

IEEE Standard for Information technology—
Telecommunications and information exchange between systems
Local and metropolitan area networks—
Specific requirements

Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

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3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 802.11™-2016
(Revision of
IEEE Std 802.11-2012)

**IEEE Standard for Information technology—
Telecommunications and information exchange between systems
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Specific requirements**

Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

**Prepared by the 802.11 Working Group of the
LAN/MAN Standards Committee
of the
IEEE Computer Society**

**Approved 7 December 2016
IEEE-SA Standards Board**

Abstract: Technical corrections and clarifications to IEEE Std 802.11 for wireless local area networks (WLANs) as well as enhancements to the existing medium access control (MAC) and physical layer (PHY) functions are specified in this revision. Amendments 1 to 5 published in 2012 and 2013 have also been incorporated into this revision.

Keywords: 2.4 GHz, 256-QAM, 3650 MHz, 4.9 GHz, 5 GHz, 5.9 GHz, 60 GHz, advanced encryption standard, AES, audio, beamforming, carrier sense multiple access/collision avoidance, CCMP, channel switching, clustering, contention based access period, Counter mode with Cipher-block chaining Message authentication code Protocol, confidentiality, CSMA/CA, DFS, direct link, directional multi-gigabit, dynamic allocation of service period, dynamic extension of service period, dynamic frequency selection, dynamic truncation of service period, E911, EDCA, emergency alert system, emergency services, fast session transfer, forwarding, GCMP, generic advertisement service, high throughput, IEEE 802.11™, international roaming, interworking, interworking with external networks, LAN, local area network, MAC, management, measurement, medium access control, media-independent handover, medium access controller, mesh, MIH, millimeter-wave, MIMO, MIMO-OFDM, multi-band operation, multi-hop, multi-user MIMO, multiple input multiple output, network advertisement, network discovery, network management, network selection, noncontiguous frequency segments, OCB, path-selection, personal basic service set, PHY, physical layer, power saving, QoS, quality of service, quality-of-service management frame, radio, radio frequency, RF, radio resource, radio management, relay operation, spatial sharing, SSPN, subscriber service provider, television white spaces, TPC, transmit power control, video, wireless access in vehicular environments, wireless LAN, wireless local area network, WLAN, wireless network management, zero-knowledge proof

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Introduction

This introduction is not part of IEEE Std 802.11-2016, IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area network—Specific requirements—Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.

This revision gives users, in one document, the IEEE 802.11 standard for wireless local area networks (WLANs) with all of the amendments that have been published to date.

Incorporating published amendments

The original standard was published in 1997, revised in 1999 with MIB changes, and reaffirmed in 2003.

A revision was published in 2007, which incorporated into the 1999 edition the following amendments:

- IEEE Std 802.11a™-1999: High-speed Physical Layer in the 5 GHz Band (Amendment 1)
- IEEE Std 802.11b™-1999: Higher-Speed Physical Layer Extension in the 2.4 GHz Band (Amendment 2)
- IEEE Std 802.11b-1999/Corrigendum 1-2001: Higher-speed Physical Layer (PHY) extension in the 2.4 GHz band (Corrigendum 1 to Amendment 2)
- IEEE Std 802.11d™-2001: Specification for operation in additional regulatory domains (Amendment 3)
- IEEE Std 802.11g™-2003: Further Higher Data Rate Extension in the 2.4 GHz Band (Amendment 4)
- IEEE Std 802.11h™-2003: Spectrum and Transmit Power Management Extensions in the 5 GHz band in Europe (Amendment 5)
- IEEE Std 802.11i™-2004: Medium Access Control (MAC) Security Enhancements (Amendment 6)
- IEEE Std 802.11j™-2004: 4.9 GHz–5 GHz Operation in Japan (Amendment 7)
- IEEE Std 802.11e™-2005: Medium Access Control (MAC) Quality of Service Enhancements (Amendment 8)

A revision was published in 2012, which incorporated into the 2007 revision the following amendments:

- IEEE Std 802.11k™-2008: Radio Resource Measurement of Wireless LANs (Amendment 1)
- IEEE Std 802.11r™-2008: Fast Basic Service Set (BSS) Transition (Amendment 2)
- IEEE Std 802.11y™-2008: 3650–3700 MHz Operation in USA (Amendment 3)
- IEEE Std 802.11w™-2009: Protected Management Frames (Amendment 4)
- IEEE Std 802.11n™-2009: Enhancements for Higher Throughput (Amendment 5)
- IEEE Std 802.11p™-2010: Wireless Access in Vehicular Environments (Amendment 6)
- IEEE Std 802.11z™-2010: Extensions to Direct-Link Setup (DLS) (Amendment 7)
- IEEE Std 802.11v™-2011: Wireless Network Management (Amendment 8)
- IEEE Std 802.11u™-2011: Interworking with External Networks (Amendment 9)
- IEEE Std 802.11s™-2011: Mesh Networking (Amendment 10)

This revision is based on IEEE Std 802.11-2012, into which the following amendments have been incorporated:

- IEEE Std 802.11ae™-2012: Prioritization of Management Frames (Amendment 1)
- IEEE Std 802.11aa™-2012: MAC Enhancements for Robust Audio Video Streaming (Amendment 2)

- IEEE Std 802.11ad™-2012: Enhancements for Very High Throughput in the 60 GHz Band (Amendment 3)
- IEEE Std 802.11ac™-2013: Enhancements for Very High Throughput for Operation in Bands below 6 GHz (Amendment 4)
- IEEE Std 802.11af™-2013: Television White Spaces (TVWS) Operation (Amendment 5)

Technical corrections, clarifications, and enhancements

In addition, this revision specifies technical corrections and clarifications to IEEE Std 802.11 as well as enhancements to the existing medium access control (MAC) and physical layer (PHY) functions. In addition, this revision removes some features previously marked as obsolete and adds new indications of other obsolete features.

Renumbering of clauses and annexes

The numbering of certain clauses and annexes has been modified since IEEE Std 802.11-2012.

The evolution of this numbering is shown in Figure i.

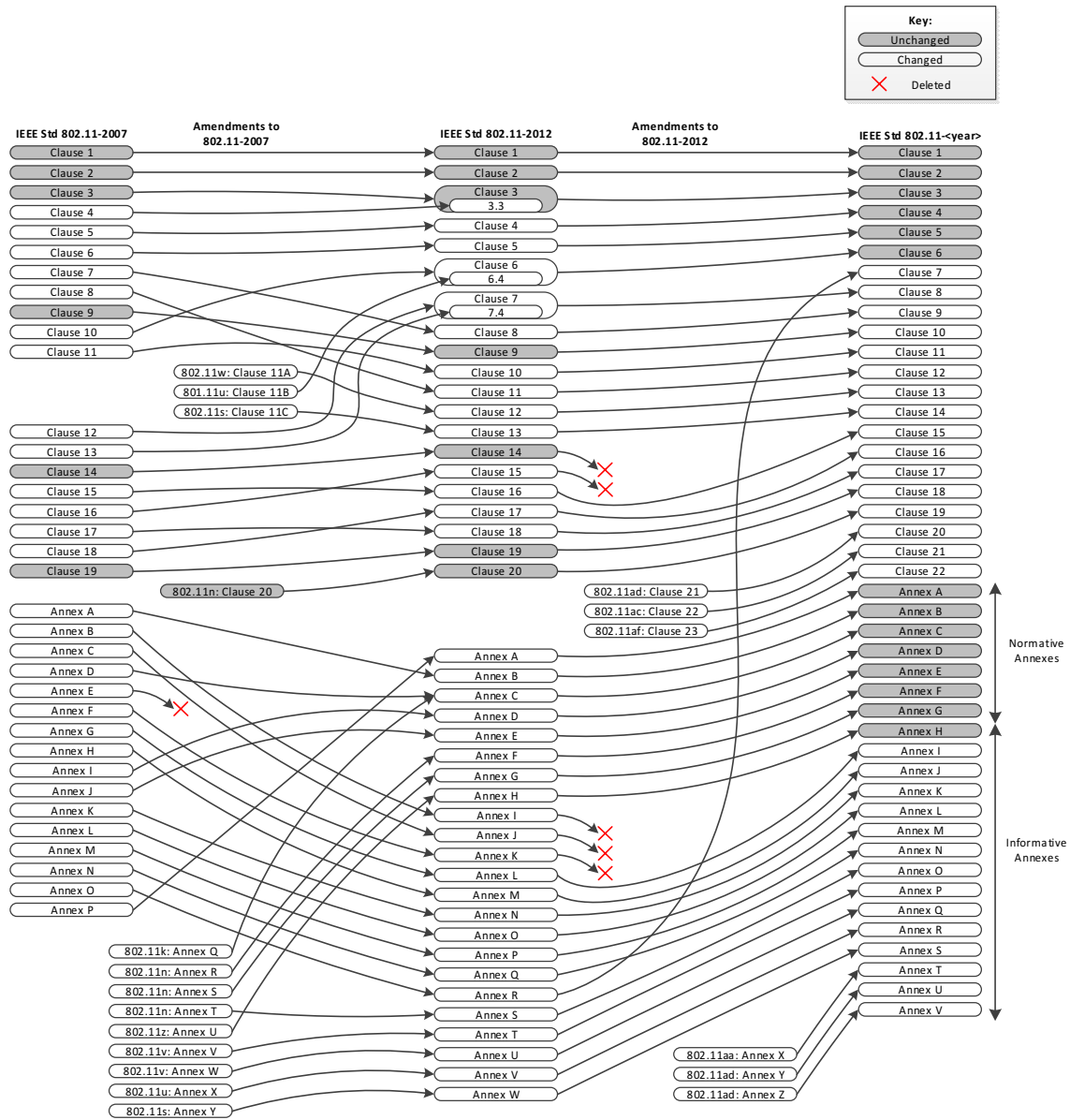


Figure i—The evolution of numbering in IEEE Std 802.11

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**IEEE Standard for Information technology—
Telecommunications and information exchange between systems
Local and metropolitan area networks—
Specific requirements**

Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

1. Overview

1.1 Scope

The scope of this standard is to define one medium access control (MAC) and several physical layer (PHY) specifications for wireless connectivity for fixed, portable, and moving stations (STAs) within a local area.

