}=1}^{N_{LTF}-1} r_{HT-LTF2}^{(i_{Tx},i_{LTF})}\left(t - t_{HT-STF} - T_{HT-LTF1} - i_{LTF}T_{HT-LTF2}\right) \\ &+ r_{HT\ DATA}^{(i_{Tx})}(t - t_{HT\ DATA}) \end{aligned} \quad (9)$$

where

$$t_{L-LTF} = T_{L-STF}, \quad (10)$$

$$t_{L-SIG} = t_{L-LTF} + T_{L-LTF}, \quad (11)$$

$$t_{HT-SIG} = t_{L-SIG} + T_{L-SIG},$$

$$t_{HT-SIG} = t_{L-SIG} + T_{L-SIG}, \quad (12)$$

$$t_{HT-STF} = t_{HT-SIG} + T_{HT-SIG},$$

$$t_{HT-LTF} = t_{HT-STF} + T_{HT-STF} \quad (13)$$

and

$$t_{HT-Data} = t_{HT-LTF} + T_{HT-LTF1} + (N_{LTF} - 1)T_{HT-LTF2}. \quad (14)$$

The time offsets t_{Field} determines the starting time of the corresponding subframe.

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Each baseband waveform $r_{Field}^{(i_{Tx})}(t)$ is defined via the discrete Fourier transform as

$$r_{Field}^{(i_{Tx})}(t) = \frac{1}{\sqrt{N_{Field}^{Tone}}} w_{Field}(t) \sum_{k} X_k^{(i_{Tx})} \exp\left(j 2\pi k \Delta_F t \right) \quad (15)$$

This general representation holds for all fields, which are L-STF, L-LTF, L-SIG, HT-SIG, HT-STF, HT-LTF and HT-Data. The frequency domain symbols $X_k^{(i_{Tx})}$ define the field, as shall be specified in the following subsections. We adopt the convention that:

$$\sum_{i_{Tx}=0}^{N_{Tx}} E\left[| X_k^{(i_{Tx})} |^2 \right] = 1 \quad (16)$$

With this convention, the $1/\sqrt{N_{Field}^{Tone}}$ scale factor in (15) ensures that the total power of the time domain signal as summed over all transmit antennas is 1. The following table summarizes the various values of N_{Field}^{Tone}.

Table 24: Number of tones for different fields.

Field	N_{Field}^{Tone}	
	20 MHz	40 MHz
L-STF	12	24
L-LTF	52	104
L-SIG	52	104
HT-SIG	52	104
HT-STF	24	48
HT-LTF	56	114
HT-Data	56	114
HT-Data 40 MHz Dup. Format	-	104

The windowing function $w_{Field}(t)$ defines the time duration of the waveform. The windowing roll is not specified, although raised-cosine is typical. This function is illustrated in

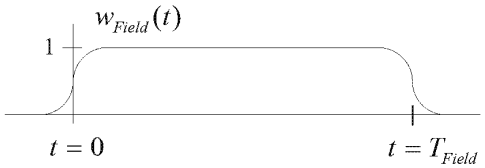


Figure 33: Illustration of time-domain windowing function.

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11.2.1.6 Training symbols specification

The training fields are used for synchronization purposes.

11.2.1.6.1 Legacy Short Training Field

The L-STS is identical to the 802.11a short training symbol. The legacy short training OFDM symbol in the 20MHz mode is the L-STS is

$$S_{-28,28} = \sqrt{1/2}\,\{0,0,1+j,0,0,0,-1-j,0,0,0,1+j,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,\\ 0,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0\} \quad (17)$$

The normalization factor $\sqrt{1/2}$ is the QPSK normalization.

The legacy short training OFDM symbol in 40MHz mode is:

$$S_{-58,58} = \sqrt{1/2}\{0,0,1+j,0,0,0,-1-j,0,0,0,1+j,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,\\ 0,0,0,0,-1-j,0,0,0,-1-j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,1+j,0,0,0,0,0,\\ 0,0,0,0,0,0,0,0,0,0,j-1,0,0,0,-j+1,0,0,0,j-1,0,0,0,-j+1,0,0,0,-j+1,0,0,0,j-1,\\ 0,0,0,0,0,0,0,-j+1,0,0,0,-j+1,0,0,0,j-1,0,0,0,j-1,0,0,0,j-1,0,0,0,j-1,0,0\} \quad (18)$$

The tones in the upper subchannel (see Figure 25) are obtained by phase rotating the 802.11a short OFDM training symbol tones by 90 degrees, whereas the tones in the lower subchannel are identical to the 802.11a short training OFDM symbol tones. The 90° rotation helps keep the PAPR of the STF in 40MHz comparable to that in 20MHz.
The L-STF is

$$r_{L-STF}^{(i_{TX})}(t) = \frac{1}{\sqrt{N_{L-STF}^{Tone}}}\, w_{T_{L-STF}}(t) \sum_{k=-N_{SR}}^{N_{SR}} q_{i_{Tx}}^{L(k)} S_k \exp\left(j2\pi k\Delta_F t \right) \quad (19)$$

where we recall that $\mathbf{q}^{L(k)}$ is the column vector that defines the antenna map for the legacy compatible part. Observe that equation (19) is identical to the general expression (15) with $X_k^{(i_{Tx})} = q_{i_{Tx}}^{L(k)} S_k$.

The L-STS has a period of 0.8 μs. The entire short training field includes ten such periods, with a total duration of $T_{L-STF} = 8$ μs, hence there are 10 L-STSs in the L-STF.

11.2.1.6.2 Legacy Long Training Field

The legacy long training OFDM symbol is identical to the 802.11a long training OFDM symbol. In the 20MHz mode, the long training OFDM symbol is given by

$$L_{-26,26} = \{1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,0,\\ 1,-1,-1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,-1,-1,1,-1,1,-1,1,1,1,1,1\} \quad (20)$$

The legacy long training OFDM signal in the 40MHz mode is given by:

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$$L_{-58,58} = \{1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,1,-1,-1,1,1,-1,1,-1,1,1,1,1,1,0,$$
$$1,-1,-1,1,1,-1,1,-1,1,-1,-1,-1,-1,-1,1,1,-1,-1,1,-1,1,-1,1,1,1,1,1,0,0,0,0,0,0$$
$$0,0,0,0,0,0,0,j,j,-j,-j,j,j,-j,j,-j,j,j,j,j,j,j,-j,-j,j,j,-j,j,-j,j,j,j,j,0,$$
$$j,-j,-j,j,j,-j,j,-j,j,-j,-j,-j,-j,-j,j,j,-j,-j,j,-j,j,-j,j,-j,j,j,j\} \quad (21)$$

Tones in the upper subchannel (subcarriers +6 to +58) are obtained by phase rotating the 802.11a long OFDM training symbol tones by 90 degrees, whereas the tones within the lower subchannel (subcarriers -58 to -6) are identical to the 802.11a long OFDM training symbol tones. It should be noted that neither the legacy fields (L-STF, L-LTF, LSIG) nor the HT-SIG undergo any phase rotation in the lower subchannel. The subcarriers at ±32 in 40MHz, which are the DC subcarriers for the legacy 20MHz transmission, are both nulled in the L-LTF. Such an arrangement allows proper synchronization of the 20MHz legacy device.

The L-LTF waveform is

$$r_{L-LTF}^{(i_{TX})}(t) = \frac{1}{\sqrt{N_{L-LTF}^{Tone}}} w_{T_{L-LTF}}(t) \sum_{k=-N_{SR}}^{N_{SR}} q_{i_{Tx}}^{L(k)} L_k \exp\left(j2\pi k\Delta_F (t - T_{2GI}) \right) \quad (22)$$

where T_{G12} = 1.6 μ sec. Observe that equation (22) is identical to the general expression (15) with $X_k^{(i_{Tx})} = q_{i_{Tx}}^{L(k)} L_k$.

Since T_{L-LTF} = 8.0 μ sec and the symbol duration is T_{FFT} = 3.2 μ sec, we see that the L-LTF consists of a double GI followed by two full symbols.

11.2.1.6.3 HT-Short Training Field

The HT-STF follows the HT-SIG (see Figure 30), whose purpose it to "fine tune" the AGC for HT MIMO reception. Note that the first AGC operation is performed on the L-STF.

The HT-STS for 20MHz is

$$HTS_{-26,26} = \frac{1}{\sqrt{2}} \begin{cases} \{0, 0, 1+j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, \\ 0, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 0\} & N_{Tx} = 1 \\ \{0, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, \\ 0, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, \} & N_{Tx} = 2 \\ \{0, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, \\ 0, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, 0\} & N_{Tx} = 3 \\ \{0, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, \\ 0, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 0\} & N_{Tx} = 4 \end{cases} \quad (23)$$

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The HT-STS for 40 MHz consists of 48 tones, and is given by:

$$HTS_{-58,58} = \frac{1}{\sqrt{2}} \begin{cases} \{0, 0, 1+j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, \\ 0, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 0, 0, 0, 0, 0, 0, \\ 0, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, 1+j, 0, & N_{TX}=1 \\ 0, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 0\} \\ \\ \{0, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, \\ 0, 0, 1+j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, 0, 0, 0, 0, 0, 0, \\ 0, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, 1+j, 0, & N_{TX}=2 \\ 0, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 0\} \\ \\ \{0, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, \\ 0, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, 0, 0, 0, 0, 0, 0, \\ 0, 0, 0, 0, 0, 0, 0, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, 1+j, 0, & N_{TX}=3 \\ 0, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 1+j, 0, -1-j, 0, -1-j, 0, -1-j, 0, 0\} \\ \\ \{0, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, \\ 0, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 0, 0, 0, 0, 0, 0, \\ 0, 0, 0, 0, 0, 0, 0, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, & N_{TX}=4 \\ 0, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 1+j, 0, 1+j, 0, 1+j, 0, 1+j, 0, -1-j, 0, -1-j, 0, 0\} \end{cases} \quad (24)$$

In the duplicate 6Mbps mode in 40MHz, the HT-STF shown in (24) is used, except for a scaling factor change.

The HT-STF signal is then generated by the following rule.

$$r_{HT-LTS}^{(i_{TX})}(t) = \frac{1}{\sqrt{N_{HT-LTF}^{Tone}}} w_{HT-LTF}(t)\sqrt{N_{TX}} \sum_{k} q_{i_{TX},\left(k+N_{HT-STF}^{Tone}-u(k)\right)\%N_{SS}}^{(k)} HTS_k \exp\left(j2\pi k\Delta_F(t-T_{GI})\right) \quad (25)$$

where $T_{GI} = 0.8\mu s$, N_{HT-STF}^{Tone} is the number of active tones (= 24 for 20 MHz and 48 for 40 MHz), and $u(k)$ is the unit step function (= 0 for $k < 0$ and = 1 for $k \geq 0$).

Tone interleaving across spatial streams works as follows. Define $i(k) = k + N_{HT-STF}^{Tone} - u(k)$, which appears in the column subscript of the Q-matrix. HTS_k is non-zero only for even values of the tone index k between $-N_{HT-STF}^{Tone}$ and $+N_{HT-STF}^{Tone}$, excluding $k = 0$. Thus, $i(k)$ runs through the integer values 0, …, $N_{HT-STF}^{Tone} - 1$ as k runs through the even values $-N_{HT-STF}^{Tone}$, …, –2, +2, …, $+N_{HT-STF}^{Tone}$. The index $i(k)$ can be called the "interleaving index" because it is used to select the column of the Q-matrix, which define to spatial streams, that used on tone index k. We select spatial stream $i(k)\%N_{SS}$ for tone k.

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The HT-STF signal has a period of 1.6μs, which is deemed sufficient for power measurement purposes. Since the HT-STF is tone-interleaved at the transmitter, the power periodicity of the HT-STF is also $1.6\mu s$.

11.2.1.6.4 HT-Long Training Field

The HT-LTFs are transmitted after the HT-STF. The number of HT-LTFs is equal to N_{LTF}. For any PPDU, there must be at least as many HT-LTFs as spatial streams in the HT Data portion of the PPDU, i.e. $N_{LTF} = N_{SS}$ (the number of spatial streams). For a sounding PPDU $N_{LTF} \geq N_{SS}$, because these PPDUs provide channel measurement capability for potentially more spatial dimensions than the number of spatial streams. In the case of a sounding packet, the HT-LTFs are partitioned as data HT-LTFs and extension HT-LTFs. The data HT-LTFs are the first N_{SS} fields, which are indexed $i_{LTF} = 0, \ldots, N_{SS} - 1$. The last $N_{LTF} - N_{SS}$ HT-LTFs are the extension fields, which are indexed $i_{LTF} = N_{SS}, \ldots, N_{LTF} - 1$. The result is referred to as a segmented HT-LTF. As always, spatial streams are defined by columns of an orthogonal antenna map matrix $\mathbf{Q}^{(k)}$, with the first N_{SS} columns defining the spatial streams used for data transmission, and the last $N_{LTF} - N_{SS}$ columns defining the extension spatial streams. Thus, for the purpose of defining HT-LTFs, $\mathbf{Q}^{(k)}$ is an $N_{Tx} \times N_{LTF}$ dimension matrix.

The first HT-LTF consists of two Long Training Symbols (LTS) as in 802.11a/g and a regular guard interval of 0.8 μs, giving a total length of 7.2μs. When present, the second and all subsequent HT-LTFs each consist of a single HT-LTS with a regular guard interval of 0.8 μs, giving a total length of 4μs.

To minimize the power fluctuation between the HT-LTF and the AGC setting (which is derived from the HT-STF), the HT-LTS is tone-interleaved across spatial streams, similar to the HT-STF definition. There are a total of 9 sequences. These sequences are defined to minimize PAPR for both direct MAP and spatial spreading, with tone-interleaving.