1.2 Purpose

The purpose of this standard is to provide wireless connectivity for fixed, portable, and moving stations within a local area. This standard also offers regulatory bodies a means of standardizing access to one or more frequency bands for the purpose of local area communication.

1.3 Supplementary information on purpose

Specifically, in the context of IEEE 802.11™-compliant devices, this standard

- Describes the functions and services required by a device to operate within independent, personal, and infrastructure networks as well as the aspects of device mobility (transition) within those networks.
- Describes the functions and services that allow a device to communicate directly with another such device outside of an independent or infrastructure network.
- Defines the MAC procedures to support the MAC service data unit (MSDU) delivery services.
- Defines several PHY signaling techniques and interface functions that are controlled by the MAC.
- Permits the operation of a device within a wireless local area network (WLAN) that coexists with multiple overlapping IEEE 802.11 WLANs.
- Describes the requirements and procedures to provide data confidentiality of user information and MAC management information being transferred over the wireless medium (WM) and authentication of devices.
- Defines mechanisms for dynamic frequency selection (DFS) and transmit power control (TPC) that may be used to satisfy regulatory requirements for operation in any band.

- Defines the MAC procedures to support local area network (LAN) applications with quality-of-service (QoS) requirements, including the transport of voice, audio, and video.
- Defines mechanisms and services for wireless network management of devices that include BSS transition management, channel usage and coexistence, collocated interference reporting, diagnostic, multicast diagnostic and event reporting, flexible multicast, efficient beacon mechanisms, proxy ARP advertisement, location, timing measurement, directed multicast, extended sleep modes, traffic filtering, and management notification.
- Defines functions and procedures aiding network discovery and selection by devices, information transfer from external networks using QoS mapping, and a general mechanism for the provision of emergency services.
- Defines the MAC procedures that are necessary for wireless multi-hop communication to support wireless LAN mesh topologies.
- Defines medium access control mechanisms to support the prioritization of Management frames.
- Defines mechanisms to improve audio video (AV) streaming QoS while maintaining data and voice performance.
- Defines the PHY signaling, MAC, and beamforming procedures required for operation with directional antenna patterns.

1.4 Word usage

In this document, the word *shall* is used to indicate a mandatory requirement. The word *should* is used to indicate a recommendation. The word *may* is used to indicate a permissible action. The word *can* is used for statements of possibility and capability.

The construction “*x* to *y*” or “*x-y*” represents an inclusive range (i.e., the range includes both values *x* and *y*).

The construction “up to *y*” represents an inclusive upper bound (i.e., the range includes the value *y*).

Any action specified as relating to a SAP primitive is to be interpreted as an action on an invocation or instance of that primitive.

If *<x>* represents a scalar field, scalar subfield, scalar parameter or scalar MIB attribute:

- if “*<x>* is” is used in a context that relates to the testing or setting the value of “*<x>*” this usage is to be interpreted as though written “the value of *<x>* is”
- “*<x>* indicate(s)” is to be interpreted as though written “the value of *<x>* indicate(s)”
- “indicated by *<x>*” is to be interpreted as though written “indicated by the value of *<x>*”
- “*<x>* that indicate” is to be interpreted as though written “*<x>* whose value indicates”

If *<x>* represents a frame, element, subelement, structured field, structured subfield, structured parameter or structured MIB attribute:

- “*<x>* indicate(s)” is to be interpreted as though written “the contents of *<x>* indicate”
- “indicated by *<x>*” is to be interpreted as though written “indicated by the contents of *<x>*”
- “*<x>* that indicate” is to be interpreted as though written “*<x>* whose contents indicate”

If *<x>* represents a SAP primitive:

- “*<x>* indicate(s)” is to be interpreted as though written “the (or an) invocation of *<x>* indicates”
- “indicated by *<x>*” is to be interpreted as though written “indicated by the (or an) invocation of *<x>*”

The construction of descriptions for uses of the SHA family of hash functions [HMAC-]SHA-<1,256,384>[- n] is used to refer to hash functions/HMACs where square brackets indicate optional information, and n is an integer indicating the length, in bits, of the output when truncating.

1.5 Terminology for mathematical, logical, and bit operations

Floor (x), also written as $\lfloor x \rfloor$, is the largest integer smaller than or equal to x . For example, Floor (2.3) is 2 and Floor (−2.3) is −3. The two parameter form, Floor (x , y), is the largest multiple of y smaller than or equal to x ; this operator is not used in this standard if y is negative. For example, Floor (3.3, 2) is 2 and Floor (−3.3, 2) is −4.

Ceil (x), also written as $\lceil x \rceil$ is the smallest integer larger than or equal to x . For example, Ceil (2.3) is 3 and Ceil (−2.3) is −2. The two parameter form, Ceil (x , y), is the smallest multiple of y larger than or equal to x ; this operator is not used in this standard if y is negative. For example, Ceil (2.3, 2) is 4 and Ceil (−2.3, 2) is −2.

Round (x) is the integer closest to x , rounding values with a fractional part of 0.5 away from zero. For example, Round (2.3) is 2, Round (2.5) is 3, Round (−2.3) is −2 and Round (−2.5) is −3.

$x \bmod y$ is the remainder when x is divided by y ; this operator is not used in this standard if y is negative; the result is positive even if x is negative. For example, $5 \bmod 3$ is 2 and $-5 \bmod 3$ is 1.

The symbol $\oplus$ represents bitwise exclusive OR (XOR).

$\log_2(x)$ is the logarithm of x to the base 2. For example, $\log_2(32)$ is 5.

Re (z) is the real part of complex number z . Im (z) is the imaginary part of complex number z (not including the factor i). For example, Re ($1 - 2i$) is 1 and Im ($1 - 2i$) is −2.

$x \&\& y$ is the short-circuiting Boolean AND.

$x \parallel y$ is the concatenation of x and y , except in code, where it sometimes is the short-circuiting Boolean OR (as determined by the context).

$!x$ is the Boolean NOT.

$x \gg y$ is x logically shifted right (i.e., zeros are inserted at the most significant end) by y ; this operator is not used in this standard if y is negative.

$x \ll y$ is x shifted left (i.e., zeros are inserted at the least significant end) by y ; this operator is not used in this standard if y is negative.

$x == y$ is Boolean equality.

$x != y$ Boolean inequality.

$x \& y$, where x and y are numbers, is the bitwise AND of x and y .

$x | y$, where x and y are numbers, is the bitwise OR of x and y .

0x introduces a hexadecimal number. For example, 0x12 is 18 decimal.

$L(S, F, N)$ is bits F to $F+N-1$ of the bit string S starting from the left, using the IEEE 802.11 bit conventions from 9.2.2.

$\text{Truncate-}N(S)$ is bits 0 to $N-1$ of the bit string S starting from the left, using the IEEE 802.11 bit conventions from 9.2.2). Other bits are irretrievably deleted.

$\exp(x)$ is e to the power x , where e is the base of natural logarithms.

2. Normative references

The following referenced documents are indispensable for the application of this standard (i.e., they must be understood and used; therefore, each referenced document is cited in the text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) at the time of publication of this standard applies.

3GPP TS 24.302, Access to the 3GPP Evolved Packet Core (EPC) via non-3GPP access networks; Stage 3.¹

ETSI EN 301 893, Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN; Part 2: Harmonized EN covering essential requirements of article 3.2 of the R&TTE Directive.²

FIPS PUB 180-4, Secure Hash Standard.³

FIPS PUB 197, Advanced Encryption Standard (AES).

IANA EAP Method Type Numbers, <http://www.iana.org/assignments/eap-numbers>.

IEEE Std 754™-2008, IEEE Standard for Binary Floating-Point Arithmetic.^{4,5}

IEEE Std 802®-2014, IEEE Standards for Local and Metropolitan Area Networks: Overview and Architecture.

IEEE Std 802.1AS™, IEEE Standard for Local and Metropolitan Area Networks—Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks.

IEEE Std 802.1Q™-2003, IEEE Standard for Local and Metropolitan Area Networks: Media Access Control (MAC) Bridges and Virtual Bridged Local Area Networks.

IEEE Std 802.1Q™-2011, IEEE Standard for Local and Metropolitan Area Networks: Media Access Control (MAC) Bridges and Virtual Bridged Local Area Networks.

IEEE Std 802.1X™-2010, IEEE Standard for Local and Metropolitan Area Networks: Port-Based Network Access Control.

IEEE Std 802.21™-2008, IEEE Standard for Local and Metropolitan Area Networks: Media Independent Handover Services.

¹3GPP™ documents are available from the 3rd Generation Partnership Project Web site (<http://www.3gpp.org>).

²ETSI documents are available from the European Telecommunications Standards Institute (<http://www.etsi.org>).

³FIPS publications are available from the National Technical Information Service (NTIS) (<http://csrc.nist.gov>).

⁴The IEEE standards or products referred to in this clause are trademarks owned by The Institute of Electrical and Electronics Engineers, Inc.

⁵IEEE publications are available from The Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).

IEEE Std 802.3™-2012, IEEE Standard for Ethernet.

IETF RFC 791, Internet Protocol, Sept. 1981.⁶

IETF RFC 826, An Ethernet Address Resolution Protocol, David C. Plummer, November 1982.

IETF RFC 925, Multi-LAN Address Resolution, J. Postel, Oct. 1984.

IETF RFC 1035, Domain Names — Implementation and Specification, P. Mockapetris, Nov. 1987.

IETF RFC 1042, A Standard for the Transmission of IP Datagrams over IEEE 802® Networks, J. Postel, J. Reynolds, Feb. 1988.

IETF RFC 1321, The MD5 Message-Digest Algorithm, Apr. 1992 (status: informational).

IETF RFC 2104, HMAC: Keyed-Hashing for Message Authentication, H. Krawczyk, M. Bellare, R. Canetti, Feb. 1997 (status: informational).