Table 25: List of HT Long Training Fields

Sequence Number	NTX	BW	Comment
1	1	20MHz	56 tones
2	2	20MHz	56 tones
3	3	20MHz	56 tones
4	4	20MHz	56 tones
5	1	40MHz	Duplicate format, 6Mbps in 40MHz (104 Tones)
6	1	40MHz	114 tones
7	2	40MHz	114 tones
8	3	40MHz	114 tones
9	4	40MHz	114 tones

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In 20MHz, for $N_{TX} = 1$, sequence 1 is:

$$\begin{aligned}\text{HTL}_{-28:28}=[&-1,-1,-1,1,1,1,1,-1,1,-1,-1,-1,-1,1,-1,1,1,1,-1,\ -1,1,1,1,1,-1,1,1,-1,1,0,\\ &-1,-1,-1,1,-1,-1,-1,-1,-1,-1,1,-1,-1,-1,1,-1,1,-1,1,-1,1,-1,-1,1,1,-1,-1,-1]\end{aligned} \quad (26)$$

In 20MHz, for $N_{TX} = 2$, sequence 2 is:

$$\begin{aligned}\text{HTL}_{-28:28}=[&-1,-1,1,1,1,-1,1,1,-1,-1,1,1,1,-1,1,-1,-1,1,1,-1,1,-1,-1,-1,-1,1,-1,1,0,\\ &-1,-1,-1,1,-1,1,-1,-1,1,1,-1,1,-1,-1,1,1,-1,-1,-1,-1,1,1,1,1,1,1,1,1]\end{aligned} \quad (27)$$

In 20MHz, for $N_{TX} = 3$, sequence 3 is:

$$\begin{aligned}\text{HTL}_{-28:28}=[&1,-1,-1,-1,1,1,1,1,-1,1,-1,-1,-1,1,1,1,1,-1,-1,1,1,1,-1,\ -1,1,-1,-1,-1,0,\\ &1,-1,1,1,1,1,-1,1,-1,-1,1,-1,-1,1,-1,-1,1,-1,-1,\ -1,-1,1,-1,1,1,-1,-1,1]\end{aligned} \quad (28)$$

(29)

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

$$\begin{aligned}\text{HTL}_{-28:28}=[&1,1,1,1,-1,1,-1,1,-1,1,1,1,1,1,-1,1,-1,1,1,1,1,-1,1,-1,\ -1,-1,-1,-1,0,\\ &-1,1,1,-1,-1,-1,1,1,1,-1,-1,-1,1,1,-1,1,1,-1,-1,-1,1,1,-1,-1,1,-1,-1,1]\end{aligned} \quad (30)$$

In the 40MHz mode, the subcarriers at $k = \pm 32$ are populated in the HT-STS. 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.

$$\begin{aligned}HTL_{-58,+58} = \{&-1\ 1\ 1\ 1\ 1\ -1\ 1\ \ 1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ 1\ -1\ 1\ 1\ -1\ -1\\ &1\ 1\ -1\ -1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ 1\ -1\ 1\ 1\ -1\ -1\ -1\ 1\ -1\ -1\ 1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ 1\\ &0\,0\,0\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ 1\ -1\ 1\ 1\ -1\ -1\ 1\ -1\ -1\ 1\ -1\ 1\\ &-1\ 1\ -1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ -1\ -1\ -1\ 1\ -1\ 1\ -1\ 1\ -1\ 1\ 1\ -1\ 1\ -1\ -1\ 1\ -1\ 1\ 1\ 1\}\end{aligned} \quad (31)$$

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

$$\begin{aligned}HTL_{-58,+58} = \{&-1\ 1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ -1\ 1\ 1\ -1\ 1\ -1\ 1\ 1\ -1\\ &-1\ 1\ 1\ -1\ -1\ 1\ 1\ -1\ -1\ -1\ 1\ -1\ 1\ -1\ 1\ 1\ 1\ -1\ -1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ -1\ 1\ -1\ 1\\ &0\,0\,0\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ 1\ -1\ 1\ 1\ -1\ -1\ 1\ -1\ 1\ 1\ -1\ 1\ -1\\ &1\ -1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ -1\ -1\ -1\ -1\ 1\ -1\ 1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ 1\ -1\ 1\ 1\ 1\}\end{aligned} \quad (32)$$

In 40MHz, for $N_{TX} = 3$, sequence 8 is:

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$$HTL_{-58,+58}=\{-1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1$$
$$1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 0 \quad (33)$$
$$0\ 0\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1$$
$$-1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ \}$$

The tone-interleaving rule across 3 antennas in 40MHz is grouped into 3 sets:
In 40MHz, for $N_{TX} = 4$, sequence 9 is:

$$HTL_{-58,+58}=\{-1\ 1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ 1\ 1\ -1\ \ -1\ -1\ -1\ 1\ -1\ -1\ -1\ 1\ -1\ 1\ -1$$
$$1\ -1\ -1\ -1\ -1\ 1\ 1\ -1\ \ -1\ -1\ 1\ 1\ 1\ 1\ -1\ 1\ -1\ -1\ 1\ -1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ 1\ 0 \quad (34)$$
$$0\ 0\ -1\ 1\ 1\ -1\ -1\ -1\ -1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ -1\ 1\ -1\ 1\ -1\ -1\ -1\ 1\ -1\ 1\ -1$$
$$-1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ -1\ -1\ -1\ -1\ 1\ 1\ -1\ 1\ 1\ 1\ -1\ 1\ 1\ -1\ -1\ 1\ -1\ 1\ -1\ -1\ 1\ 1\}$$

The HT-LTF is generated similarly to the HT-STF. For the data HT-LTFs $i_{LTF} = 0, \ldots, N_{SS} - 1$, the signal is

$$r_{HT-LTF}^{(i_{Tx},i_{LTF})}(t) = \frac{1}{\sqrt{N_{HT-LTF}^{Tone}}} w_{HT-LTF}(t) \sum_{k=-N_{SR}}^{N_{SR}} Q_{i_{Tx},(k+i_{LTF}+N_{SR}-u(k))\%N_{SS}}^{(k)} HTL_k \exp\left(j2\pi k\Delta_F(t-T_{GI})\right) \quad (35)$$

where $N_{SR} = 28$ for 20 MHz and 58 for 40 MHz,

$$u(k) = \begin{cases} 1 & k > 0 \\ 0 & k < 0 \end{cases} \quad \text{for 20 MHz} \quad (36)$$

and

$$u(k) = \begin{cases} 3 & k > 0 \\ 0 & k < 0 \end{cases} \quad \text{for 40 MHz.} \quad (37)$$

In the case of a sounding packet, the extension HT-LTFs are tone interleaved over the extension spatial dimensions. Thus, the extension HT-LTFs are

$$r_{HT-LTF}^{(i_{Tx},i_{LTF})}(t) = \frac{1}{\sqrt{N_{HT-LTF}^{Tone}}} w_{HT-LTF}(t) \sum_{k=-N_{SR}}^{N_{SR}} q_{i_{Tx},N_{SS}+(k+(i_{LTF}-N_{SS})+N_{SR}-u(k))\%(N_{LTF}-N_{SS})}^{(k)} HTL_k \exp\left(j2\pi k\Delta_F(t-T_{GI})\right) \quad (38)$$

for $i_{LTF} = N_{SS}, \ldots, N_{LTF} - 1$.

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Since the HT-LTF is tone interleaved across antennas, the 56 tones are partitioned across the antenna array during each OFDM symbol. Tone partitioning into sets for 20MHz is shown in Table 26. At each OFDM symbol interval, each set of tones maps to one transmit antenna. And over time, all sets get mapped to an antenna.

Nss	Set 0	Set 1	Set 2	Set 3
1	[-28:1:-1] [1:1:+28]			
2	[-28:2:-2] [2:2:28]	[-27:2:-1] [1:2:27]		
3	[-28:3:-1] [2:3:26]	[-27:3:-3] [3:3:27]	[-26:3:-2] [1:3:28]	
4	[-28:4:-4] [1:4:25]	[-27:4:-3] [2:4:26]	[-26:4:-2] [3:4:27]	[-25:4:-2] [4:4:28]

Table 26: Tone partitioning into sets for 20MHz (56 tones)

Tone partitioning into sets for 40MHz is shown in Table 27.

Nss	Set 0	Set 1	Set 2	Set 3
1	[-58:1:-2] [2:1:+58]			
2	[-58:2:-2] [2:2:+58]	[-57:2:-3] [3:2:57]		
3	[-58:3:-4] [2:3:56]	[-57:3:-3] [3:3:57]	[-56:3:-2] [4:3:58]	
4	[-58:4:-2] [5:4:57]	[-57:4:-5] [2:4:58]	[-56:4:-4] [3:4:55]	[-55:4:-3] [4:4:56]

Table 27: Tone partitioning into sets for 40MHz (114 tones)

An example of tone interleaving across 4 transmit antennas is shown in Figure 34.

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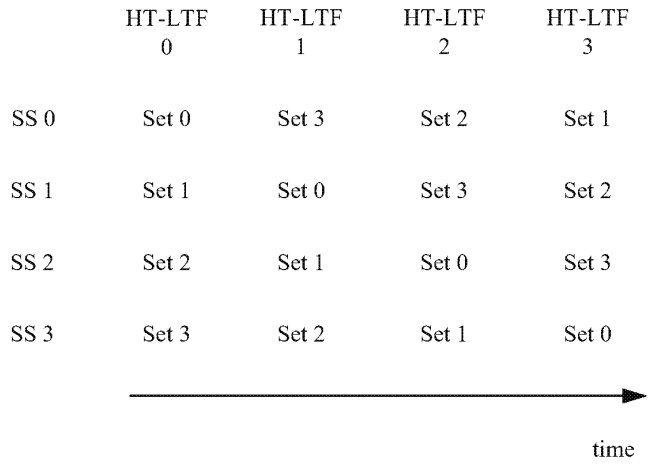


Figure 34: HT-LTF tone interleaving across 4 spatial streams

11.2.1.7 Signal fields specification

The L-LTF shall be followed by the signal fields L-SIG and HT-SIG. The coding and modulation follow the steps of clause 17.3.4 in ref[2]: BPSK modulation is used for the L-SIG and HT-SIG, with code rate ½ resulting in 6 Mbit/s. Between the LSIG and the HT-SIG symbol, the BPSK modulation shall be rotated counter-clockwise by 90 degrees. This phase rotation can be used to "auto-detect" whether the frame being received is legacy or HT. The constellation bit encoding is depicted in Figure 35.

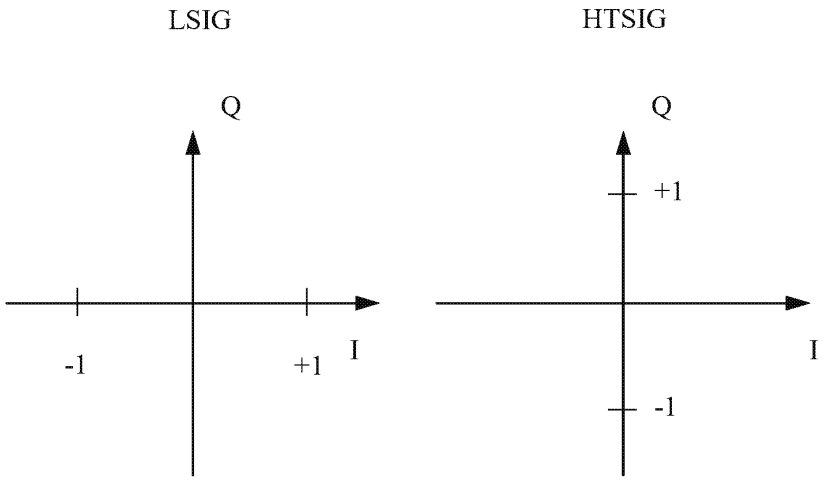


Figure 35: Constellation specification for LSIG and HTSIG

11.2.1.7.1 L-SIG

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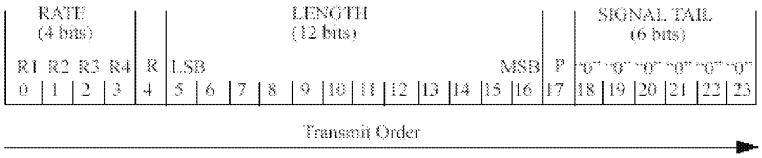


Figure 36: SIGNAL field bit assignment

In the 20MHz mode, the format of the LSIG field shall be the same as the SIGNAL field as defined in figure 111 in 17.3.4 in [1]. The combination of RATE and LENGTH is used to signal a station (OFDM mode only) the duration of a HT transmission. This duration does not have to be the actual duration of the HT frame. It can be used to reserve the medium beyond the actual transmission. The reservation of the medium through this kind of signalling is called "spoofing".

To prevent a legacy station from accessing the medium during a HT frame transmission, the "duration" calculated from the RATE and LENGTH fields shall be at least as large as the actual duration of the HT frame, which is measured from the end of the L-SIG field to the end of the DATA field. During an HT transmission, the RATE field is set to 6Mbps, whereas the LENGTH field is set based on the "duration" value.

In the 40MHz mode, the legacy signal field is duplicated such that tones are filled from -58 to -6 (lower-subchannel), and from +6 to +58 (upper-subchannel). The upper subchannel shall be phase rotated by 90 degrees, in the same way as the LTS as described in 11.2.1.6.2

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 11.2.1.6.2. Denote $LSIG_{-26,26}$ and $LSIG_{-58,58}$ as the LSIG OFDM symbol generated for 20 MHz and 40 MHz respectively.

The L-SIG waveform is

$$r_{L-SIG}^{i_{Tx}}(t) = \frac{1}{\sqrt{N_{L-SIG}^{Tone}}} w_{L-SIG}(t) \sum_{k=-N_{SR}}^{N_{SR}} q_{i_{Tx}}^{L(k)} LSIG_k \exp\left(j2\pi k\Delta_F\left(t - T_{GI}\right)\right) \quad (39)$$

11.2.1.7.1.1 Data rate (RATE)

For a legacy station (11a or 11g), RATE has the original meaning as is defined in Table 80 of section 17.3.4.1 in [1]. For reference the table is repeated here:

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Rate (Mbits/s)	R1–R4
6	1101
9	1111
12	0101
18	0111
24	1001
36	1011
48	0001
54	0011

Table 28: Content of the legacy SIGNAL field

11.2.1.7.1.2 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 11.2.1.7.1, 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.

11.2.1.7.2 HT-SIG

The L-SIG field shall be followed by the HT-SIG, which serves as the signal field for the HT PHY. HT-SIG consists of two OFDM symbols: HT-SIG1 and HT-SIG2. HT-SIG1 shall be transmitted first in time.

The encoding of HT-SIG-1 and HT-SIG-2 shall be the same as L-SIG, with the exception that the BPSK modulation is rotated 90 degrees as described in clause 11.2.1.7.

In the 40MHz mode, the HT-SIG-1 and HT-SIG-2 are duplicated. The upper sub-channel shall be phase rotated by 90 degrees in the same way as the L-LTF, as described in 11.2.1.6.2 Figure 37 shows the bit assignment for the two symbols. They will be described in the next clauses.

HT-SIG-1 and HT-SIG-2 shall be transmitted in a similar fashion as the LSIG. Denote $HTSIG^{0}_{-26,26}$ and $HTSIG^{1}_{-58,58}$ as the first and second OFDM symbol of the following defined HT-SIG as a data field. Then

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$$r_{HT-SIG}^{(i_{Tx})}(t) = \frac{1}{\sqrt{N_{HT-SIG}^{Tone}}} \sum_{n=0}^{1} w_{Symb}\left(t - nT_{Symb}\right) \sum_{k=-N_{SR}}^{N_{SR}} q_{i_{Tx}}^{L(k)} HTSIG_k^n \exp\left(j2\pi k\Delta_F\left(t - T_{GI} - nT_{Symb}\right)\right) \quad (40)$$

where T_{Symb} = 4 μ sec is the OFDM symbol duration.

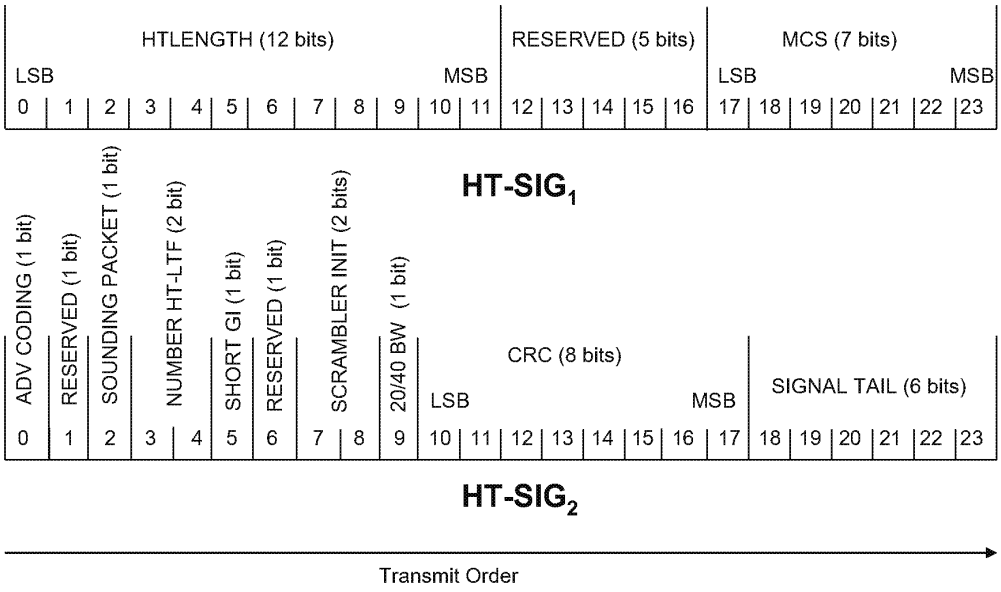


Figure 37: HT SIGNAL FIELD (HTSIG1 and HTSIG2) bit assignment

11.2.1.7.2.1 HTLENGTH field

The HTLENGTH field shall be an unsigned 12-bit integer, which is interpreted using the following table:

HTLENGTH b'$H_{11}H_{10}$_$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$	**Aggregate packet?**	**Length interpretation**
b'00_$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$	No	b'00_$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$ octets
b'01_$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$	No	b'01_$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$ octets
b'10_$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$	No	b'10_$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$ octets
b'11_$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$	Yes	b'$H_9H_8H_7H_6H_5H_4H_3H_2H_1H_0$ OFDM symbols

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Table 29: Interpretation of HT-LENGTH field in HT-SIG

Bit 0 (i.e. H_0) is the LSB (least significant bit) and shall be transmitted first in time to the channel encoder.

11.2.1.7.2.2 MCS field

The MCS field is a 7-bit field (bit 17-23 of HT-SIG1) that defines the modulation and coding scheme, as indicated in Table 21 and Table 22.

MCS indices from 0 to 32 belong to the basic MCS set (Table 21). MCS indices from 33 to 126 (94 in number) belong to the extended MCS set (Table 22).

11.2.1.7.2.3 ADVCODING

ADVCODING is a 1-bit field that indicates if advanced coding has been applied to the PPDU.

11.2.1.7.2.4 SOUNDING PACKET

This bit indicates that MIMO training is per antenna, implying that all transmit antennas are excited. If this bit is set, the packet can be used for antenna-to-antenna channel estimation necessary for closed loop beam forming. If NOT set, the packet cannot be used as a sounding packet either because the MIMO training excites fewer spatial streams than antennas, or because beam forming has been applied.

11.2.1.7.2.5 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.

11.2.1.7.2.6 SHORT GI (Optional)

SHORT GI is a 1-bit field. If SHORT GI is 1, the Short Guard Interval is used in the data portion of the frame.

11.2.1.7.2.7 SCRAMBLERINIT

SCRAMBLERINIT is a 2-bit field that contains the initialization value of the scrambler. This value is used to initialize the scrambler at the receiver. The mapping of the 2-bit field to initialization sequences is described in Table 15.

11.2.1.7.2.8 20/40 BW

This bit indicates whether the current PPDU is signaled in 20MHz or 40MHz bandwidth. A value of 0 indicates 20MHz, whereas a value of 1 indicates 40MHz.

11.2.1.7.2.9 CRC

The CRC field is an 8-bit CRC value. It is used as a Frame Check Sequence (FCS) to protect the information-bearing fields of LSIG, HT-SIG1 and HT-SIG2.

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The CRC field shall be the one's complement of the remainder generated by the modulo 2 division of the protected bits by the polynomial

$$x^8 + x^2 + x^1 + 1 \qquad (41)$$

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 38.

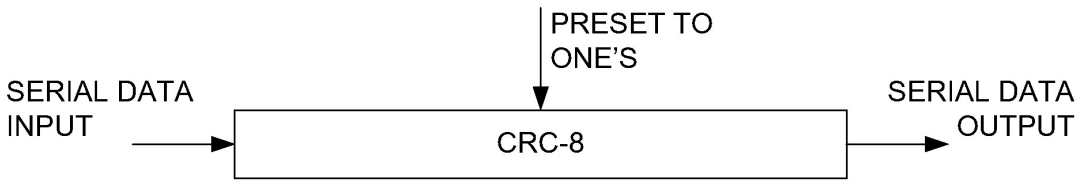
As an example, given the following LSIG, HT-SIG1 and HT-SIG2 fields
1101 0001 1101 1101 0000 0000 [LSIG]
0111 1011 0100 1011 1010 0000 [HT-SIG1]
0010 1101 10CC CCCC CC00 0000 [HT-SIG2]
b0.....b23 [leftmost bit (b0) transmitted first in time]

then the protected bits input to the CRC encoder are
1101 0001 1101 1101 0, 0111 1011 0100 1011 1010 0000, 0010 1101 10

and the calculated CRC8 equals
00001101

so that HT-SIG2 equals
0010 1101 1000 0011 0100 0000

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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

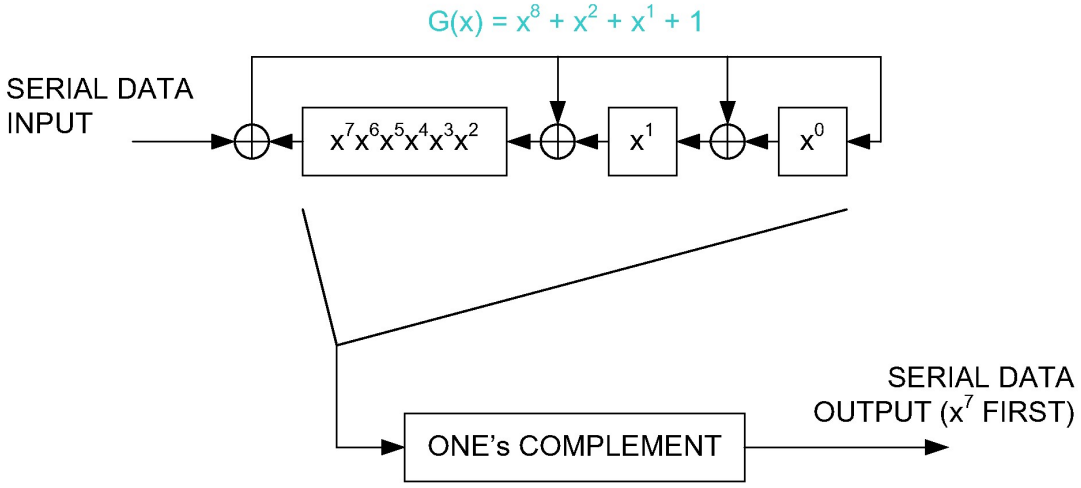


Figure 38: CRC8 implementation

11.2.1.7.2.10 SIGNALTAIL

The bits 18-23 constitute the SIGNALTAIL field, and all 6 bits shall be set to zero.

11.2.1.8 Datafield

Contrary to 801.11a, the data field in our proposal does not contain a SERVICE field.

The data field contains the PSDU, the Tail bits and the PAD bits. All bits in the DATA field are scrambled, as described in 11.2.1.8.3. The PPDU is de-multiplexed across several spatial streams, which are created after the parser.

11.2.1.8.1 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

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end of the message. The PLCP tail bit field shall be produced by replacing six scrambled "zero" bits following the message end with six non-scrambled "zero" bits.

11.2.1.8.2 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.

11.2.1.8.3 PLCP Data Scrambler and Descrambler

The 11a Scrambler and Descrambler will be used as described in 17.3.5.4 in ref [1].
The DATA field, composed of PSDU, tail, and pad parts, shall be scrambled with the length-127 frame-synchronous scrambler.
The scrambler shall be initialized according to the SCRAMBLERINIT fields in HT-SIG2.
As described in 11.2.1.8.1 the PLCP tail bit field shall be produced by replacing six scrambled "zero" bits following the message end with six nonscrambled "zero" bits.

11.2.1.8.4 Antenna streams / Transmitter architecture

In the basic MIMO mode, spatial streams may be mapped to transmit antennas wither using direct mapping (11.2.1.2.1), or spatial spreading (11.2.1.2.2). In the case of direct mapping, the number of spatial streams equals the number of active transmit antennas. By active, we imply those antennas that transmit datafields. In the case of spatial spreading, the number of spatial streams must be less than or equal to the number of transmit antennas.

The information bits first go through a convolutional encoder. The convolutional encoder is of rate ½ , from which other rates are derived by puncturing (see 11.2.1.8.6). The output of the puncturer feeds into the spatial parser, which creates several spatial streams, using round robin cycling. The frequency interleaver places the bits in the frequency domain and the constellation position according to the rules of the 802.11a interleaver. The interleaved bits are then mapped to constellation points. The resulting QAM symbols are fed to the antenna map transformation (Figure 21), and the output of this for each transmit antenna is fed as a block of data to the iFFT to create the time-domain signal. The pilot tones are also inserted in the frequency domain. The cyclical prefix is inserted in the time domain, and windowing of the OFDM symbols is also performed in the time domain. The resulting signal is then converted into analog format via a Digital-to-Analog (D/A) converter.

11.2.1.8.5 Encoder

The DATA field shall be coded with the convolutional encoder of coding rate R=1/2. The encoder is defined in clause 17.3.5.5 in [1] (i.e. the 11a encoder).
.

11.2.1.8.6 Puncturing of Coded Data

Coded bits at the output of the convolutional encoder are at rate 1/2. For lower rates, the puncturer can selectively puncture the coded bits to achieve the desired "effective" coding rate of 2/3, 3/4 or 5/6. For code rates of 2/3 and 3/4 the puncturing patterns are as defined in clause 17.3.5.5 in [1]. For a code rate of 5/6, the puncturing pattern is illustrated in Figure 39.

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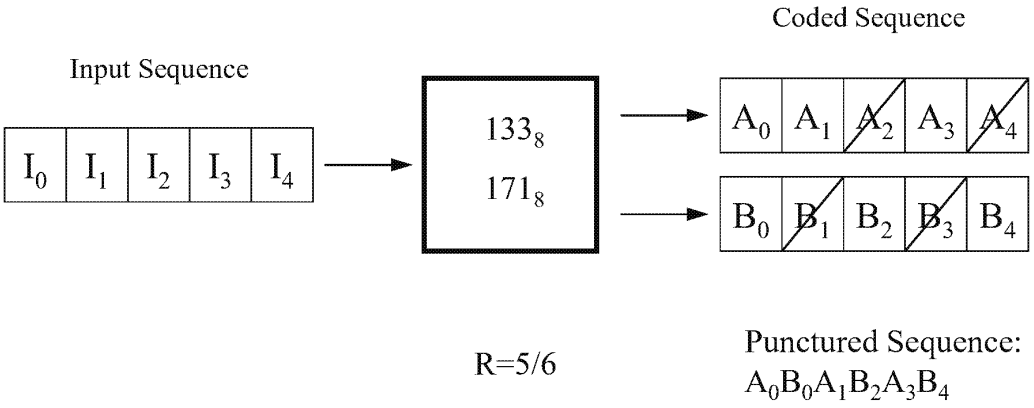


Figure 39: Puncturing pattern for code rate = 5/6

In the basic MIMO mode, all spatial streams are identically punctured.