IETF RFC 2409, The Internet Key Exchange (IKE), D. Harkins, D. Carrel, Nov. 1998 (status: Standards Track).

IETF RFC 2460, Internet Protocol, Version 6 (IPv6), S. Deering, R. Hinden, Dec. 1998.

IETF RFC 5424, The Syslog Protocol, R. Gerhards, March 2009.

IETF RFC 3394, Advanced Encryption Standard (AES) Key Wrap Algorithm, J. Schaad, R. Housley, Sept. 2002 (status: informational).

IETF RFC 3610, Counter with CBC-MAC (CCM), D. Whiting, R. Housley, N. Ferguson, Sept. 2003 (status: informational).

IETF RFC 3629, UTF-8, a transformation format of ISO 10646, F. Yergeau, Nov. 2003.

IETF RFC 3748, Extensible Authentication Protocol (EAP), B. Aboba, L. Blunk, J. Vollbrecht, J. Carlson, H. Levkowetz, June 2004.

IETF RFC 3986, Uniform Resource Identifier (URI): Generic Syntax, Jan. 2005.

IETF RFC 4017, Extensible Authentication Protocol (EAP) Method Requirements for Wireless LANs, D. Stanley, J. Walker, B. Aboba, Mar. 2005 (status: informational).

IETF RFC 4119, A Presence-based GEOPRIV Location Object Format, J. Peterson, December 2005.

IETF RFC 4282, The Network Access Identifier, Dec. 2005.

IETF RFC 4776, Dynamic Host Configuration Protocol (DHCPv4 and DHCPv6) Option for Civic Addresses Configuration Information, Nov. 2006.

IETF RFC 4861, Neighbor Discovery for IP version 6 (IPv6), T. Narten, E. Nordmark, W. Simpson, H. Soliman, Sept. 2007.

IETF RFC 5216, The EAP-TLS Authentication Protocol, D. Simon, B. Aboba, R. Hurst, March 2008.

⁶IETF documents (i.e., RFCs) are available for download at <http://tools.ietf.org/html/> and <http://tools.ietf.org/pdf/>.

IETF RFC 5227, IPv4 Address Conflict Detection, S. Cheshire, July 2008.

IETF RFC 5297, Synthetic Initialization Vector (SIV) Authenticated Encryption Using the Advanced Encryption Standard (AES), D. Harkins, October 2008 (status: informational).

IETF RFC 5985, HTTP-Enabled Location Delivery (HELD), M. Barnes (Ed.), September 2010.

IETF RFC 6225, Dynamic Host Configuration Protocol Options for Coordinate-Based Location Configuration Information, J. Polk, M. Linsner, M. Thomson, B. Aboba, July 2011.

ISO 639, Codes for the Representation of Names of Languages.

ISO 14962:1997, Space data and information transfer systems — ASCII encoded English.

ISO 3166-1, Codes for the representation of names of countries and their subdivisions—Part 1: Country codes.⁷

ISO 3166-2, Codes for the representation of names of countries and their subdivisions— Part 2: Country subdivision code.

ISO 4217 Currency codes.⁸

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

ISO/IEC 8802-2:1998, Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 2: Logical link control.

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

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

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

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

ISO/IEC 11802-5:1997, Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Technical reports and guidelines—Part 5: Medium Access Control (MAC) Bridging of Ethernet V2.0 in Local Area Networks (previously known as IEEE Std 802.1H-1997 [B24]⁹).

ISO/IEC 15802-3, Information Technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Common specifications—Part 3: Media Access Control (MAC) Bridges.

⁷ISO/IEC publications are available from the ISO Central Secretariat (<http://www.iso.ch/>). ISO/IEC publications are also available in the United States from the American National Standards Institute (<http://www ansi.org/>).

⁸See <http://www.currency-iso.org/en/home/tables/table-a1.html>

⁹The numbers in brackets correspond to the numbers of the bibliography in Annex A.

ITU-R Recommendation TF.460-4(2002), Standard-frequency and time-signal emissions.¹⁰

ITU-T Recommendation O.150, General requirements for instrumentation for performance measurements on digital transmission equipment.

ITU-T Recommendation Z.120 (2004), Programming Languages—Formal Description Techniques (FDT)—Message Sequence Chart (MSC).

NIST Special Publication 800-38B, Recommendation for Block Cipher Modes of Operation: The CMAC Mode for Authentication, Dworkin, M.¹¹

NIST Special Publication 800-38D, Recommendation for Block Cipher Modes of Operation: Galois/Counter Mode (GCM) and GMAC, Morris Dworkin, November 2007.

OASIS Emergency Management Technical Committee, “Emergency Data Exchange Language (EDXL) Distribution Element, v. 1.0.” OASIS Standard EDXL-DE v1.0, May 2006.

OMA OMA-TS-ULP-V2_0_1 UserPlane Location Protocol, December 2012.¹²

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this standard, the following terms and definitions apply. IEEE Standards Dictionary Online should be referenced for terms not defined in this clause.¹³

access control: The prevention of unauthorized usage of resources.

access point (AP): An entity that contains one station (STA) and provides access to the distribution services, via the wireless medium (WM) for associated STAs. An AP comprises a STA and a distribution system access function (DSAF).

access point (AP) reachability: An AP is reachable by a station (STA) if preauthentication messages can be exchanged between the STA and the target AP via the distribution system (DS).

NOTE—Preauthentication is defined in 12.6.10.2.¹⁴

additional authentication data (AAD): Data that are not encrypted, but are cryptographically protected.

admission control: An algorithm intended to prevent the violation of parameterized service commitments made by the network to admitted flows by controlling the admittance of a new flow into a resource constrained network.

aggregate medium access control (MAC) protocol data unit (A-MPDU): A structure that contains one or more MPDUs and is transported by a physical layer (PHY) as a single PHY service data unit (PSDU).

¹⁰ITU publications are available from the International Telecommunications Union (<http://www.itu.int/>).

¹¹NIST publications are available from the National Institute of Standards and Technology (<http://csrc.nist.gov/>).

¹²OMA publications are available from the Open Mobile Alliance (<http://openmobilealliance.org/>).

¹³IEEE Standards Dictionary Online is available at <http://ieeexplore.ieee.org/xpls/dictionary.jsp>.

¹⁴Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement the standard.

aggregate medium access control (MAC) protocol data unit (A-MPDU) subframe: A portion of an A-MPDU that contains a delimiter and optionally contains an MPDU plus any necessary padding.

aggregate medium access control (MAC) service data unit (A-MSDU): A structure that contains one or more MSDUs and is transported within a single (unfragmented) data medium access control (MAC) protocol data unit (MPDU).

aggregate medium access control (MAC) service data unit (A-MSDU) subframe: A portion of an A-MSDU that contains a header and associated MSDU.

antenna connector: The measurement point of reference for radio frequency (RF) measurements in a station (STA). The antenna connector is the point in the STA architecture representing the input of the receiver (output of the antenna) for radio reception and the input of the antenna (output of the transmitter) for radio transmission. In systems using multiple antennas or antenna arrays, the antenna connector is a virtual point representing the aggregate output of (or input to) the multiple antennas. In systems using active antenna arrays with processing, the antenna connector is the output of the active array, which includes any processing gain of the active antenna subsystem.

antenna selection (ASEL) receiver: A station (STA) that performs receive ASEL.

antenna selection (ASEL) transmitter: A station (STA) that performs transmit ASEL.

antenna weight vector (AWV): A vector of weights describing the excitation (amplitude and phase) for each element of an antenna array.

association: The service used to establish access point/station (AP/STA) mapping and enable STA invocation of the distribution system services (DSSs).

authentication: The service used to establish the identity of one station (STA) as a member of the set of STAs authorized to associate with another STA.

Authentication Server (AS): An entity that provides an authentication service to an Authenticator. This service determines, from the credentials provided by the Supplicant, whether the Supplicant is authorized to access the services provided by the Authenticator. (IEEE Std 802.1X-2010¹⁵)

Authenticator: An entity at one end of a point-to-point LAN segment that facilitates authentication of the entity attached to the other end of that link. (IEEE Std 802.1X-2010)

authenticator address (AA): The medium access control (MAC) address of the IEEE 802.1X Authenticator.

authorization: The act of determining whether a particular right, such as access to a resource, is granted to an entity.

NOTE—See IETF RFC 2903 [B35].

authorized: To be explicitly allowed.

average noise plus interference power indicator (ANIP): A medium access control (MAC) indication of the average noise plus interference power measured on a channel that meets the two simultaneous conditions: 1) the station (STA) is not transmitting a frame, and 2) the station (STA) is not receiving a frame addressed to itself.

¹⁵Information on references can be found in Clause 2.

azimuth: The horizontal orientation of the front surface of a station or of a radio antenna system's main lobe measured clockwise from true north.

basic service area (BSA): The area containing the members of a basic service set (BSS). It might contain members of other BSSs.

basic service set (BSS): A set of stations (STAs) that have successfully synchronized using the JOIN service primitives¹⁶ and one STA that has used the START primitive. Alternatively, a set of STAs that have used the START primitive specifying matching mesh profiles where the match of the mesh profiles has been verified via the scanning procedure. Membership in a BSS does not imply that wireless communication with all other members of the BSS is possible.

basic service set (BSS) max idle period: A time period during which the access point (AP) does not disassociate a station (STA) due to nonreceipt of frames from that STA.

basic service set (BSS) transition: Change of association by a station (STA) from one BSS to another BSS in the same extended service set (ESS).

beamformee: A station (STA) that receives a physical layer (PHY) protocol data unit (PPDU) that was transmitted using a beamforming steering matrix.

beamformer: A station (STA) that transmits a physical layer (PHY) protocol data unit (PPDU) using a beamforming steering matrix.

beamforming: A spatial filtering mechanism used at a transmitter to improve the received signal power or signal-to-noise ratio (SNR) at an intended receiver. *Syn:* **beam steering**.

beamforming steering matrix: A matrix determined using knowledge of the channel between a transmitter and an intended receiver that maps from space-time streams to transmit antennas with the goal of improving the signal power or signal-to-noise ratio (SNR) at the intended receiver.

big endian: The concept that, for a given multi-octet numeric representation, the most significant octet has the lowest address.

broadcast address: A unique group address that specifies all stations (STAs).

calibration initiator: A station (STA) that initiates a calibration sequence.

calibration responder: A station (STA) that transmits during a calibration sequence in response to a transmission by a calibration initiator.

candidate peer mesh station (STA): A neighbor mesh STA to which a mesh peering has not been established but meets eligibility requirements to become a peer mesh STA.

channel: An instance of wireless medium (WM) use for the purpose of passing physical layer (PHY) protocol data units (PDUs) between two or more stations (STAs).

channel spacing: The difference between the center frequencies of two nonoverlapping and adjacent channels of the radio transmitter.

cipher suite: A set of one or more algorithms, designed to provide data confidentiality, data authenticity or integrity, and/or replay protection.