11.2.1.8.7 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.

11.2.1.8.7.1 Spatial Parsing

Encoded and punctured bits are parsed to multiple spatial streams by a round-robin parser. Define:

$$s = \max\{N_{BPSC}/2, 1\} \quad (42)$$

which is the number of QAM bit order values, as in [1] equation (17). Then the parser sends consecutive blocks of s bits to different spatial streams in a round-robin fashion starting with the first spatial stream. The reason for parsing in blocks of s bits is to prevent clustering of QAM orders.

11.2.1.8.7.2 Frequency interleaver

All encoded bits shall be interleaved by a separate block interleaver for each spatial stream, with a block size corresponding to the number of coded bits in a single OFDM symbol, N_{CBPS}. The block interleavers are based on the 802.11a interleaver, with certain modifications to allow for multiple spatial streams and 40MHz transmissions as shown in Figure 40.

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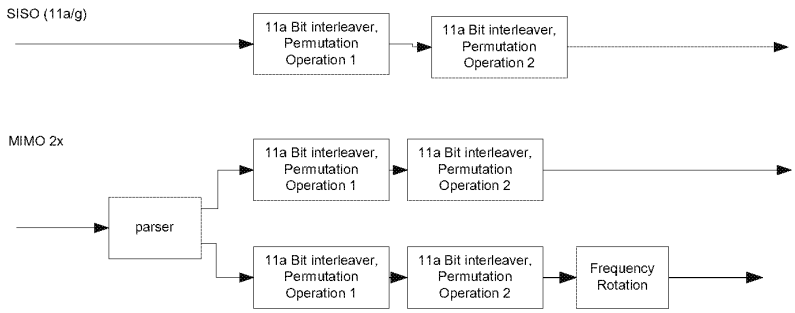


Figure 40: Structure of interleaver

The interleaver is defined by a three-step permutation. The first permutation ensures that adjacent coded bits are mapped onto nonadjacent subcarriers. The second permutation ensures that coded bits are mapped alternately onto less and more significant bits of the constellation and thereby long runs of low reliability (LSB) bits are avoided. The third permutation ensures that coded bits are mapped to achieve better frequency-spatial diversity among all spatial streams via frequency rotation. The operations of the first two permutations are the same as in 802.11a.

The basic interleaver array has N_{row} rows and N_{column} columns and the base of frequency rotation is defined by N_{rot}. These parameters are specified in Table 30 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 30: Interleaver Parameters

	N_{column}	N_{row}	N_{rot}
20 MHz channels	13	$4N_{BPSC}$	11
40 MHz channels	18	$6\ N_{BPSC}$	29

The exact amount of frequency rotation for different spatial streams is illustrated in Table 31.

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Table 31: Amount of Frequency Rotation

Frequency Rotation	Total Number of Streams			
	1	2	3	4
1st stream	0	0	0	0
2nd stream		$2N_{rot}$	$2N_{rot}$	$2N_{rot}$
3rd stream			N_{rot}	N_{rot}
4th stream				$3N_{rot}$

The index of the coded bit before the first permutation shall be denoted by k; i shall be the index after the first and before the second permutation; j shall be the index after the second permutation and before the third permutation; r shall be the index after the third permutation and just prior to modulation mapping. Mathematically,

The first permutation is defined by the rule

$$i = N_{row} \times \left(k \bmod N_{column}\right) + \text{floor}\left(k / N_{column}\right) \quad k = 0,1,\ldots,N_{CBPS}-1 \tag{43}$$

The second permutation is defined by the rule

$$j = s \times \text{floor}\left(i/s\right) + \left(i + N_{CBPS} - \text{floor}\left(N_{column} \times i / N_{CBPS}\right)\right) \bmod s \quad i = 0,1,\ldots,N_{CBPS}-1 \tag{44}$$

where s is determined according to

$$s = \max\left(N_{BPSC}/2,1\right) \tag{45}$$

The third permutation is defined by the rule

$$r = \left(j - \left(\left(2 \times i_{ss}\right) \bmod 3 + 3 \times \text{floor}(i_{ss}/3)\right) \times N_{rot} \times N_{BPSC}\right) \bmod N_{CBPS} \quad j = 0,1,\ldots,N_{CBPS}-1 \tag{46}$$

where $i_{SS} = 0,1,\ldots,N_{SS}-1$ is the index of the spatial stream on which this interleaver is operating.

The deinterleaver, which performs the inverse relation, is also defined by three permutations. Here the index of the original received bit before the first permutation shall be denoted by r; j shall be the index after the first and before the second permutation; i shall be the index after the second and before the third permutation; and k shall be the index after the third permutation.

The first permutation is defined by the rule

$$j = \left(r + \left(\left(2 \times i_{ss}\right) \bmod 3 + 3 \times \text{floor}(i_{ss}/3)\right) \times N_{rot} \times N_{BPSC}\right) \bmod N_{CBPS}, \quad r = 0,1,\ldots,N_{CBPS}-1 \tag{47}$$

This permutation is the inverse of the permutation described in Equation (43).

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The second permutation is defined by the rule

$$i = s \times \text{floor}\left(j/s\right) + \left(j + \text{floor}\left(N_{column} \times j / N_{CBPS}\right)\right) \bmod s, \quad j = 0,1,\ldots,N_{CBPS}-1 \qquad (48)$$

where s is as defined in Equation (45). This permutation is the inverse of the permutation described in Equation (44).

The third permutation is defined by the rule

$$k = N_{column} \times i - \left(N_{CBPS}-1\right)\text{floor}\left(i / N_{row}\right), \quad i = 0,1,\ldots,N_{CBPS}-1 \qquad (49)$$

This permutation is the inverse of the permutation described in Equation (46).

11.2.1.8.8 Subcarrier Modulation Mapping

The subcarrier modulation mapping for BPSK, QPSK, 16-QAM, and 64-QAM will be identical to clause 17.3.5.7 in [1]

There is one exception as described in clause 11.2.1.7. The mapping of the HT-SIG field shall be rotated by 90 degrees.

11.2.1.8.8.1 Subcarrier Modulation Mapping for 256-QAM (optional)

256QAM is introduced in the extended MCS set. The normalization factor K_{MOD} for 256QAM is $1/\sqrt{170}$. For 256-QAM, $b_0b_1b_2b_3$ determines the I value and $b_4b_5b_6b_7$ determines the Q value. The constellation mapping for 256QAM is as follows.

Table 32: Constellation Mapping for 256-QAM

Input bits $b_0b_1b_2b_3$	I-out
0000	-15
0001	-13
0011	-11
0010	-9
0110	-7
0111	-5
0101	-3
0100	-1
1100	1
1101	3
1111	5
1110	7
1010	9
1011	11
1001	13
1000	15

Input bits $b_4b_5b_6b_7$	Q-out
0000	-15
0001	-13
0011	-11
0010	-9
0110	-7
0111	-5
0101	-3
0100	-1
1100	1
1101	3
1111	5
1110	7
1010	9
1011	11
1001	13
1000	15

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11.2.1.8.9 MIMO-OFDM symbol iFFT mapping

For the MIMO-OFDM operation in 20 MHz bandwidth, each OFDM symbol is constructed from 56 tones, of which 52 are data tones and 4 are pilot tones. The tone mapping is identical to that in IEEE 802.11a (subclause 17.3.5.9 in reference) except to 2 extra tones on either side.

Construction of the OFDM data symbol in 40MHz begins with bonding two adjacent 20MHz OFDM symbols, as shown in Figure 41. There are a total of 11 guard tones between the two 20MHz channels, ranging from -5 to +5. Note that the legacy channels occupy tones from -58 to -6 in the lower sub-channel, and from +6 to +58 in the upper sub-channel. Of the 11 guard tones, 3 are nulled out: -1, 0, +1. This provides 8 additional data tones. Two DC tones are also inherited from the legacy sub-channels. These occur at -32 and +32 in the lower and upper sub-channels respectively. There are 4 pilot tones in each legacy sub-channel, and when mapped to the 40MHz iFFT indices, they occur at ±53, ±39, ±25, ±11. Of these 8 tones, the two tones at -39 and +39 are swapped with data, leading to a total of 6 pilot tones in the 40MHz channel. Tone assigned during 40MHz for DATA symbols can be summarized as:

$$
\begin{aligned}
&Nulled\ Tones = \{-64 \ldots -59, -1, 0, +1, +59 \ldots +63\} \\
&Populated\ Tones = \{-58 \ldots -2, +2 \ldots +58\} \\
&Pilot\ Tones = \{-53, -25, -11, +11, +25, +53\} \\
&Data\ Tones = \{Populated\ Tones\} - \{Pilot\ Tones\}
\end{aligned}
\tag{50}
$$

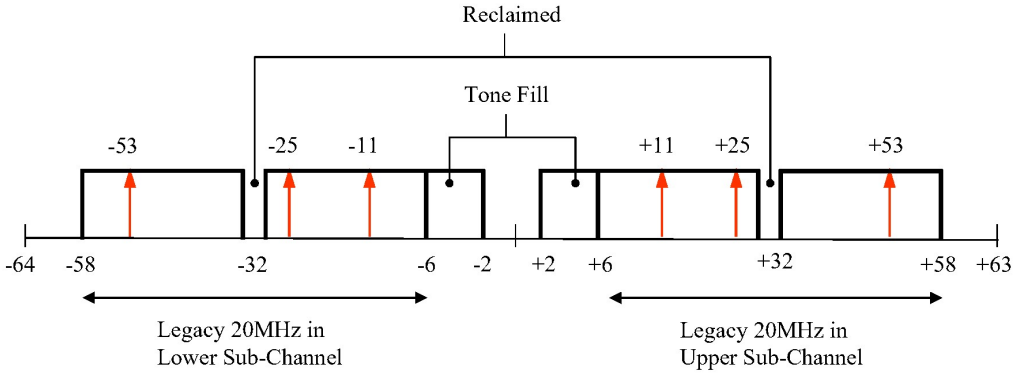


Figure 41: Tone Format for 40MHz channelization

The mapping of the input of the 40MHz channel to a 128-point IFFT is illustrated in Figure 42.

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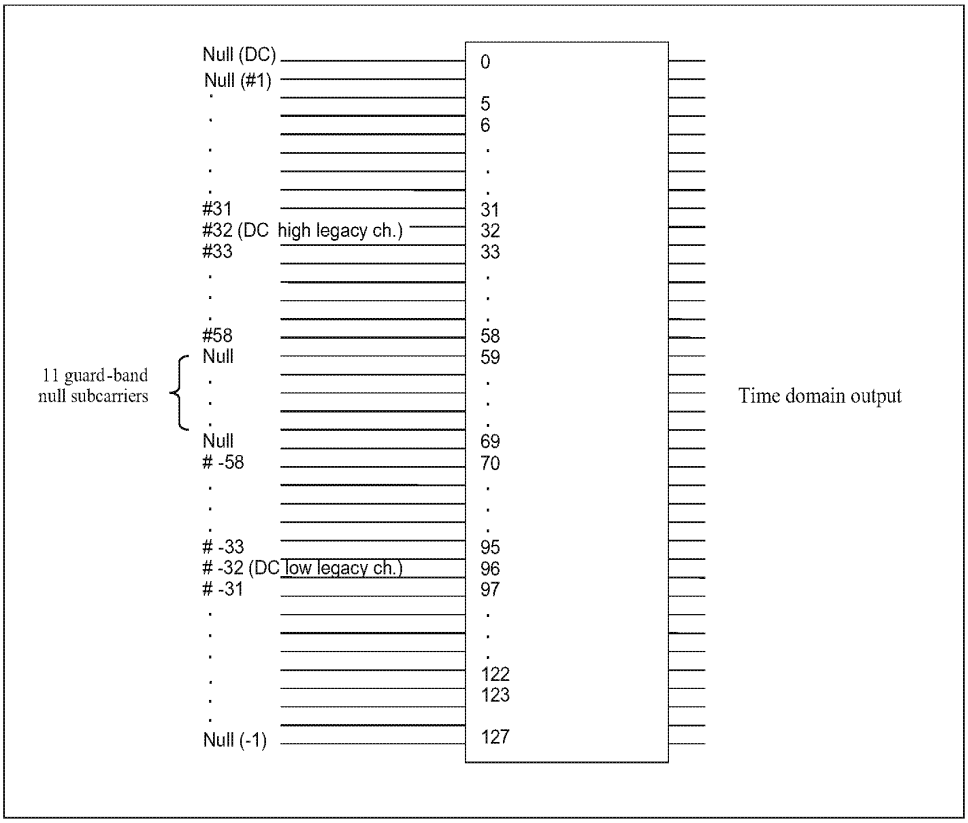


Figure 42 Inputs and Outputs of IFFT for a 40 MHz channel

The complex numbers after the mapping are divided into groups of N_{SD}, where N_{SD} = 52 in the 20MHz mode and N_{SD} = 108 in the 40MHz mode (excluding 6 Mbps duplicate format).

Following the convention in clause 17.3.5.9 in [1], the complex number is denoted as $d_{k,n}^{(i_{SS})}$, which corresponds to the k th modulation symbol in the n th OFDM symbol that is transmitted on spatial stream i_{SS} (= 0, …, $N_{SS}-1$).

The complete data field is

$$r_{HT-Data}^{(i_{Tx})}(t) = \sum_{n=0}^{N_{Data}-1} r_{HT-Data,n}^{(i_{Tx})}\left(t - nT_{Symb}\right). \tag{51}$$

The nth OFDM data symbol is

$$r_{HT-Data,n}^{i_{TX}}(t) = w_{Symb}(t)\left\{ \sum_{k=0}^{N_{SD}-1}\left(\sum_{i_{SS}=0}^{N_{SS}-1} q_{i_{Tx},i_{SS}}^{(k)} d_{i_{SS}}^{(k,n)} \right)\exp\left(j2\pi M(k)\Delta_F\left(t - T_{GI}\right)\right) \right.$$
$$\left. + p_{n+3}\sum_{k=-N_{SR}}^{N_{SR}}\left(\sum_{i_{SS}=0}^{N_{SS}-1} q_{i_{Tx},i_{SS}}^{(k)} P_{i_{SS}}^{(k,n)} \right)\exp\left(j2\pi k\Delta_F\left(t - T_{GI}\right)\right) \right\} \tag{52}$$

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where function $M(k)$, defines the mapping from the logical subcarrier number k to a value between $-N_{SR}$ and $+N_{SR}$, while skipping the pilot subcarriers and DC and its adjacent subcarriers. $M(k)$ in the 20MHz mode is same as the one defined in clause 17.3.5.9 in [1]. $M(k)$ in the 40MHz mode is defined as

$$M(k)=\begin{cases} k-58 & 0\le k\le 4 \\ k-57 & 5\le k\le 31 \\ k-56 & 32\le k\le 44 \\ k-55 & 45\le k\le 53 \\ k-52 & 54\le k\le 62 \\ k-51 & 63\le k\le 75 \\ k-50 & 76\le k\le 102 \\ k-49 & 103\le k\le 107 \end{cases} \tag{53}$$

The contribution of pilot subcarriers in the 20MHz mode is given by (24) in clause 17.3.5.9 in ref [1]. The subcarrier frequency locations in the 20MHz mode is shown in Figure 117 in clause 17.3.5.9 in ref [1]. The subcarrier frequency locations in the 40MHz mode is shown in Figure 41.

The iFFT mapping for the 6Mbps duplicate mode in 40MHz differs from the mapping shown in (52):

$$\begin{aligned} & r_{HT-Data,n}^{i_{TX}}(t) \\ & = w_{Symb}(t)\left\{ \sum_{k=0}^{N_{SD}-1}\left(\sum_{i_{SS}=0}^{N_{SS}-1} q_{i_{Tx},i_{SS}}^{(k)} d_{i_{SS}}^{(k,n)} \right) \left(\exp\left(j2\pi\left(M(k)-32\right)\Delta_F\left(t-T_{GI}\right)\right)\right.\right. \\ & \qquad \left.\left. + j\exp\left(j2\pi\left(M(k)+32\right)\Delta_F\left(t-T_{GI}\right)\right)\right) \right. \\ & \quad + p_{n+3}\sum_{k=-N_{SR}}^{N_{SR}}\left(\sum_{i_{SS}=0}^{N_{SS}-1} q_{i_{Tx},i_{SS}}^{(k)} P_{i_{SS}}^{(k,n)} \right)\left(\exp\left(j2\pi\left(k-32\right)\Delta_F\left(t-T_{GI}\right)\right)\right. \\ & \qquad \left.\left. + j\exp\left(j2\pi\left(k+32\right)\Delta_F\left(t-T_{GI}\right)\right)\right) \right\} \end{aligned} \tag{54}$$

where, $N_{SD}=52$ and $N_{SR}=28$ are values that correspond to a 20 MHz transmission. $M(k)$, $P_{i_{SS}}^{(k)}$ and p_n follow the definitions in (23) to (25) in clause 17.3.5.9 in [ref 2]. $P_{i_{SS}}^{(k)}$ for the HT 40MHz mode is defined in 11.2.1.8.10.2.

11.2.1.8.10 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

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frequency offsets and phase noise. These pilot signals shall be put in subcarriers –21, -7, 7, and 21 in 20MHz mode, and in subcarriers -53, -25, -11, 11, 25 and 53 in 40MHz mode.

11.2.1.8.10.1 Legacy pilot subcarriers

Legacy pilots are defined as in 802.11a; refer to clause 17.3.5.8 in [1].

11.2.1.8.10.2 Pilot subcarriers in HT mode

The contribution of pilot subcarriers at the i_{Tx} th transmission stream in 20MHz mode is produced by inverse Fourier transform of sequence $P_{k,n}^{(i_{Tx})}$ given by

$$
\begin{aligned}
P_{i_{SS}}^{(-28..28,n)} = \{&0,0,0,0,0,0,0,P_{i_{SS}}^{(-21,n)},0,0,0,0,0,0,0,0,0,0,0,0,0,P_{i_{SS}}^{(-7,n)},0,0,0,0,0,0,0,\\
&0,0,0,0,0,0,P_{i_{SS}}^{(-7,n)},0,0,0,0,0,0,0,0,0,0,0,0,0,-P_{i_{SS}}^{(21,n)},0,0,0,0,0,0,0\}
\end{aligned}
\quad (55)
$$

where non-zero element of $P_{i_{Tx}}^{(k,n)}$ is generated by the following rule

$$
P_{i_{SS}}^{(k,n)} = \exp\left\{\frac{j\pi}{2}(i_{SS}-1)m\right\}, \quad m = \left(\frac{1}{2}\left(\frac{k}{7}+3\right)+n\right) \bmod 4 \quad (56)
$$

In the 40MHz mode, $P_{k,n}^{(i_{Tx})}$ is given by

$$
\begin{aligned}
P_{i_{SS}}^{(-58..58,n)} = \{&0,0,0,0,0,P_{i_{SS}}^{(-53,n)},0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,P_{i_{SS}}^{(-25,n)},0,0,\\
&0,0,0,0,0,0,0,0,0,0,0,-P_{i_{SS}}^{(-11,n)},0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,P_{i_{SS}}^{(11,n)},0,0,0,0,\\
&0,0,0,0,0,0,0,0,0,-P_{i_{SS}}^{(25,n)},0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,\\
&0,0,P_{i_{SS}}^{(53,n)},0,0,0,0,0\}
\end{aligned}
\quad (57)
$$

where non-zero element of $P_{k,n}^{(i_{Tx})}$ is generated by the following rule

$$
P_{i_{SS}}^{(k,n)} = \exp\left\{\frac{j\pi}{2}(i_{SS}-1)m\right\}, \quad m = \begin{cases} \left(\frac{(k+11)}{14}+3+n\right) \bmod 4, & k = -53,-25,-11 \\ \left(\frac{(k+3)}{14}+3+n\right) \bmod 4, & k = 11,\ 25,\ 53 \end{cases} \quad (58)
$$

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].

11.2.1.8.11 GI / windowing

The windowing function in both 20MHz and 40MHz modes is the same as the one described in clause 17.3.2.4 and 17.3.2.5 in [1]. The example in clause 17.3.2.5 in [1] still holds for the

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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

$$w_T[n] = w_T(nT_s) = \begin{Bmatrix} 1 & 1 \le n \le 159 \\ 0.5 & 0,160 \\ 0 & otherwise \end{Bmatrix} \quad (59)$$

11.2.1.9 Clear channel assessment

When operating in the 5 GHz band the HT PHY shall follow the CCA requirements of 11a, clause 17.3.10.5 in [1]. When operating in the 2.4 GHz band the HT PHY shall follow the 11g spec according to 19.3.5 and 19.4.6 in ref [3].

11.2.1.10 PMD operating spec

In the 20 MHz bandwidth mode the HT PHY shall follow the 11a spec (clause 17.3.8 in ref [1]) and subsequent specifications when operating in the 5 GHz band.
In the 20 MHz bandwidth mode the HT PHY shall follow the 11g spec (clause 19.4) when operating in the 2.4 MHz band.

11.2.1.10.1 Transmit spectral mask

11.2.1.10.1.1 20MHz channel spacing

In the 20 MHz bandwidth mode the HT PHY shall follow 17.3.9.2 in ref [1]. The transmitted spectrum shall have a 0dBr (dB relative to the maximum spectral density of the signal) bandwidth not exceeding 18MHz, -20dBr at 11 MHz frequency offset, -28dBr at 20MHz frequency offset and -45dBr at 30MHz frequency offset and above. The transmitted spectral density of the transmitted signal shall fall within the spectral mask, as shown in Figure 1. The measurements shall be made using a 100kHz resolution bandwidth and a 30kHz video bandwidth.

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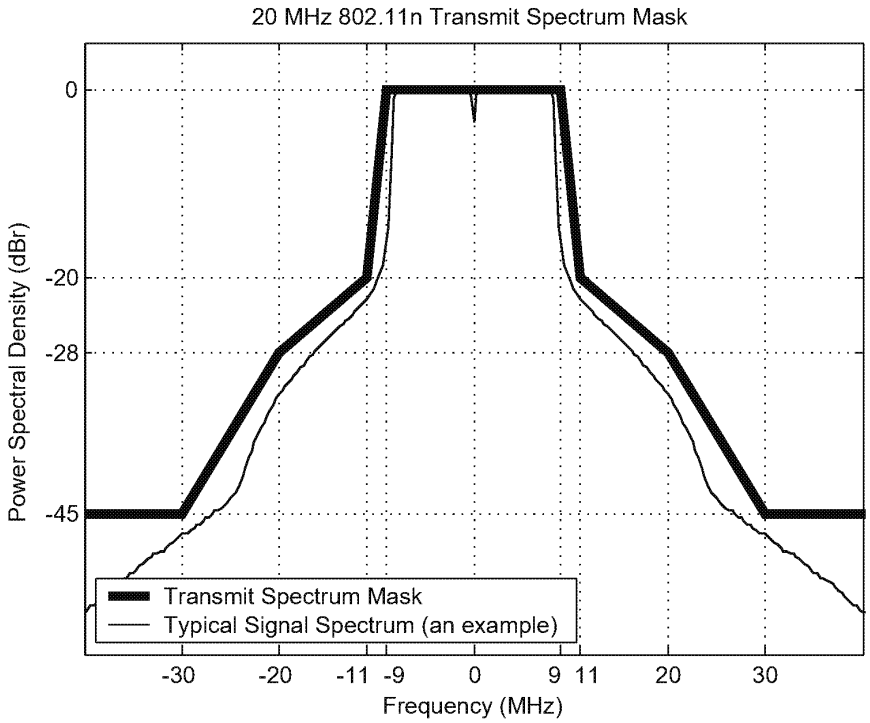


Figure 43: Transmit Spectrum Mask for 20MHz channelization

11.2.1.10.1.2 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.

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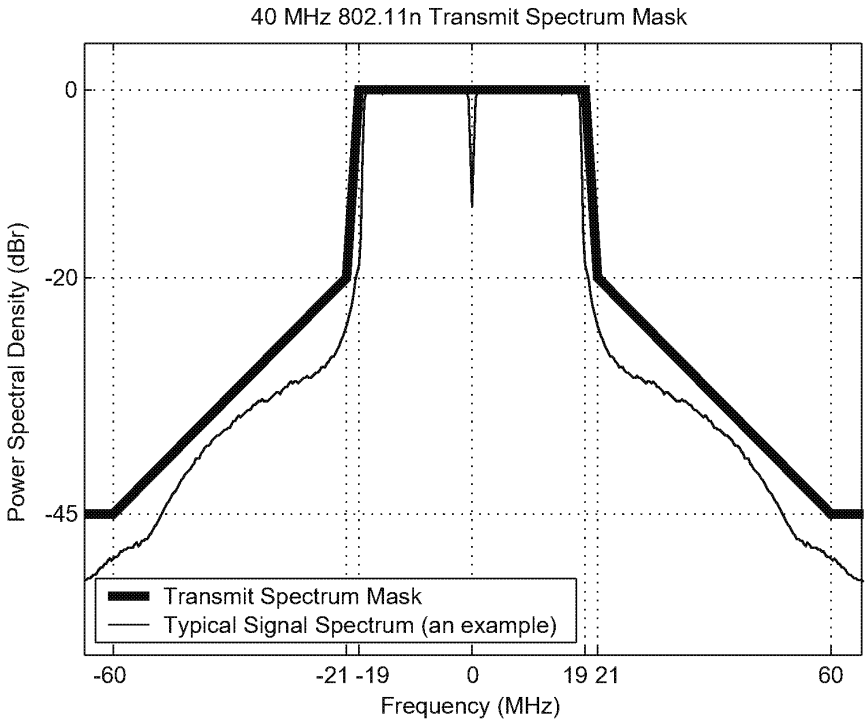


Figure 44: Transmit spectrum mask for 40MHz channelization

A HT device transmitting a 20MHz signal in a 40MHz BSS shall conform to the spectral mask shown in Figure 44.

11.2.2 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 TRQ, which is a request for a sounding packet, to the intended recipient. The recipient in turn sends a sounding packet back to the initiator. The initiator extracts the CSI from this packet, and uses the CSI to compute transmit steering vectors for the forward channel.

This successful application of this process depends on the presumption that the forward channel is reciprocal to the reverse channel. This presumption relies on calibrated RFs to compensate for imbalances between the gain and phase responses of the transmit and receive RF chains in a STA. Our proposal also includes a packet exchange sequence to enable calibration of RF chains at a STA.

While support for the calibration protocol is not mandatory, any STA that supports transmit beamforming should also implement support for calibration in order to ensure reliable reception

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of beamformed PPDUs that it transmits. A STA that does not support transmit beamforming does not need to implement calibration in order to ensure reliable reception of beamformed PPDUs that are directed to it.

11.2.2.2 Motivation of MIMO-Beamforming (Informative)

Beamforming-MIMO can achieve higher throughput than basic MIMO at the same SNR, or conversely, higher range at the same data rate. The benefit of TX beamforming is most pronounced when the number of TX antennas is larger than the RX antennas, when multiple spatial streams are being transmitted. For e.g., a typical configuration involving TX beamforming could be either 3 or 4 antennas at the AP, and 2 antennas at the client. Hence, the client is kept low-cost, while the AP shoulders a higher cost burden.