¹⁶Description of these primitives can be found in 6.3.4.

clear channel assessment (CCA) function: The logical function in the physical layer (PHY) that determines the current state of use of the wireless medium (WM).

collocated interference: Interference that is caused by another radio or station (STA) emitting radio energy located in the same physical device as the reporting STA, where the reported characteristics of the interference are known a priori without interference detection, measurement, or characterization by the reporting STA.

collocated radio: A radio capable of emitting radio-frequency energy located in the same physical device as the reporting station (STA), where the radio's type and some link characteristics are known without signal detection or measurement by the reporting STA.

configuration profile: A collection of parameters identified by a profile identifier (ID) that represent a current or available configuration of a station (STA).

contiguous transmission: A transmission that uses only one frequency segment.

coordination function: The logical function that determines when a station (STA) is permitted to transmit protocol data units (PDUs) via the wireless medium (WM).

Counter mode with Cipher-block chaining Message authentication code (CCM): A symmetric key block cipher mode providing confidentiality using counter mode (CTR) and data origin authenticity using cipher-block chaining message authentication code (CBC-MAC).

NOTE—See IETF RFC 3610.

cryptographic encapsulation: The process of generating the cryptographic payload from the plaintext data. This comprises the cipher text as well as any associated cryptographic state required by the receiver of the data, e.g., initialization vectors (IVs), sequence numbers, message integrity codes (MICs), key identifiers.

data confidentiality: A property of information that prevents disclosure to unauthorized individuals, entities, or processes.

deauthentication service: The service that voids an existing authentication relationship.

decapsulate: To recover an unprotected frame from a protected one.

decapsulation: The process of generating plaintext data by decapsulating an encapsulated frame.

dependent station (STA): A STA that is not registered and whose operational parameters are dictated by messages it receives from an enabling STA. Once enabled by the dynamic STA enablement (DSE) process, a dependent STA's continued operation becomes contingent upon being able to receive messages from its enabling STA over the wireless medium (WM).

destination mesh station (STA): A mesh STA that is the final destination of a MAC service data unit (MSDU). This mesh STA might reside in a proxy mesh gate that might forward the MSDU to a STA outside of the mesh basic service set (MBSS). A destination mesh STA might be an end station as defined in IEEE Std 802.

direct link: A bidirectional link from one quality-of-service (QoS) station (STA) to another QoS STA operating in the same infrastructure QoS basic service set (BSS) that does not pass through a QoS access point (AP). Once a direct link has been set up, all frames between the two QoS STAs are exchanged directly.

directed frame: *See: individually addressed.*

directed multicast service (DMS): A service in which the access point (AP) transmits group addressed frames as individually addressed frames to the requesting non-AP station (STA).

disassociation service: The service that removes an existing association.

distributed coordination function (DCF): A class of coordination function where the same coordination function logic is active in every station (STA) in the basic service set (BSS) whenever the network is in operation.

distribution service: The service that, by using association information, delivers medium access control (MAC) service tuples within the distribution system (DS).

distribution system (DS): A system used to interconnect a set of basic service sets (BSSs) and integrated local area networks (LANs) to create an extended service set (ESS).

distribution system access function (DSAF): A function within an access point (AP) or mesh gate that uses the medium access control (MAC) service and distribution system service (DSS) to provide access between the distribution system (DS) and the wireless medium (WM).

distribution system medium (DSM): The medium or set of media used by a distribution system (DS) for communications between access points (APs), mesh gates, and the portal of an extended service set (ESS).

distribution system service (DSS): The set of services provided by the distribution system (DS) that enable the medium access control (MAC) to transport MAC service tuples between stations (STAs) that are not in direct communication with each other over a single instance of the wireless medium (WM).

NOTE 1—These services include transport of MAC service tuples between the access points (APs) of basic service sets (BSSs) within an extended service set (ESS), transport of MAC service tuples between the portal and BSSs within an ESS, transport of MAC service tuples between mesh gates in the same or different mesh basic service sets (MBSSs), transport of MAC service tuples between mesh gates and APs, transport of MAC service tuples between mesh gates and a portal, and transport of MAC service tuples between STAs in the same BSS when the MAC service tuples has a group destination address or the destination is an individual address and the STA is associated with an AP.

NOTE 2—DSSs are provided between pairs of MACs not on the same instance of the WM.

dynamic frequency selection (DFS): Facilities mandated to satisfy requirements in some regulatory domains for radar detection and uniform channel spreading in the 5 GHz band. These facilities might also be used for other purposes, such as automatic frequency planning.

dynamic station (STA) enablement (DSE): The process by which an enabling STA grants permission and dictates operational procedures to STAs that are subject to its control.

effective isotropic radiated power (EIRP): The equivalent power of a transmitted signal in terms of an isotropic (omnidirectional) radiator. The EIRP equals the product of the transmitter power and the antenna gain (reduced by any coupling losses between the transmitter and antenna).

emergency alert system (EAS): A U.S. national public warning system.

enabling station (STA): A registered STA that has the authority to control when and how a dependent STA can operate. An enabling STA communicates an enabling signal to its dependents over the wireless medium (WM). An enabling STA chooses whether other dynamic STA enablement (DSE) messages are exchanged over the air, over the distribution system (DS), or by mechanisms that rely on transport via higher layers.

encapsulate: To construct a protected frame from an unprotected frame.

encapsulation: The process of generating a protected frame by encapsulating plaintext data.

extended service area (ESA): The area within which members of an extended service set (ESS) can communicate. An ESA is larger than or equal to a basic service area (BSA) and might involve several basic service sets (BSSs) in overlapping, disjointed, or both configurations.

extended service set (ESS): A set of one or more interconnected basic service sets (BSSs) that appears as a single BSS to the logical link control (LLC) layer at any station (STA) associated with one of those BSSs.

extended service set (ESS) transition: Change of association by a station (STA) from one basic service set (BSS) in one ESS to another BSS in a different ESS.

fast basic service set (BSS) transition: Change of association by a station (STA) that is from one BSS in one extended service set (ESS) to another BSS in the same ESS and that minimizes the amount of time that the data connectivity is lost between the STA and the distribution system (DS).

fast session transfer (FST): The transfer of a session from a channel to another channel, in the same or different frequency bands. The term “session” refers to non-physical layer state information kept by a pair of stations (STAs) that communicate directly (i.e., excludes forwarding).

fixed station (STA): A STA that is physically attached to a specific location. In licensed bands, a fixed STA might be authorized to operate only at a specific location.

forwarding information: The information maintained by a mesh station (STA) that allows the mesh STA to perform its path selection and forwarding functions.

frame: A unit of data exchanged between peer protocol entities.

frequency segment: A contiguous block of spectrum used by a transmission.

frame exchange sequence: A sequence of frames specified by Annex G.

Gaussian frequency shift keying (GFSK): A modulation scheme in which the data are first filtered by a Gaussian filter in the baseband and then modulated with a simple frequency modulation.

geolocation: A location within an earth-centric frame of reference.

group: The entities in a wireless network, e.g., an access point (AP) and its associated stations (STAs), or all of the STAs in an independent basic service set (IBSS) network.

group address: A medium access control (MAC) address that has the group bit equal to 1. *Syn:* **multicast address**.

group addressed: A group addressed medium access control (MAC) service data unit (MSDU) is an MSDU that has a group address as its destination address (DA). A group addressed MAC protocol data unit (MPDU) is an MPDU that has a group address in its Address 1 field. *Syn:* **multicast**.

group master key (GMK): An auxiliary key that might be used to derive a group temporal key (GTK).

group temporal key (GTK): A random value, assigned by the group source, which is used to protect group addressed medium access control (MAC) protocol data units (MPDUs) from that source. The GTK might be derived from a group master key (GMK).

hidden station (STA): A STA whose transmissions are not detected using carrier sense (CS) by a second STA, but whose transmissions interfere with transmissions from the second STA to a third STA

homogenous extended service set (ESS): A collection of basic service sets (BSSs), within the same extended service set (ESS), in which every subscription service provider network (SSPN) or other external network reachable at one BSS is reachable at all of them.

idle power indicator (IPI): A physical layer (PHY) indication of the total channel power (noise and interference) as measured in the channel at the receiving antenna connector while the station (STA) is idle, i.e., neither transmitting nor receiving a frame.