11.2.2.3 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,

$$y_{N_{TX}\times 1} = V_{N_{TX}\times N_{SS}} \cdot x_{N_{ss}\times 1} \quad (60)$$

The y vector is an N_{TX} dimensional vector whose elements get mapped to the N_{TX} antennas. The beamforming matrix V is applied to the HT-STF and HT-LTF training fields as well as the data. There are several methods for calculating V. One of them involves singular value decomposition (SVD) of the channel transfer matrix H.

It is optional for a device to be able to perform TX beamforming.

11.2.2.3.2 MIMO Channel sounding

11.2.2.3.2.1 MIMO Channel sounding principles

MIMO channel measurement takes place in every PPDU as a result of transmitting the HT-LTFs as part of the PLCP preamble. At a minimum, the number of HT-LTFs transmitted must be equal to the number of spatial streams transmitted, and these must be transmitted using the same spatial steering transformation that is used for the HT-Data. This enables the computation of the spatial equalization at the receiver.

When the number of spatial streams, N_{SS}, is less than the number of transmit antennas, sending only N_{SS} HT-LTFs does not allow the receiver to recover a full characterization of the MIMO channel, even though the resulting MIMO channel measurement is sufficient for receiving the

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HT-Data. However, there are several cases where it is necessary to obtain a full characterization of the channel, thus requiring transmitting either N_{Tx} HT-LTFs or $N_{SS,\max} = \min(N_{Tx}, N_{Rx})$ HT-LTFs. We refer to these cases of MIMO channel measurement as MIMO channel sounding, and the PPDUs carrying the resulting HT-LTFs as sounding PPDUs. These cases include

- Obtaining an estimate of the full MIMO channel matrix, $\mathbf{H}^{(k)}$, in each subcarrier, for the purposes of computing calibration matrices.
- Obtaining an estimate of the complete effective MIMO channel matrix, $\mathbf{H}^{(k)}\mathbf{Q}^{(k)}$, resulting from transmit steering, for the purposes of channel quality measurement for making rate and stream count decisions
- Obtaining an estimate of the sample channel covariance matrix $\mathbf{R}^{(k)} = \left(\mathbf{H}^{(k)}\right)^H \mathbf{H}^{(k)}$ for the purposes of computing transmit steering vectors using eigenvalue decomposition.

11.2.2.3.2.1.1 Sounding PPDU for calibration

In the case of a bidirectional calibration exchange, two STAs exchange sounding packets where the number of HT-LTFs equals the number of transmit antennas, enabling the receiving STA to compute an estimate of the full MIMO channel matrix, $\mathbf{H}^{(k)}$, for each subcarrier. In general, in an exchange of calibration messages, the number of spatial streams will be less than the number of transmit antennas, which requires that spatial spreading be used for the HT-Data portion of the PPDU, so that the spatial spreading transmit steering will also be used for the HT-LTF. Also, since the number of spatial streams is less than the number of HT-LTFs, the HT-LTFs will be segmented, as in equation (38).

11.2.2.3.2.1.2 Sounding PPDU for channel quality assessment

A MIMO channel with N_{Tx} transmit antennas and N_{Rx} receive antennas can support a maximum of $N_{SS,\max} = \min\left(N_{Tx}, N_{Rx}\right)$ spatial streams. In order for a receiving STA to obtain a channel quality assessment for all $N_{SS,\max}$ available spatial streams when using a transmit steering matrix $\mathbf{Q}^{(k)}$, it needs an estimate of the effective channel $\mathbf{H}^{(k)}\mathbf{Q}^{(k)}$, where $\mathbf{Q}^{(k)}$ is in this case a $N_{Tx} \times N_{SS,\max}$ orthonormal steering matrix. This requires that the transmitting STA must send $N_{SS,\max}$ HT-LTFs, using the tone interleaved columns of $\mathbf{Q}^{(k)}$. Thus a PPDU containing $N_{SS,\max}$ HT-LTFs can be considered a sounding PPDU, containing N_{SS} data HT-LTFs and $N_{SS,\max} - N_{SS}$ extension HT-LTFs.

11.2.2.3.2.1.3 Sounding PPDU for transmit steering computation

In order to compute transmit steering vectors through either eigenvalue decomposition or singular value decomposition, a transmitting STA must in general have a good estimate of the channel matrix, $\mathbf{H}^{(k)}$, for each subcarrier of the channel over which it is transmitting. The STA computing transmit steering vectors can obtain this estimate if the STA to which it intends to transmit sends it a sounding PPDU that allows it to estimate $\mathbf{H}_R^{(k)} = \left(\mathbf{H}_F^{(k)}\right)^T$ (assuming channel

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reciprocity is in effect), where $\mathbf{H}_R^{(k)}$ is the reverse channel, which is the channel over which the HT-LTFs were transmitted, and $\mathbf{H}_F^{(k)}$ is the forward channel, which is the channel for which the transmit steering vectors are being computed. The format of the sounding PPDU may be either direct-mapped, spatially spread, or beamformed.

If the HT-LTF is transmitted in direct-mapped format, then it must contain N_{Tx} HT-LTFs, and the receiver may then obtain a direct estimate of the channel matrices $\mathbf{H}_R^{(k)}$ from which it may compute an SVD or the eigenvalue decomposition of $\mathbf{R}_F^{(k)} = \left(\mathbf{H}_F^{(k)}\right)^H \mathbf{H}_F^{(k)} = \left(\mathbf{H}_R^{(k)}\right)^* \left(\mathbf{H}_R^{(k)}\right)^T$.

If the HT-LTF is transmitted in spatially spread mode, then it must also contain N_{Tx} HT-LTFs. The receiver may obtain a direct estimate of $\mathbf{H}_F^{(k)}$ by right multiplying its estimate of the effective channel, $\mathbf{H}_R^{(k)}\mathbf{Q}^{(k)}$, by $\left(\mathbf{Q}^{(k)}\right)^H$. Alternately, the receiver can compute an estimate of $\mathbf{R}_F^{(k)}$ directly, since $\left(\mathbf{H}_R^{(k)}\mathbf{Q}^{(k)}\right)^* \left(\mathbf{H}_R^{(k)}\mathbf{Q}^{(k)}\right)^T = \left(\mathbf{H}_R^{(k)}\right)^* \left(\mathbf{H}_R^{(k)}\right)^T = \mathbf{R}_F^{(k)}$, since $\mathbf{Q}^{(k)}$ is in this case an $N_{Tx,R} \times N_{Tx,R}$ unitary matrix, where the notation $N_{Tx,R}$ refers to the number of transmit antennas on the reverse link.

Finally, if the HT-LTF is transmitted in beamforming mode, so that $\mathbf{Q}_R^{(k)} = \mathbf{V}_R^{(k)}$ is the $N_{Tx,R} \times N_{SS,\max}$ matrix of right singular vectors of the reverse channel matrix $\mathbf{H}_R^{(k)}$, then the PPDU only needs to contain $N_{SS,\max} = \min(N_{Tx}, N_{Rx})$ HT-LTFs. The receiver obtains from this an estimate of the $N_{Rx,R} \times N_{SS,\max}$ equivalent channel matrix $\mathbf{H}_R^{(k)}\mathbf{V}_R^{(k)}$. The receiver can compute from this an estimate of the sample covariance matrix as $\mathbf{R}_F^{(k)} = \left(\mathbf{H}_R^{(k)}\mathbf{V}_R^{(k)}\right)^* \left(\mathbf{H}_R^{(k)}\mathbf{V}_R^{(k)}\right)^T = \left(\mathbf{H}_R^{(k)}\right)^* \left(\mathbf{H}_R^{(k)}\right)^T$. Even though $\mathbf{V}_R^{(k)}$ is not in general unitary (i.e. it is not, in general, square, since the channel is not symmetrical), this equality holds since $\mathbf{H}_R^{(k)}\mathbf{V}_R^{(k)} = \mathbf{U}_R^{(k)}\mathbf{\Sigma}_R^{(k)}$ and $\left(\mathbf{U}_R^{(k)}\mathbf{\Sigma}_R^{(k)}\right)^* \left(\mathbf{U}_R^{(k)}\mathbf{\Sigma}_R^{(k)}\right)^T = \mathbf{R}_F^{(k)}$.

11.2.2.3.2.2 Sounding PPDU format

The only way that a sounding PPDU differs structurally from other PPDUs is that it always contains a number of HT-LTFs that is either equal to $N_{SS,\max}$ or to N_{Tx}. If $N_{LTF} > N_{SS}$, then the HT-LTFs are segmented into Data HT-LTFs and extension HT-LTFs.

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.

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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,

$$H = UDV^H \quad (61)$$

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,

$$H_U = H_D^T \quad (62)$$

11.2.2.3.4 Calibration Methodology (Informative)

11.2.2.3.4.1 Calibration Overview

In order for a transmitting 802.11n STA to transmit to another 802.11n STA using beamforming, it must have a good characterization of the channel that it is transmitting over so that it can choose the correct transmit steering vectors. The STA obtains this characterization by observing the HT-LTF transmitted by the STA to which it is transmitting. This approach is based on the reciprocal property of the over-the-air (antenna-to-antenna) TDD channel, and reciprocity must be in effect for the approach to provide the best rate and range performance available.

Although the Basic MIMO and Walsh-CDD modes do not require it, calibration neither improves nor degrades performance with those modes. Thus, STAs may calibrate upon entering a BSS in which the AP is transmit beamforming capable, or at any other time, and if they are capable of transmitting in beamforming mode, the resulting calibration correction vectors may be

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employed for all transmission modes and on all frames. STAs that are not capable of transmitting in beamforming mode may also perform the calibration procedure with any transmit beamforming capable AP with which they associate, in order to enable that AP to transmit to them in beamforming mode.

Throughout the discussion of beamforming transmission in this document, it is assumed that communication in beamforming mode takes place between devices that have been calibrated.

The following section describes the calibration procedure for a communication link, where the two communicating STAs are referred to as STA A and STA B. Note: calibration as described here is only applicable to STAs with two or more antennas, where both transmission and reception are possible on each antenna.

11.2.2.3.4.2 Calibration procedure for Tx Corrections

In order to consider the operation of a TDD MIMO OFDM system in conjunction with beamforming techniques through transmit and receive steering, it is necessary to first consider the need to ensure that the over-the-air reciprocity of the TDD channel is preserved in the observed, baseband-to-baseband TDD channel. Reciprocity is critical in the functioning of these systems because it provides efficient means for a STA to learn the transfer function of the channel over which it will transmit.

In order to ensure that the baseband-to-baseband channel seen by the spatial processing engines is reciprocal, it is necessary to calibrate the STA radio to correct the differences in phase and amplitude response in the transmit and receive chains.

The reciprocity of the over-the-air TDD MIMO channel can be expressed as a transpose relationship between the channel response matrices associated with forward and reverse channels between two STAs. Consider, for example, STA A and STA B, where we will refer to the channel over which STA A transmits as the forward link, and the channel over which STA B transmits as the reverse link. Thus we will define the following two gain matrices for the over-the-air channels (the over-the-air channel is the complex baseband channel that would be realized if the transmitter and receiver responses have ideal constant gain and zero phase across the channel bandwidth):

- $\mathbf{H}_{A\to B}(\ell)$: forward link gain matrix for subcarrier ℓ
- $\mathbf{H}_{B\to A}(\ell)$: reverse link gain matrix for subcarrier ℓ,

The reciprocal relationship between these two channels is expressed as:

$$\mathbf{H}_{B\to A}(\ell) = \mathbf{H}^{t}_{A\to B}(\ell).$$

The observed channels, however, are effected by the amplitude and phase responses of the transmit and receive chains. Assuming good isolation, these can be expressed as diagonal matrices with complex valued diagonal entries, of the form $\mathbf{C}_{A,Tx}(\ell)$. The relationship between the observed channels, $\tilde{\mathbf{H}}_{A\to B}(\ell)$ and $\tilde{\mathbf{H}}_{B\to A}(\ell)$, and the over-the-air channel is

$$\tilde{\mathbf{H}}_{A\to B}(\ell) = \mathbf{C}_{B,Rx}(\ell)\mathbf{H}_{A\to B}(\ell)\mathbf{C}_{A,Tx}(\ell), \text{ and}$$

$$\tilde{\mathbf{H}}_{B\to A}(\ell) = \mathbf{C}_{A,Rx}(\ell)\mathbf{H}_{B\to A}(\ell)\mathbf{C}_{B,Tx}(\ell).$$

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The resulting observed channels are not, in general, reciprocal. However, through a simple channel sounding procedure that involves an exchange of training sequences, correction vectors can be calculated that are applied on transmit to restore reciprocity. The resulting calibration is quite stable and needs to be updated infrequently, typically on association.

The object of the procedure is to compute correction vectors $\mathbf{K}_A(\ell)$ and $\mathbf{K}_B(\ell)$ that restore reciprocity such that

$$\tilde{\mathbf{H}}_{A\to B}(\ell)\mathbf{K}_A(\ell) = \left[\tilde{\mathbf{H}}_{B\to A}(\ell)\mathbf{K}_B(\ell)\right]^t.$$

The correction vectors are applied on transmit in such a way that each element in the correction vector scales the transmit vector element associated with a specific antenna. Given a modulation symbol vector, $\mathbf{s}_A(\ell)$, in subcarrier ℓ at STA A, and beamforming matrix $\mathbf{V}(\ell)$, then the transmitted vector in subcarrier ℓ is given by $\mathbf{x}(\ell) = \mathbf{K}_A(\ell)\mathbf{V}_A(\ell)\mathbf{s}_A(\ell)$.