IEEE 802.1X authentication: Extensible Authentication Protocol (EAP) authentication transported by the IEEE 802.1X protocol.

independent basic service set (IBSS): A basic service set (BSS) that forms a self-contained network, and in which no access to a distribution system (DS) is available.

individual address: A medium access control (MAC) address in which the group bit is 0. *Syn:* **directed address, unicast address.**

individually addressed: When applied to a medium access control (MAC) service data unit (MSDU), it is an MSDU with an individual address as the destination address (DA). When applied to a MAC protocol data unit (MPDU), it is an MPDU with an individual address in the Address 1 field. *Syn:* **directed, unicast.**

infrastructure: An infrastructure comprises a distribution system (DS), one or more APs, zero or one portal, and zero or more mesh gates. It is also the logical location of distribution and integration service functions of an extended service set (ESS).

infrastructure authorization information: The information that specifies the access rights of the user of a non-access-point (non-AP) station (STA). This information might include the rules for routing the user traffic, a set of permissions about services that a user is allowed to access, quality-of-service (QoS) configuration information, or the accounting policy to be applied by the infrastructure.

integration service: The service that enables delivery of medium access control (MAC) service data units (MSDUs) between the distribution system (DS) and a local area network (LAN) (via a portal).

integrity group temporal key (IGTK): A random value, assigned by the broadcast/multicast source station (STA), which is used to protect group addressed medium access control (MAC) management protocol data units (MMPDUs) from that source STA.

link margin: Ratio of the received signal power to the minimum required by the station (STA). The STA might incorporate rate information and channel conditions, including interference, into its computation of link margin. The specific algorithm for computing the link margin is implementation dependent.

link metric: A criterion used to characterize the performance, quality, and eligibility of a link.

little endian: The concept that, for a given multi-octet numeric representation, the least significant octet has the lowest address.

liveness: A demonstration that the peer is actually participating in this instance of communication.

location subject local: The term used when a location request is for the location of the requesting STA, i.e., when the requesting STA asks, “Where am I?”

location subject remote: The term used when a location request is for the location of the reporting STA, i.e., when the requesting STA asks, “Where are you?”

location subject third party: The term used when the location request is for the location of a station (STA) other than the requesting STA or the requested STA, (i.e., when the requesting STA asks, “Where is he/she?”)

master session key (MSK): Keying material that is derived between the Extensible Authentication Protocol (EAP) peer and exported by the EAP method to the Authentication Server (AS).

NOTE—In this standard, this key is at least 64 octets in length.

medium access control (MAC) frame: The unit of data exchanged between MAC entities. *Syn:* **medium access control (MAC) protocol data unit (MPDU)**.

NOTE—In contexts in which the MAC is clearly the subject, “frame” is an implicit reference to a MAC frame.

medium access control (MAC) protocol data unit (MPDU): The unit of data exchanged between two peer MAC entities using the services of the physical layer (PHY). *Syn:* **medium access control (MAC) frame**.

medium access control (MAC) service data unit (MSDU): Information that is delivered as a unit between MAC service access points (SAPs).

medium access control (MAC) service tuple: The collection of a MAC service data unit (MSDU) along with the source address, destination addresses, priority, and service class associated with the MSDU, which are passed as parameters across the MAC service access point (SAP) and are delivered across the distribution system between access points (APs), mesh gates, and the portal of an extended service set (ESS).

mesh basic service set (MBSS): A basic service set (BSS) that forms a self-contained network of mesh stations (STAs) that use the same mesh profile. An MBSS contains zero or more mesh gates, and can be formed from mesh STAs that are not in direct communication.

mesh facility: The set of enhanced functions, channel access rules, frame formats, mutual authentication methods, and managed objects used to provide data transfer among autonomously operating stations (STAs) that might not be in direct communication with each other over a single instance of the wireless medium. Communication between STAs using the mesh facility takes place using only the wireless medium. The mesh facility transports an MSDU between source and destination STAs over potentially multiple hops of the wireless medium without transiting the MAC SAP at intermediate STAs.

mesh gate: Any entity that has a mesh station (STA) function and a distribution system access function (DSAF) to provide access to a single distribution system for the mesh basic service set (MBSS).

mesh link: A link from one mesh station (STA) to a neighbor mesh STA that have a mesh peering with each other.

mesh neighborhood: The set of all neighbor mesh stations (STAs) of a particular mesh STA.

mesh path: A concatenated set of mesh links from a source mesh station (STA) to a destination mesh STA.

mesh path selection: The process of selecting a mesh path.

mesh peering: A relationship between two mesh stations (STAs) that is required for direct communication over a single instance of the wireless medium (WM). A mesh peering is established with a mesh peering protocol.

mesh profile: A set of values of parameters that identifies the attributes of the mesh basic service set (MBSS) and that is used in a single MBSS.

NOTE—The mesh profile consists of the identifiers that are the values for the parameters: mesh ID, active path selection protocol, active path selection metric, congestion control mode, synchronization method, and authentication protocol.

mesh services: The set of services that enable the creation and operation of a mesh basic service set (MBSS).

mesh station (STA): A quality-of-service (QoS) STA that implements the mesh facility.

message integrity code (MIC): A value generated by a cryptographic function. If the input data are changed, a new value cannot be correctly computed without knowledge of the cryptographic key(s) used by the cryptographic function.

NOTE—This is traditionally called a *message authentication code* (MAC), but the acronym MAC is already reserved for another meaning in this standard.

mobile station (STA): A type of STA that uses network communications while in motion.

mobility domain: A set of basic service sets (BSSs), within the same extended service set (ESS), that support fast BSS transitions between themselves and that are identified by the set's mobility domain identifier (MDID).

mobility domain identifier (MDID): An identifier that names a mobility domain.

multi-level precedence and preemption (MLPP): A framework used with admission control for the treatment of traffic streams based on precedence, which supports the preemption of an active traffic stream by a higher precedence traffic stream when resources are limited. Preemption is the act of forcibly removing a traffic stream in progress in order to free up resources for another higher precedence traffic stream.

multi-user multiple input, multiple output (MU-MIMO): A technique by which multiple stations (STAs), each with one or more antennas, either simultaneously transmit to a single STA or simultaneously receive from a single STA independent data streams over the same radio frequencies.

NOTE—IEEE Std 802.11 supports only downlink (DL) MU-MIMO. *See* **downlink multi-user multiple input, multiple output (DL-MU-MIMO)** (in 3.2).

multicast: *See:* **group addressed.**

multicast address: *See:* **group address.**

multicast-group address: A medium access control (MAC) address associated by higher level convention with a group of logically related stations (STAs).

multiple basic service set identifier (BSSID) capability: The capability to advertise information for multiple BSSIDs using a single Beacon or Probe Response frame instead of using multiple Beacon or Probe Response frames, each corresponding to a single BSSID, and the capability to indicate buffered frames for these multiple BSSIDs using a single traffic indication map (TIM) element in a single Beacon.

multiple input, multiple output (MIMO): A physical layer (PHY) configuration in which both transmitter and receiver use multiple antennas.

multiple medium access control (MAC) station management entity (SME) (MM-SME): Component of station management that manages multiple cooperating stations (STAs).

neighbor access point (AP): Any AP that is a potential service set transition candidate.

neighbor station (STA): A STA in the following relationship: STA A is a neighbor to STA B if STA A can both directly transmit to and receive from STA B over the wireless medium.

network access identifier (NAI): The user identity submitted by the Supplicant during IEEE 802.1X authentication.

NOTE—See IETF RFC 4282.

network access server (NAS) client: The client component of a NAS that communicates with the Authentication Server (AS).

network allocation vector (NAV): An indicator, maintained by each station (STA), of time periods when transmission onto the wireless medium (WM) is not initiated by the STA regardless of whether the STA's clear channel assessment (CCA) function senses that the WM is busy.

next-hop mesh station (STA): The next peer mesh STA on the mesh path to the destination mesh STA.

non-access-point (non-AP) station (STA): A STA that is not contained within an access point (AP).

nonce: A numerical value, used in cryptographic operations associated with a given cryptographic key, that is not to be reused with that key, including over all reinitializations of the system through all time.

noncontiguous transmission: A transmission that uses nonadjacent frequency segments.

nonoperating channel: A channel that is not the operating channel of the basic service set (BSS) of which the station (STA) is a member.

non-quality-of-service (non-QoS) access point (AP): An AP that does not support the quality-of-service (QoS) facility.

non-quality-of-service (non-QoS) basic service set (BSS): A BSS that does not support the quality-of-service (QoS) facility.

non-quality-of-service (non-QoS) station (STA): A STA that does not support the quality-of-service (QoS) facility.

operating channel: The operating channel is the channel in which beacons are transmitted.

NOTE—In IEEE Std 802.11, the serving access point (AP) of an infrastructure basic service set (BSS) or the dynamic frequency selection (DFS) owner of an independent basic service set (IBSS) transmits beacons.

operating channel width: The channel width in which the station (STA) is currently able to receive.

overlapping basic service set (OBSS): A basic service set (BSS) operating on the same channel as the station's (STA's) BSS and within (either partly or wholly) its basic service area (BSA).

over-the-air fast basic service set (BSS) transition (FT): An FT method in which the station (STA) communicates over a wireless medium (WM) link to the target access point (AP).

over-the-DS (distribution system) fast basic service set (BSS) transition (FT): An FT method in which the station (STA) communicates with the target access point (AP) via the current AP.

pairwise: Referring to, or an attribute of, two entities that are associated with each other, e.g., an access point (AP) and an associated station (STA), or two STAs in an independent basic service set (IBSS) network. This term is used to refer to a type of encryption key hierarchy pertaining to keys shared by only two entities.

pass-phrase: A secret text string employed to corroborate the user's identity.

password: A shared, secret, and potentially low-entropy word, phrase, code, or key used as a credential for authentication purposes.

NOTE—The method of distribution of a password to the units in the system is outside the scope of this standard.

path metric: An aggregate multi-hop criterion used to characterize the performance, quality, and eligibility of a mesh path.

peer mesh station (STA): A mesh STA to which a mesh peering has been established.

peer-to-peer link: A direct link within a quality-of-service (QoS) basic service set (BSS), a tunnelled direct-link setup (TDLS) link, or a STA-to-STA communication in an independent basic service set (IBSS).

peer-to-peer traffic specification (PTP TSPEC): The quality-of-service (QoS) characteristics of a data flow between non-access point (non-AP) QoS stations (STAs).

per-frame encryption key: A unique encryption key constructed for each medium access control (MAC) protocol data unit (MPDU).

physical layer (PHY) frame: The unit of data exchanged between PHY entities. *Syn:* **physical layer (PHY) protocol data unit (PPDU).**

NOTE—In contexts in which the PHY is clearly the subject, “frame” is an implicit reference to a PHY frame.

physical layer (PHY) protocol data unit (PPDU): The unit of data exchanged between two peer PHY entities to provide the PHY data service.

piggyback: The overloading of data with an acknowledgment of a previously received frame to the station (STA) to which the data is directed.

portable station (STA): A type of station (STA) that might be moved from location to location, but that only uses network communications while at a fixed location.

portal: The logical point at which the integration service is provided.