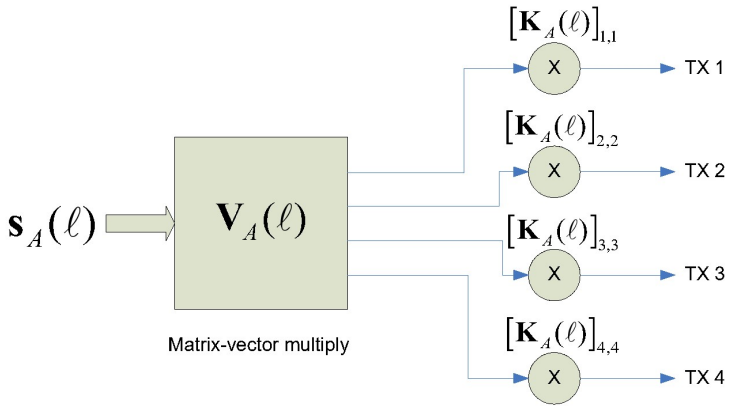


Figure 45: Application of calibration correction vector on Tx

Correction vectors that will satisfy this relationship are given by:

$$\mathbf{K}_A(\ell) = \left(\mathbf{C}_{A,Tx}(\ell)\right)^{-1}\mathbf{C}^t_{A,Rx}(\ell), \text{ and}$$

$$\mathbf{K}_B(\ell) = \left(\mathbf{C}_{B,Tx}(\ell)\right)^{-1}\mathbf{C}^t_{B,Rx}(\ell).$$

Calibration can also be applied on receive in a similar manner. Tx calibration only is addressed here.

For STAs that support only 20 MHz operation, calibration must be performed for subcarriers with indices between -26 and 26, except for the subcarrier with index 0. For STAs supporting both 20 MHz and 40 MHz operation, calibration must be performed for subcarriers with indices between -58 and 58, except for the subcarriers with indices -1, 0, and 1.

The calibration procedure is as follows:

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1. STA A transmits a Calibration Training message, initiating the calibration procedure.

2. STA B transmits a Calibration Training message, which includes the HT-LTF that allows a receiving STA A to estimate the channel matrices $\mathbf{H}_{B\to A}(\ell)$.

3. STA A transmits a Calibration Training message, which includes the HT-LTF that allows STA B to estimate the channel matrices $\mathbf{H}_{A\to B}(\ell)$.

    a. The previous two steps must occur over a sufficiently short time interval that the channel does not change over the interval.

4. STA A computes an estimate of $\mathbf{H}_{B\to A}(\ell)$ based on the received HT-LTF.

5. STA B computes an estimate of $\mathbf{H}_{A\to B}(\ell)$ based on the received HT-LTF.

6. STA B sends the quantized estimates of $\mathbf{H}_{A\to B}(\ell)$ to STA A using the Calibration Measurement Message that contains the Channel Measurement Report.

7. STA A uses the estimates of $\mathbf{H}_{B\to A}(\ell)$ and $\mathbf{H}_{A\to B}(\ell)$ to compute the correction vectors $\mathbf{K}_A(\ell)$ and $\mathbf{K}_B(\ell)$.

8. STA A sends the quantized correction vectors $\mathbf{K}_B(\ell)$ to STA B using the Calibration Correction Vector Message that contains the Correction Vector element.

9. STA A and STA B now have correction vectors and are considered to be calibrated.

Once a STA has completed the calibration procedure, the correction vectors, $\mathbf{K}(\ell)$, are assumed to be available at the STA's transmitter, and are incorporated into the transmit spatial processing procedure for all subsequent communications.

This procedure needs to be performed only once for any STA that will participate in a beamforming exchange with another STA. For example, once an AP performs this procedure with one STA, it is calibrated and may participate in a beamforming exchange with any other calibrated STA. However, in many networks, the AP will be the primary agent for calibrating client STAs. Thus a typical AP will participate in many of these calibration procedures.

11.2.2.3.4.3 Calibration for Beamforming Rx-only STAs

STAs that have no transmit beamforming capabilities, but that still are capable of receiving beamforming transmissions, are referred to as Rx-only STAs. Such STAs may participate in a calibration procedure similar to that described above. However, it is not necessary for such a STA to have calibrated RFs in order to reliably receive PPDUs that are transmitted to it using Tx beamforming.

11.2.2.3.4.4 Calibration Processing

The MIMO calibration training sequence consists of $N_{\mathrm{CAL}} = N_{Tx}$ HT-LTFs. The HT-LTF for the first stream consists of an 800 ns guard interval followed by two periods of a 3.2 μs training

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symbol sequence, for a total duration of 7.2 µs. The HT-LTF for the second, third, and fourth stream, if exist, consists of an 800 ns guard interval followed by one periods of a 3.2 µs training symbol sequence, for a total duration of 4.0 µs. For details on the format of the HT-LTF, see section 11.2.1.6.4.

11.2.2.3.5 HT-Short Training Field in BF-MIMO mode

HT-STF is identical to basic MIMO case (refer to section 11.2.1.6.3). 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 11.2.1.6.4). The HT-LTF undergoes the same spatial steering as the DATA.

11.2.2.3.7 MCS field in BF-MIMO mode

MCS set for BF-MIMO is identical to that of basic MIMO, as described in section 11.2.1.7.2.2.

11.2.2.3.8 Antenna streams / Transmitter architecture in BF-MIMO mode

The only difference in the transmitter architecture with respect to the basic MIMO mode is the introduction of the spatial steering matrix, as shown in Figure 46:

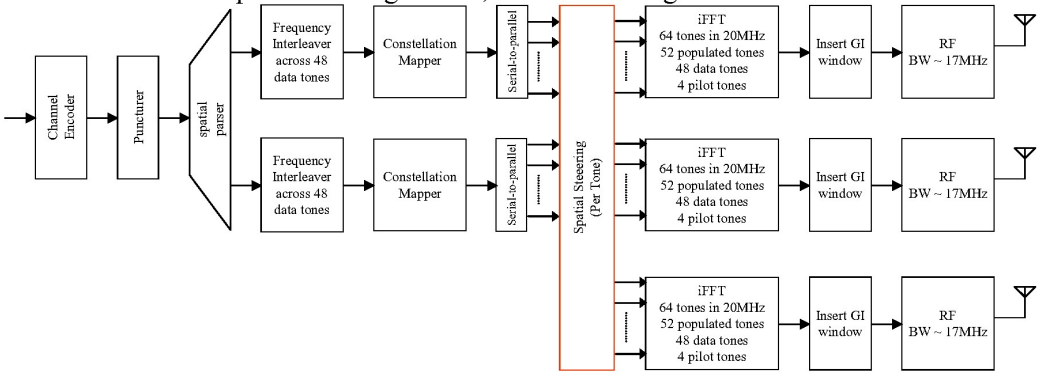


Figure 46: Transmitter architecture for TX Beamforming for N_{ss}=2,and N_{TX} = 3

11.2.2.3.9 Puncturing of Coded Data in BF-MIMO mode

TX Beamforming uses the same puncturing pattern as the basic MIMO mode, described in 11.2.1.8.6.

11.2.2.3.10 MCS set in BF-MIMO mode

Any MCS in the basic MCS set (Table 21) or the extended MCS set (Table 22) may be used in BF-MIMO. A station intending to transmit using any optional MCS (those with indices above 15) must establish support of the optional MCS at the receiving STA.

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11.2.2.3.11 Power Loading of spatial streams in BF-MIMO

All spatial streams in the BF-MIMO mode are transmitted at the same power level.

11.2.3 Low-Density Parity-Check Coding (Optional Mode)

Optional Low-Density Parity-Check (LDPC) coding may be used with all MCS's from Table 21 and Table 22.When encoding specified in this clause is applied, convolutional encoder and associated puncturing and padding shall not be used.

11.2.3.1 Code Rates and Codeword Lengths

Code rate (R) of the LDPC code may be selected from the set of code rates defined for mandatory convolutional codes (1/2, 2/3, 3/4 and 5/6). One of three codeword sizes is used to encode packets. Codeword size in bits, N, may be 576, 1152, or 1728.

11.2.3.2 PPDU Encoding using LDPC Codes

This subclause, which specifies the LDPC encoding, replaces corresponding procedure defined for mandatory convolutional codes.

LDPC codes are block codes that are specified by the parity check matrix of size MxN , which defines an LDPC block code (N,K), where K is the information block size in bits, N is the length of the codeword, and M is the number of parity check bits, M=N-K. Code rate is defined as R=K/N. The general characteristic of an LDPC parity check matrix is a low density of non-zero elements (1's in this case), which allows utilization of efficient decoding algorithms. LDPC parity check matrix is designed in a way that enables simple encoding as well. It can be represented in the following form:

$$\mathbf{H} = [\mathbf{H}^d \mid \mathbf{H}^p]$$

$\mathbf{H}^d$ is an MxK matrix and corresponds to the "data" bits of the codeword. The design of this matrix ensures high coding gain. $\mathbf{H}^p$ is an MxM modified "dual diagonal" matrix, which corresponds to the "parity" bits of the codeword. LDPC codes applied here are systematic and canonic block codes. Codewords have the following structure:

$$\mathbf{c} = \begin{bmatrix} \mathbf{d} \\ \mathbf{p} \end{bmatrix}$$

where $\mathbf{d} = [d_0, d_1, ..., d_{K-1}]^T$ is the block of (uncoded) data bits and $\mathbf{p} = [p_0, p_1, ..., p_{M-1}]^T$ are the parity bits. A codeword is any binary N-vector $\mathbf{c}$ that satisfies:

$$\mathbf{Hc} = \mathbf{H}^d\mathbf{d} + \mathbf{H}^p\mathbf{p} = \mathbf{0}.$$

Since the information packet size may not in general be a multiple of number of information bits per codeword, procedure for encoding is defined in this subclause.
Based on the MCS, following two parameters are derived first:

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$N_{CBPS} = N_{BPSC} \times N_{SD} \times N_{SS}$, number of coded bits per OFDM symbol
$N_{DBPS} = N_{CBPS} \times R$, number of information bits per OFDM symbol

where: N_{BPSC} is the number of coded bits per sub-carrier, N_{SD} is the number of data sub-carriers, and N_{SS} is the number of spatial streams.

Both shortening (padding the payload with zeros before encoding and removing those extra zero bits from transmission), and puncturing (reduction of number of bits of the codeword prior to transmission) may be applied in order to ensure minimum overhead without degrading performance.

HTLENGTH parameter in HT_SIGNAL field is calculated based on the value of two TXVECTOR array parameters: AGGREGATE and HT_LENGTH, as follows:

```
if AGGREGATE == 0
        HTLENGTH = HT_LENGTH
else
        if(N_DBPS <= 234)
                N_OFDM = ceiling (HT_LENGTH × 8/ N_DBPS) +1
        else
                N_CWORDS_MIN = ceiling (HT_LENGTH × 8/(1728 × R))
                N_SHORTENING = N_CWORDS_MIN × 1728 × R – HT_LENGTH × 8
                N_OFDM = ceiling ((N_CWORDS_MIN × 1728 – N_SHORTENING)/ N_CBPS)
        end
        HTLENGTH = 110000000000b + N_OFDM
end
```

This means that in the non-aggregate mode the HTLENGTH field specifies the number of octets in the PSDU, whereas in the aggregate mode, the HTLENGTH field (bits 0 through 9) specifies the number of transmitted OFDM symbols in the data mode.

The encoding procedure uses the following parameters as input:

HTLENGTH – containing the information as described in the previous paragraph
MCS – modulation type and code rate set

The procedure for encoding consists of the following steps:

a) Based on the contents of HTLENGTH, compute the following parameters:

```
if (the two MSBs of  HTLENGTH are NOT 11b)     // non-aggregate mode

        N_INFO_BITS = HTLENGTH ×8
        N_OFDM_MIN = ceiling (N_INFO_BITS / N_DBPS)
        N_CWORDS = ceiling (N_INFO_BITS / (1728 × R))
        n1 = ceiling (((N_INFO_BITS /R)/ N_CWORDS)/576)
        n2 = floor ((N_CBPS × N_OFDM_MIN – N_INFO_BITS) / (576 × (1-R) × N_CWORDS))
        N = max(n1, min(3,n2)) × 576
        K = N × R, M = N - K
```