NOTE—For the purposes of this Standard, there is at most one portal in a given ESS's infrastructure. In an implementation, a single logical portal function may be provided by multiple devices that provide integration services for the ESS. How such multiple devices coordinate to appear as a single logical portal is implementation dependent.

precursor mesh station (STA): A neighbor peer mesh STA on the mesh path to the destination mesh STA, that identifies the mesh STA as the next-hop mesh STA.

preshared key (PSK): A static key that is distributed to the units in the system by some out-of-band means.

primary channel: The common channel of operation for all stations (STAs) that are members of the basic service set (BSS).

prioritized quality of service (QoS): The provisioning of service in which the medium access control (MAC) protocol data units (MPDUs) with higher priority are given a preferential treatment over MPDUs with a lower priority.

NOTE—Prioritized QoS is provided through the enhanced distributed channel access (EDCA) mechanism.

protection mechanism: Any procedure that attempts to update the network allocation vector (NAV) of all receiving stations (STAs) prior to the transmission of a frame that might or might not be detected as valid network activity by the physical layer (PHY) entities at those receiving STAs.

protection mechanism frame: Any frame that is sent as part of a protection mechanism procedure.

protocol instance: An execution of a particular protocol that consists of the state of the communicating parties as well as the messages exchanged.

proxy mesh gate: A mesh gate acting as an intermediary for IEEE 802 stations (STAs) outside the mesh basic service set (MBSS).

pseudorandom function (PRF): A function that hashes various inputs to derive a pseudorandom value. In order to ensure liveness of a communication in which a pseudorandom value is used, a nonce is used as one of the inputs to the function.

public safety answering point (PSAP): A physical location where emergency calls are received and routed to the appropriate emergency service dispatch center.

NOTE—See NENA 08-002 [B56].

quadrature binary phase shift keying (QPSK): A binary phase shift keying modulation in which the binary data is mapped onto the imaginary (Q) axis.

quality-of-service (QoS) access point (AP): An AP that supports the QoS facility.

NOTE—In IEEE Std 802.11, the functions of a QoS AP are a superset of the functions of a non-QoS AP, and thus a QoS AP is able to function as a non-QoS AP to non-QoS stations (STAs).

quality-of-service (QoS) basic service set (BSS): A BSS that provides the QoS facility. An infrastructure QoS BSS contains a QoS access point (AP).

quality-of-service (QoS) facility: The set of enhanced functions, channel access rules, frame formats, frame exchange sequences and managed objects used to provide parameterized and prioritized QoS.

quality-of-service (QoS) independent basic service set (IBSS): An IBSS in which one or more of its stations (STAs) support the QoS facility.

quality-of-service (QoS) station (STA): A STA that implements the QoS facility.

NOTE—A QoS STA acts as a non-QoS STA when associated in a non-QoS basic service set (BSS).

radio frequency (RF) chain: The physical entity that is able to act as a receive chain or transmit chain, or both.

reassociation service: The service that enables an established association [between access point (AP) and station (STA)] to be transferred from one AP to another (or the same) AP.

receive chain: The physical entity that implements any necessary signal processing to provide the received signal to the digital baseband. Such signal processing includes filtering, amplification, down-conversion, and sampling.

receive power: Mean power measured at the antenna connector.

received channel power indicator (RCPI): An indication of the total channel power (signal, noise, and interference) of a received frame measured on the channel and at the antenna connector used to receive the frame.

received power indicator (RPI): A quantized measure of the received power level as seen at the antenna connector.

registered location: The geolocation of a station (STA) registered in accordance with the requirements for the regulatory domain.

registered location query protocol (RLQP): The query protocol for registered location information that is received and transported by generic advertisement service (GAS) Public Action frames.

registered location secure server (RLSS): An entity that accesses and manages a database that organizes storage of information by geographic location and securely holds the location and some operating parameters of one or more basic service sets (BSSs).

registered station (STA): A STA for which information needs to be submitted to an appropriate regulatory or coordination authority before it is allowed to transmit.

remote request broker (RRB): The component of the station management entity (SME) of an access point (AP) that supports fast basic service set (BSS) transitions over the distribution system (DS).

roaming consortium: A group of subscription service providers (SSPs) having inter-SSP roaming agreements.

service set transition: A station (STA) movement from one basic service set (BSS) to another BSS, i.e., either a BSS transition or an extended service set (ESS) transition.

serving access point (AP): The AP to which the station (STA) is associated.

single-user (SU) physical layer (PHY) protocol data unit (PPDU): A PPDU with a format that is capable of carrying only a single PHY service data unit (PSDU), or no PSDU.

sounding: The use of preamble training fields to measure the channel for purposes other than demodulation of the Data portion of the physical layer (PHY) protocol data unit (PPDU) containing the training fields.

NOTE—These uses include calculation of transmit steering, calculation of recommended modulation and coding scheme (MCS), and calculation of calibration parameters.

source mesh station (STA): A mesh STA from which a medium access control (MAC) service data unit (MSDU) enters the mesh basic service set (MBSS). A source mesh STA is either a mesh STA that is the source of an MSDU or a proxy mesh gate that receives an MSDU from a STA outside of the MBSS and forwards the MSDU on a mesh path.

space-time streams: Streams of modulation symbols created by applying a combination of spatial and temporal processing to one or more spatial streams of modulation symbols.

spatial multiplexing (SM): A transmission technique in which data streams are transmitted on multiple spatial channels that are provided through the use of multiple antennas at the transmitter and the receiver.

spatial stream: One of several streams of bits or modulation symbols that might be transmitted over multiple spatial dimensions that are created by the use of multiple antennas at both ends of a communications link.

station (STA): A logical entity that is a singly addressable instance of a medium access control (MAC) and physical layer (PHY) interface to the wireless medium (WM).

NOTE—For IEEE 802.11 purposes, a station is any MAC/PHY entity providing the IEEE 802.11 MAC services. This differs from the IEEE 802 definition of ‘station,’ which includes bridges (or ‘end stations’) that are endpoints of link layer data traffic.

station service (SS): The set of services that support transport of medium access control (MAC) service data units (MSDUs) between stations (STAs) within a basic service set (BSS).

subscription service provider (SSP): An organization (operator) offering connection to network services, perhaps for a fee.

subscription service provider network (SSPN): The network controlled by a subscription service provider (SSP). The network maintains user subscription information.

Supplicant: An entity at one end of a point-to-point LAN segment that is being authenticated by an Authenticator attached to the other end of that link. (IEEE Std 802.1X-2010)

Supplicant address (SPA): The medium access control (MAC) address of the IEEE 802.1X Supplicant.

television white spaces (TVWS): The opportunistic use of allocated but not assigned spectrum—spectrum allocated for broadcast television, but with no assignment at a particular location.

time unit (TU): A measurement of time equal to 1024 μ s.

traffic category (TC): A label for medium access control (MAC) service data units (MSDUs) that have a distinct user priority (UP), as viewed by higher layer entities, relative to other MSDUs provided for delivery over the same link. Traffic categories are meaningful only to MAC entities that support quality of service (QoS) within the MAC data service. These MAC entities determine the UP for MSDUs belonging to a particular traffic category using the priority value provided with those MSDUs at the MAC service access point (MAC SAP).

traffic classification (TCLAS): The specification of certain parameter values to identify a protocol data unit (PDU) or a medium access control (MAC) service data unit (MSDU). The classification process is performed above the MAC service access point (MAC SAP), within the MLME, or within the MAC, based on the type of classification.

traffic filter: A set of traffic specifications defined by the use of traffic classification (TCLAS) elements that are utilized by the traffic filtering service (TFS) to identify specific allowed frames.

traffic filtering service (TFS): A service provided by an access point (AP) to a non-AP station (STA) to reduce the number of frames sent to the non-AP STA by not forwarding individually addressed frames addressed to the non-AP STA that do not match traffic filters specified by the non-AP STA.

traffic identifier (TID): Any of the identifiers usable by higher layer entities to distinguish medium access control (MAC) service data units (MSDUs) to MAC entities that support quality of service (QoS) within the MAC data service.

NOTE—There are 16 possible TID values; eight identify traffic categories (TCs), and the other eight identify parameterized traffic streams (TSs). The TID is assigned to an MSDU in the layers above the MAC.

traffic specification (TSPEC): The quality-of-service (QoS) characteristics of a data flow to and from a QoS station (STA).

traffic stream (TS): A set of medium access control (MAC) service data units (MSDUs) to be delivered subject to the quality-of-service (QoS) parameter values provided to the MAC in a particular traffic specification (TSPEC). TSs are meaningful only to MAC entities that support QoS within the MAC data service. These MAC entities determine the TSPEC applicable for delivery of MSDUs belonging to a particular TS using the priority parameter provided with those MSDUs at the MAC service access point (MAC SAP).

transmission opportunity (TXOP): An interval of time during which a particular quality-of-service (QoS) station (STA) has the right to initiate frame exchange sequences onto the wireless medium (WM).

NOTE—A TXOP is defined by a starting time and a maximum duration.

transmit chain: The physical entity that implements any necessary signal processing to generate the transmit signal from the digital baseband. Such signal processing includes digital to analog conversion, filtering, amplification and up-conversion.

type/length/value (TLV): A format that consists of a type, a length, and a value.

unauthorized disclosure: The process of making information available to unauthorized individuals, entities, or processes.

unauthorized resource use: The use of a resource not consistent with the defined security policy.

unicast: *See: individually addressed.*

unicast address: *See: individual address.*

uniform spreading: A regulatory requirement for a channel selection mechanism that provides uniform usage across a minimum set of channels in the regulatory domain.

unreachable destination: A destination mesh station (STA) for which the link to the next hop of the mesh path to this destination mesh STA is no longer usable.

user priority (UP): A value associated with an medium access control (MAC) service data unit (MSDU) that indicates how the MSDU is to be handled. The UP is assigned to an MSDU in the layers above the MAC.

validated AP: An AP that has either been explicitly configured as a neighbor or learned through a mechanism such as the Beacon report.

wildcard BSSID: A BSSID value used to represent all BSSIDs.

NOTE—In IEEE Std 802.11, this is represented by all binary 1s.

wildcard SSID: A SSID value used to represent all SSIDs.

NOTE—In IEEE Std 802.11, this is represented by the value “null”.

wireless medium (WM): The medium used to implement the transfer of protocol data units (PDUs) between peer physical layer (PHY) entities of a wireless local area network (LAN).

10.34.5 VHT sounding protocol

10.34.5.1 General

Transmit beamforming and DL-MU-MIMO require knowledge of the channel state to compute a steering matrix that is applied to the transmitted signal to optimize reception at one or more receivers. The STA transmitting using the steering matrix is called the *VHT beamformer*, and a STA for which reception is optimized is called a *VHT beamformee*. An explicit feedback mechanism is used where the VHT beamformee directly measures the channel from the training symbols transmitted by the VHT beamformer and sends back a transformed estimate of the channel state to the VHT beamformer. The VHT beamformer then uses this estimate, perhaps combining estimates from multiple VHT beamformees, to derive the steering matrix.

If `dot11VHTSUBeamformerOptionImplemented` is true, a STA shall set the SU Beamformer Capable field in the VHT Capabilities element to 1. If `dot11VHTSUBeamformeeOptionImplemented` is true, a STA shall set the SU Beamformee Capable field in the VHT Capabilities element to 1.

If `dot11VHTMUBeamformerOptionImplemented` is true, a STA shall set the MU Beamformer Capable field in the VHT Capabilities element to 1. If `dot11VHTMUBeamformeeOptionImplemented` is true, a STA shall set the MU Beamformee Capable field in the VHT Capabilities element to 1.

If `dot11VHTMUBeamformerOptionImplemented` is true, a STA shall set `dot11VHTSUBeamformerOptionImplemented` to true. If `dot11VHTMUBeamformeeOptionImplemented` is true, a STA shall set `dot11VHTSUBeamformeeOptionImplemented` to true.

A STA is a VHT SU-only beamformer if it sets the SU Beamformer Capable field to 1 but sets the MU Beamformer Capable field to 0 in transmitted VHT Capabilities elements. A STA is an SU-only beamformee if it sets the SU Beamformee Capable field to 1 but sets the MU Beamformee Capable field to 0 in transmitted VHT Capabilities elements.

If `dot11VHTSUBeamformerOptionImplemented` is false, a STA shall not act in the role of a VHT beamformer. If `dot11VHTSUBeamformeeOptionImplemented` is false, a STA shall not act in the role of a VHT beamformee.

10.34.5.2 Rules for VHT sounding protocol sequences

A VHT beamformer shall initiate a sounding feedback sequence by transmitting a VHT NDP Announcement frame followed by a VHT NDP after a SIFS. The VHT beamformer shall include in the VHT NDP Announcement frame one STA Info field for each VHT beamformee that is expected to prepare VHT Compressed Beamforming feedback and shall identify the VHT beamformee by including the VHT beamformee's AID in the AID subfield of the STA Info field. The VHT NDP Announcement frame shall include at least one STA Info field.

NOTE—A STA that transmits a VHT NDP Announcement frame to a DLS or TDLS peer STA obtains the AID for the peer STA from the DLS Setup Request, DLS Setup Response, TDLS Setup Request, or TDLS Setup Response frame.

A VHT beamformer shall not transmit either a VHT NDP Announcement+HTC frame or a Beamforming Report Poll+HTC frame that contains an HT variant HT Control field.

A VHT NDP shall be transmitted only following a SIFS after a VHT NDP Announcement frame. A VHT NDP Announcement frame shall be followed by a VHT NDP after SIFS.

A VHT beamformer that has not received a VHT Capabilities element from a STA or where the last VHT Capabilities element received from a STA has the SU Beamformee Capable field set to 0 shall not transmit either of the following:

- A VHT NDP Announcement frame addressed to the STA or that includes the STA's AID in one of the STA Info fields
- A Beamforming Report Poll frame addressed to the STA

A VHT beamformer that transmits a VHT NDP Announcement frame to a VHT SU-only beamformee shall include only one STA Info field in the VHT NDP Announcement frame and set the Feedback Type subfield of the STA Info field to SU.

If the VHT NDP Announcement frame includes more than one STA Info field, the RA of the VHT NDP Announcement frame shall be set to the broadcast address. If the VHT NDP Announcement frame includes a single STA Info field, the RA of the VHT NDP Announcement frame shall be set to the MAC address of the VHT beamformee.

A VHT NDP Announcement frame shall not include two or more STA Info fields with same value in the AID subfield.

A VHT beamformer that transmits a VHT NDP Announcement frame to a VHT beamformee that is an AP, mesh STA or STA that is a member of an IBSS, shall include a single STA Info field in the VHT NDP Announcement frame and shall set the AID field in the STA Info field to 0.

A VHT NDP Announcement frame with more than one STA Info field shall not carry a VHT variant HT Control field, unless all of the STAs listed in the AID field of the STA Info fields have set +HTC-VHT Capable to 1 in the VHT Capabilities Information field.

A VHT beamformer that transmits a VHT NDP Announcement frame with more than one STA Info field should transmit any Beamforming Report Poll frames used to retrieve VHT Compressed Beamforming feedback from the intended VHT beamformees in the same TXOP. If the duration of the TXOP that contained the VHT NDP Announcement frame has insufficient duration to accommodate the transmission of all of the feedback reports, the VHT beamformer may poll for the remaining VHT Compressed Beamforming feedback in subsequent TXOPs.

A VHT beamformer may use the following worst-case parameters to estimate the duration of the expected frame(s) that contain(s) the feedback response(s): lowest rate in basic VHT-MCS set, no grouping.

NOTE—The transmission of the VHT NDP Announcement, VHT NDP, VHT Compressed Beamforming, and Beamforming Report Poll frames is subject to the rules in 10.22.2.7.

A VHT beamformer that sets the Feedback Type subfield of a STA Info field to MU shall set the Nc Index subfield of the same STA Info field to a value less than or equal to the minimum of both of the following:

- The maximum number of supported spatial streams for receive operation according to the combination of the corresponding VHT beamformee's Rx VHT-MCS Map subfield in the Supported VHT-MCS and NSS Set field and VHT Capabilities Information field
- The maximum number of supported spatial streams according to the Rx NSS subfield value and, when the value of the VHT Extended NSS BW Capable subfield received from the VHT beamformee is 1 and dot11ExtendedNSSSupported is equal to true, the 160/80+80 BW subfield value in the Operating Mode field of the most recently received Operating Mode Notification frame or Operating Mode Notification element with the Rx NSS Type subfield equal to 0 from the corresponding VHT beamformee, as computed according to 10.7.12.1

A non-AP VHT beamformee that receives a VHT NDP Announcement frame from a VHT beamformer with which it is associated or has an established DLS or TDLS session and that contains the VHT beamformee's AID in the AID subfield of the first (or only) STA Info field and also receives a VHT NDP a SIFS after the VHT NDP Announcement frame shall transmit the PPDU containing its VHT Compressed Beamforming

feedback a SIFS after the VHT NDP. A VHT beamformee that is an AP, mesh STA, or STA that is a member of an IBSS, that receives a VHT NDP Announcement frame with the RA matching its MAC address and the AID subfield of the only STA Info field set to 0, and that also receives a VHT NDP a SIFS after the VHT NDP Announcement frame shall transmit the PPDU containing its VHT Compressed Beamforming feedback a SIFS after the VHT NDP. The TXVECTOR parameter CH_BANDWIDTH of the PPDU containing the VHT Compressed Beamforming feedback shall be set to indicate a bandwidth not wider than that indicated in the RXVECTOR parameter CH_BANDWIDTH of the received VHT NDP frame. A STA ignores received VHT NDP Announcement, VHT NDP, and Beamforming Report Poll frames if dot11VHTSUBeamformeeOptionImplemented is false.

A VHT beamformee shall indicate the maximum number of space-time streams it can receive in a VHT NDP in the Beamformee STS Capability subfield of the VHT Capabilities Information field of the VHT Capabilities element. If the beamformee is a non-AP STA, this shall be less than or equal to the maximum total number of space-time streams that the STA can receive in a VHT MU PPDU.

An example of the VHT sounding protocol with a single VHT beamformee is shown in Figure 10-52.

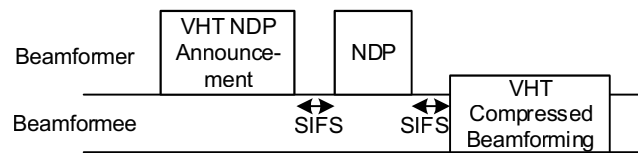


Figure 10-52—Example of the sounding protocol with a single VHT beamformee

A non-AP VHT beamformee that receives a VHT NDP Announcement frame from a VHT beamformer with which it is associated or has an established DLS or TDLS session and that contains the VHT beamformee's AID in the AID subfield of a STA Info field that is not the first STA Info field shall transmit its VHT Compressed Beamforming feedback a SIFS after receiving a Beamforming Report Poll with RA matching its MAC address and a nonbandwidth signaling TA obtained from the TA field matching the MAC address of the VHT beamformer. If the RXVECTOR parameter CH_BANDWIDTH_IN_NON_HT of the received Beamforming Report Poll frame is valid, the TXVECTOR parameter CH_BANDWIDTH of the PPDU containing the VHT Compressed Beamforming feedback shall be set to indicate a bandwidth not wider than that indicated by the RXVECTOR parameter CH_BANDWIDTH_IN_NON_HT of the Beamforming Report Poll frame; otherwise, the TXVECTOR parameter CH_BANDWIDTH of the PPDU containing VHT Compressed Beamforming feedback shall be set to indicate a bandwidth not wider than that indicated by the RXVECTOR parameter CH_BANDWIDTH of the Beamforming Report Poll frame.

An example of the VHT sounding protocol with more than one VHT beamformee is shown in Figure 10-8.