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```
else                                                    // aggregate mode
    if (N_DBPS <= 234)
        N_OFDM = HTLENGTH (bits 0 through 9)
        N_INFO_BITS = (N_OFDM – 1) × N_DBPS
        N_CWORDS = ceiling (N_INFO_BITS / (1728 × R))
        n1 = ceiling (((N_INFO_BITS /R)/ N_CWORDS)/576)
        n2 = floor ((N_CBPS × N_OFDM – N_INFO_BITS)/(576 × (1-R) × N_CWORDS))
        N = max(n1, min(3,n2)) × 576
        K = N × R, M = N - K
    else
        N = 1728, K = N × R, M = N - K
        if (rem (N_OFDM × N_CBPS, N) > M)
            N_CWORDS = ceiling (N_OFDM × N_CBPS / N)
        else
            N_CWORDS = floor (N_OFDM × N_CBPS / N)
        end
        N_INFO_BITS = min (N_OFDM × N_DBPS, N_OFDM × N_CBPS – N_CWORDS×M,
            N_CWORDS × K)
    end
end
```

b) In non-aggregate mode, extra OFDM symbols may be added to guarantee performance of punctured LDPC code. The algorithm below determines the optimum number of OFDM symbols, N_{OFDM} based on following performance parameters:

- Shortening to puncturing ratio, defined as $SP_{RATIO} = (1\text{-}R)/R \times Ns/Np$, where Ns is number of shortened bits, and Np is number of punctured bits for a transmission of current PSDU. Minimum shortening to puncturing ratio is set to $SP_{RATIO\_MIN} = 1.2$
- Maximum number of extra OFDM symbols allowed is set to $N_{OFDM\_EXTRA\_MAX} = 2$

$N_{PARITY\_BITS} = \text{ceiling}\ (N_{CWORDS} \times M - (1/\ SP_{RATIO\_MIN}) \times ((1\text{-}R)/R) \times (N_{CWORDS} \times K – N_{INFO\_BITS}))$

$N_{OFDM} = \min\ (\text{ceiling}\ (N_{INFO\_BITS} / N_{DBPS}) + N_{OFDM\_EXTRA\_MAX}, \text{ceiling}\ ((N_{PARITY\_BITS} + N_{INFO\_BITS})/ N_{CBPS}))$;

c) For each of the codewords of length N determine amount of the information bits to encode, $K_1 \le K$, as well as the number of parity check bits to be transmitted, $M_1 \le M$. This, in turn, determines by how many bits to shorten the information portion of the codeword $N_{SHORTEN\_CW}$, as well as by how many bits to puncture a codeword, $N_{PUNCTURE\_CW}$. In some cases it may be required that the last codeword has different number of data and parity bits, K_{1_LAST} and M_{1_LAST}, respectively, (and consequently $N_{SHORTEN\_CW\_LAST}$ and $N_{PUNCTURE\_CW\_LAST}$) than the other codewords.
The calculations below also ensure that the last codeword may only be shortened more than others, and punctured less than others.

$K_1 = \text{ceiling}\ (N_{INFO\_BITS} /N_{CWORDS})$

$N_{PARITY\_BITS} = \min\ (N_{CWORDS} \times M, N_{OFDM} \times N_{CBPS} - N_{INFO\_BITS})$

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$M_1 = \min(M, \text{floor}(N_{PARITY\_BITS} / N_{CWORDS})$
$K_{1\_LAST} = N_{INFO\_BITS} - K_1 \times (N_{CWORDS} - 1)$
$M_{1\_LAST} = \min(M, N_{PARITY\_BITS} - M_1 \times (N_{CWORDS} - 1))$

$N_{SHORTEN\_CW} = K - K_1$
$N_{SHORTEN\_CW\_LAST} = K - K_{1\_LAST}$
$N_{PUNCTURE\_CW} = M - M_1$
$N_{PUNCTURE\_CW\_LAST} = M - M_{1\_LAST}$

d) For aggregate mode only, calculate information bits padding, $N_{PADDING\_INFO}$.

The number of zero bits, $N_{PADDING\_INFO}$, concatenated to the information bits and passed through the scrambler is calculated the following way:

$N_{PADDING\_INFO} = N_{INFO\_BITS} - HT\_LENGTH \times 8$

e) Last OFDM symbol padding field parameter computation

If the total number of coded bits doesn't fit integer number of OFDM symbols, then additional padding (scrambled zeros) bits are added to the last OFDM symbol. Number of those bits, $N_{PAD\_OFDM\_LAST}$, is computed as follows:

$N_{PAD\_OFDM\_LAST} = N_{OFDM} \times N_{CBPS} - (N_{INFO\_BITS} + M_1 \times (N_{CWORDS} - 1) + M_{1\_LAST})$

f) LDPC encoding

Generate all N_{CWORDS} codewords by applying any of the encoding methods, such that $\mathbf{Hc}_i = \mathbf{0}$, where i=0, 1, …, N_{CWORDS}-1 with shortening and puncturing as necessary. **H** is the parity check matrix for the selected codeword size and code rate. Only one **H** matrix is used for the entire packet. The information vector for the i-th codeword to be encoded is formed by concatenating K_1 scrambled bits, which include information bits and optional $N_{PADDING\_INFO}$ zeros - (denoted as z's below, last codeword, aggregate mode only), and $N_{SHORTEN\_CW} = K - K_1$ zeros:

$$\mathbf{d}^i = [\underbrace{d^i_0, d^i_1, ..., d^i_{K_1-1}}_{K}, \overbrace{0,0,...,0}^{N_{SHORTEN\_CW}}]^T \qquad \text{// non- aggregate mode}$$

$$\mathbf{d}^i = [\underbrace{d^i_0, d^i_1, ..., d^i_n, \overbrace{z^i_{n+1}, z^i_{n+2}, ..., z^i_{K_{1\_LAST}-1}}^{N_{PADDING\_INFO}}}_{K}, \overbrace{0,0,...,0}^{N_{SHORTEN\_CW}}]^T \qquad \text{// aggregate mode, last codeword}$$

After the encoding, obtained codeword is punctured (if necessary) by removing the last $N_{PUNCTURE\_CW}$ bits:

// non- aggregate mode

$$\mathbf{c}^i = [\underbrace{d^i_0, d^i_1, ..., d^i_{K_1-1}}_{K}, \overbrace{0,0,...,0}^{N_{SHORTEN\_CW}}, \underbrace{p^i_0, p^i_1, ..., p^i_{M_1-1}, \overbrace{p^i_{M_1}}^{N_{PUNCTURE\_CW}}, p^i_{M_1+1}, ..., p^i_{M-1}}_{M}]^T$$

// aggregate mode, last codeword

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$$\mathbf{c}^i = [\underbrace{d^i_0, d^i_1, ..., d^i_n, \overbrace{z^i_{n+1}, z^i_{n+2}, ..., z^i_{K_{1\_LAST}-1}}^{N_{PADDING\_INFO}}}_{K}, \overbrace{0,0,...,0}^{N_{SHORTEN\_CW}}, \underbrace{p^i_0, p^i_1, ..., p^i_{M_1-1}, \overbrace{p^i_{M_1}, p^i_{M_1+1}, ..., p^i_{M-1}}^{N_{PUNCTURE\_CW}}}_{M}]^T$$

Shortened and punctured bits are not transmitted over the air. Rather, a concatenation of K_1 data bits and M_1 parity bits is transmitted only:

// non- aggregate mode

$$\mathbf{c}^i_{transmit} = [\underbrace{d^i_0, d^i_1, ..., d^i_{K_1-1}}_{K_1}, \underbrace{p^i_0, p^i_1, ..., p^i_{M_1-1}}_{M_1}]^T$$

// aggregate mode, last codeword

$$\mathbf{c}^i_{transmit} = [\underbrace{d^i_0, d^i_1, ..., d^i_n, z^i_{n+1}, z^i_{n+2}, ..., z^i_{K_{1\_LAST}-1}}_{K_{1\_LAST}}, \underbrace{p^i_0, p^i_1, ..., p^i_{M_1-1}}_{M_{1\_LAST}}]^T$$

g) Codeword and the last OFDM symbol padding field concatenation

Concatenate N_{CWORDS} codewords and $N_{PAD\_OFDM\_LAST}$ padding bits (denoted as q's below) to form a vector of bits to be transmitted:

// non- aggregate mode

$$\mathbf{c}_{transmit} = [d^0_0, ..., d^0_{K_1-1}, p^0_0, ..., p^0_{M_1-1}, ..., d^{N_{CWORDS}-1}_0, ..., d^{N_{CWORDS}-1}_{K_{1\_LAST}-1}, p^{N_{CWORDS}-1}_0, ..., p^{N_{CWORDS}-1}_{M_{1\_LAST}-1}, q_0, ..., q_{N_{PAD\_OFDM\_LAST}-1}]^T$$

// aggregate mode

$$\mathbf{c}_{transmit} = [d^0_0, ..., d^0_{K_1-1}, p^0_0, ..., p^0_{M_1-1}, ..., d^{N_{CWORDS}-1}_0, ..., z^{N_{CWORDS}-1}_{K_{1\_LAST}-1}, p^{N_{CWORDS}-1}_0, ..., p^{N_{CWORDS}-1}_{M_{1\_LAST}-1}, q_0, ..., q_{N_{PAD\_OFDM\_LAST}-1}]^T$$

Bit d^0_0 is transmitted first.

11.2.3.3 LDPC Coding with Extended MCS Set

LDPC codes may be utilized with both basic and extended MCS. When extended MCS (Table 22) is used, unequal data rates per spatial stream are used, i.e., equal code rate, but unequal modulation per stream. The number of coded bits per OFDM symbol, N_{CBPS}, is derived in a slightly different manner in this case:

$$N_{CBPS} = N_{SD} \times \sum_{i=1}^{N_{SS}} N_{BPSC}(i)$$

where $N_{BPSC}(i)$ is the number of coded bits per sub-carrier in the ith spatial stream, N_{SD} is the number of data sub-carriers, and N_{SS} is the number of spatial streams.

Apart from this derivation the PPDU encoding procedure is identical to that of basic MIMO.

11.2.3.4 Parity Check Matrices

Parity check matrices **H** used in Step c) of the encoding procedure, described in sub-clause 11.2.3.2, are derived from one of the "base" parity check matrices, $\mathbf{H_b}$, specified below. One base

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matrix is defined per code rate. Size of a base parity check matrix is denoted as $M_b \times N_b$. N_b, the number of columns in the base matrix, is fixed for all code rates, $N_b=24$. M_b, the number of rows in the base matrix, depends on the code rate as follows: $M_b = N_b(1-R)$. Parity check matrix **H** of size $M \times N$ is generated by expanding the base matrix for the selected rate, $\mathbf{H_b}$, z-times: $z=N/N_b=M/M_b$. The expansion operation is defined by element values of the base matrix. Each non-negative base matrix element, s, is replaced by a $z \times z$ identity matrix, $\mathbf{I}_z$, cyclically shifted to the right $s'=s_{mod(z)}$ times. Each negative number (-1) in the base matrix is replaced by a $z \times z$ zero matrix, $\mathbf{0}_{zxz}$. For the codeword of size 576 bits, z = 24, for codeword of size 1152 bits, z = 48, and for the codeword of size 1728 bits, z = 72.

Base matrices specification

Rate 1/2: $M_b \times N_b = 12 \times 24$

```
 0  0 -1  0 -1  0 -1 -1 -1  0 -1 -1  1  0 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
29 -1  0 26 -1 -1  0 -1  0 -1 -1 -1 -1  0  0 -1 -1 -1 -1 -1 -1 -1 -1 -1
-1 -1 -1 21  0 -1 17 -1 -1 38 -1  0 -1 -1  0  0 -1 -1 -1 -1 -1 -1 -1 -1
43 -1 -1 30 -1 -1 -1  0 -1 41  0 -1 -1 -1 -1  0  0 -1 -1 -1 -1 -1 -1 -1
 5 -1  1 -1 -1 20 35 -1 -1  2 -1 -1 -1 -1 -1 -1  0  0 -1 -1 -1 -1 -1 -1
-1 46 -1 -1 -1 -1 22 -1 40  8 -1 -1  0 -1 -1 -1 -1  0  0 -1 -1 -1 -1 -1
-1 -1 -1  9 -1 -1 18 13 -1 35 -1 27 -1 -1 -1 -1 -1 -1  0  0 -1 -1 -1 -1
 2 -1 44 -1 -1 -1 27 -1 -1 25 18 -1 -1 -1 -1 -1 -1 -1 -1  0  0 -1 -1 -1
33 35 -1 29 -1 -1 16 -1 -1 -1 -1 30 -1 -1 -1 -1 -1 -1 -1 -1  0  0 -1 -1
-1 -1 -1  4  4 -1 -1 -1 15 17 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1  0  0 -1
 5 -1 -1 19 -1 14 -1 -1 -1 -1 11 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1  0  0
10 -1 -1 -1 21 -1 18  8 -1 -1 -1 -1  1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1  0
```

Rate 2/3: $M_b \times N_b = 8 \times 24$

```
71 40 -1 -1 11 40 -1 -1 -1 69 -1 59 10 -1 -1 21 46  0 -1 -1 -1 -1 -1 -1
18 -1 35 51 27 -1 -1 49 17 -1 -1 37  4 -1 -1 -1 -1  0  0 -1 -1 -1 -1 -1
42 52 -1 -1 12 -1 54 -1 43 -1 62 62 52 -1 -1 -1 -1 -1  0  0 -1 -1 -1 -1
13 -1 27 -1 -1 -1  5 -1 28 33 -1 -1 58 47 18 -1  0 -1 -1  0  0 -1 -1 -1
-1 -1 -1 38 50 -1  7  9 34 -1 -1 -1 65 -1 17 70 -1 -1 -1 -1  0  0 -1 -1
71 -1 -1 39 62 14 -1 -1 53 -1 39 -1  2 67 -1 -1 -1 -1 -1 -1 -1  0  0 -1
54 56 -1 -1 53 -1 -1  2 66 57 -1 -1 -1 24 -1 52 -1 -1 -1 -1 -1 -1  0  0
17 -1 44 -1 44 29 -1 -1 48 -1 26 -1 39 -1 14 -1 46 -1 -1 -1 -1 -1 -1  0
```

Rate 3/4: $M_b \times N_b = 6 \times 24$

```
 0 23 -1 -1  0 47 53  1 -1  5 -1 13 66 34 -1 62 65 -1  1  0 -1 -1 -1 -1
14 57  7 11 -1 -1 69 -1 25 34 -1 25 13 -1 19 70 -1 35 -1  0  0 -1 -1 -1
59  3 -1 18 -1 43 48 58 -1 29 -1 54 49 -1 25  0 66 -1 -1 -1  0  0 -1 -1
15  1  2 -1 -1 39 19 -1 37 64 52 -1 28  4 -1 21 20 -1  0 -1 -1  0  0 -1
22 64 -1 48 60 -1 36 -1 15 62 68 -1 46 55 -1 41 -1  7 -1 -1 -1 -1  0  0
63 36 57 -1 55 -1 41 34 -1 45 46 -1  8 -1 37 44 -1 15  1 -1 -1 -1 -1  0
```

Rate 5/6: $M_b \times N_b = 4 \times 24$

```
11 26 59 44 36 45 51 32 13 60  3 70 47 21 -1 67 52 49 15 -1  1  0 -1 -1
39 58 28 60 43 55 30 51 49 13 50  4 -1 26 10 -1 30 58 28 22 -1  0  0 -1
36 11 35 38  1  5  9 36 15 47 -1 39 39 -1 71 53 66 -1 20 45  0 -1  0  0
54 67 51  0 15 65 24 17 38 58 53 -1 11  2  2 26 -1 15 -1  6  1 -1 -1  0
```


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(END)

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