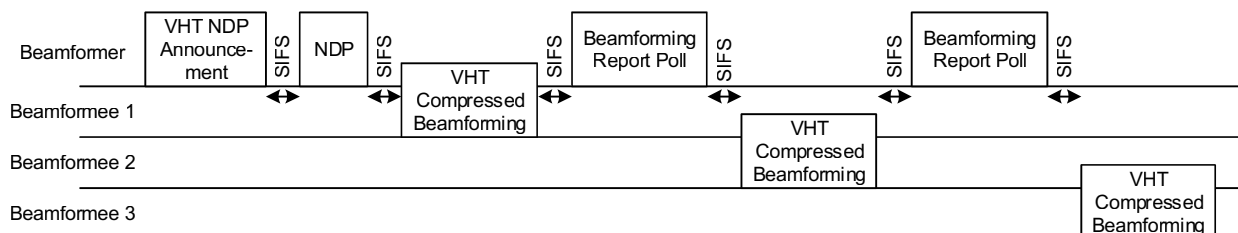


Figure 10-53—Example of the sounding protocol with more than one VHT beamformee

The RA field of the VHT Compressed Beamforming frame(s) of the VHT Compressed Beamforming feedback shall be set to a nonbandwidth signaling TA obtained from the TA field of the VHT NDP Announcement

frame or the Beamforming Report Poll frame to which this VHT Compressed Beamforming feedback is a response.

If the VHT Beamformee is transmitting VHT Compressed Beamforming frame(s) a SIFS after the VHT NDP, then the VHT Compressed Beamforming frame(s) shall include the VHT Compressed Beamforming Report information and, for the case of MU feedback, the MU Exclusive Beamforming Report information.

A VHT beamformee that transmits a VHT Compressed Beamforming frame shall set the Feedback Type field in the VHT MIMO Control field to the same value as the Feedback Type field in the corresponding STA Info field in the VHT NDP Announcement frame. If the Feedback Type field indicates MU, the STA shall send a VHT Compressed Beamforming frame with the Nc Index field value in the VHT MIMO Control field equal to the minimum of all of the following:

- The Nc Index field value in the corresponding STA Info field in the VHT NDP Announcement Frame
- The maximum number of supported spatial streams for receive operation according to the combination of its Rx VHT-MCS Map subfield in the Supported VHT-MCS and NSS Set field, VHT Capabilities Information field and Operating Mode field (see 10.7.12.1)
- The maximum number of supported spatial streams according to the Rx NSS subfield value and, when the value of the most recently transmitted VHT Extended NSS BW Capable subfield is 1, the 160/80+80 BW subfield value in the Operating Mode field of the most recently transmitted Operating Mode Notification frame or Operating Mode Notification element, as computed according to 10.7.12.1

If the Feedback Type indicates SU, the Nc Index field value in the VHT MIMO Control field is determined by the VHT beamformee.

The Nr Index field in the VHT MIMO Control field shall be set to the same value as the RXVECTOR parameter NUM_STS of the corresponding VHT NDP. The Nc Index field shall not be set to a value larger than the Nr Index value in the VHT MIMO Control field. A VHT beamformee shall set the value of the Channel Width subfield in the VHT MIMO Control field of a VHT Compressed Beamforming frame to the same value as the RXVECTOR parameter CH_BANDWIDTH of the corresponding VHT NDP frame.

A VHT beamformee shall not include MU Exclusive Beamforming Report information in VHT Compressed Beamforming feedback if the Feedback Type subfield in the MIMO Control field of the VHT Compressed Beamforming frame(s) indicates SU. A VHT beamformee shall include both VHT Compressed Beamforming Report information and MU Exclusive Beamforming Report information in VHT Compressed Beamforming feedback if the Feedback Type subfield in the MIMO Control field of the VHT Compressed Beamforming frame(s) indicates MU.

A VHT beamformee that transmits VHT Compressed Beamforming feedback shall include neither the VHT Compressed Beamforming Report information and nor the MU Exclusive Beamforming Report information if the transmission duration of the PPDU carrying the VHT Compressed Beamforming Report information and any MU Exclusive Beamforming Report information would exceed the maximum PPDU duration.

The value of the Sounding Dialog Token Number subfield in the VHT MIMO Control field shall be set to the same value as the Sounding Dialog Token Number subfield in the Sounding Dialog Token field in the corresponding VHT NDP Announcement frame.

NOTE 1—The VHT beamformer can use the sounding dialog token in the VHT Compressed Beamforming frame(s) of the VHT Compressed Beamforming feedback to associate the feedback with a prior VHT NDP Announcement frame and thus compute the delay between sounding and receiving the feedback. The VHT beamformer can use this delay time when making a decision regarding the applicability of the feedback for the link.

NOTE 2—Recovery in the case of a missing response to a VHT NDP Announcement or Beamforming Report Poll frame follows the rules for multiple frame transmission in an EDCA TXOP (see 10.22.2.7).

VHT Compressed Beamforming feedback comprises the VHT Compressed Beamforming Report information (see Table 9-69) and the MU Exclusive Beamforming Report information (see Table 9-72). Subclause 9.6.23.2 specifies how VHT Compressed Beamforming feedback is converted into a VHT Compressed Beamforming frame, and it also specifies the rules for the presence or absence of the two fields listed here.

In a frame transmitted by a TVHT STA, the TVHT Compressed Beamforming Report field replaces the VHT Compressed Beamforming Report field.

In a frame transmitted by a TVHT STA, the TVHT MU Exclusive Beamforming Report field replaces the MU Exclusive Beamforming Report field.

10.34.5.3 Rules for fragmented feedback in VHT sounding protocol sequences

VHT Compressed Beamforming feedback shall be transmitted in a single VHT Compressed Beamforming frame unless the result would be a VHT Compressed Beamforming frame that exceeds the VHT beamformer's maximum MPDU length capability.

NOTE—The VHT beamformee might therefore have to transmit an MPDU that is bigger than the VHT beamformee is capable of receiving.

If VHT Compressed Beamforming feedback would result in a VHT Compressed Beamforming frame that exceeds the VHT beamformer's maximum MPDU length capability, the VHT Compressed Beamforming feedback shall be split into up to 8 feedback segments, with each feedback segment sent in a different VHT Compressed Beamforming frame and containing successive portions of the VHT Compressed Beamforming feedback consisting of the VHT Compressed Beamforming Report information followed by any MU Exclusive Beamforming Report information. Each of the feedback segments except the last shall contain the maximum number of octets allowed by the VHT beamformer's maximum MPDU length capability. The last feedback segment may be smaller. Each feedback segment is identified by the value of the Remaining Feedback Segments subfield and the First Feedback Segment subfield in the VHT MIMO Control field as defined in 9.4.1.48; the other nonreserved subfields of the VHT MIMO Control field shall be the same for all feedback segments. All feedback segments shall be sent in a single A-MPDU and shall be included in the A-MPDU in the descending order of the Remaining Feedback Segments subfield values.

NOTE—The feedback segments of a VHT Compressed Beamforming report are not MSDU/MMPDU fragments and can be included in an A-MPDU as described in this subclause.

A VHT beamformer, in its first attempt to retrieve VHT Compressed Beamforming feedback from a VHT beamformee that is not the one indicated by the first STA Info field, shall transmit a Beamforming Report Poll frame to poll all possible feedback segments of the VHT Compressed Beamforming feedback from the VHT beamformee, by setting all of the bits in the Feedback Segment Retransmission Bitmap field of the Beamforming Report Poll frame to 1.

If a VHT beamformer fails to receive some or all feedback segments of VHT Compressed Beamforming feedback, the VHT beamformer may, subject to the condition on VHT SU-only beamformees described at the end of this subclause, request a selective retransmission of missing feedback segments by transmitting a Beamforming Report Poll frame with the Feedback Segment Retransmission Bitmap field set as described in 9.3.1.21 to indicate the feedback segments requested for retransmission. If the VHT beamformer fails to receive the feedback segment with the First Feedback Segment field set to 1, the VHT beamformer may request a selective retransmission of missing feedback segments assuming the VHT Compressed Beamforming feedback is split into 8 feedback segments. The VHT beamformer may also request the retransmission of all feedback segments by setting all of the bits in the Feedback Segment Retransmission Bitmap field of the Beamforming Report Poll frame to 1.

A VHT beamformee that transmits VHT Compressed Beamforming feedback including the VHT Compressed Beamforming Report information and any MU Exclusive Beamforming Report information in response to a

Beamforming Report Poll frame shall either transmit only the feedback segments indicated in the Feedback Segment Retransmission Bitmap field in the Beamforming Report Poll frame excluding the indicated feedback segments that do not exist at the VHT beamformee or transmit all of the feedback segments that exist at the VHT beamformee disregarding the Feedback Segment Retransmission Bitmap field in the Beamforming Report Poll frame.

A VHT beamformer shall not transmit a Beamforming Report Poll frame to a VHT SU-only beamformee unless the VHT beamformer has received at least one feedback segment of the VHT Compressed Beamforming feedback from the VHT beamformee in the current frame exchange sequence.

In a frame transmitted by a TVHT STA, the TVHT Compressed Beamforming Report field replaces the VHT Compressed Beamforming Report field.

In a frame transmitted by a TVHT STA, the TVHT MU Exclusive Beamforming Report field replaces the MU Exclusive Beamforming Report field.

10.34.6 Transmission of a VHT NDP

A VHT NDP shall use the SU PPDU format as described in 21.1.4. A STA shall transmit a VHT NDP using the following TXVECTOR parameters:

- APEP_LENGTH set to 0
- NUM_USERS set to 1
- NUM_STS indicates two or more space-time streams
- CH_BANDWIDTH set to the same value as the TXVECTOR parameter CH_BANDWIDTH in the preceding VHT NDP Announcement frame
- GROUP_ID and PARTIAL_AID are set as described in 10.20

The number of space-time streams sounded and as indicated by the NUM_STS parameter shall not exceed the value indicated in the Beamformee STS Capability field in the VHT Capabilities element of any intended recipient of the VHT NDP. The NUM_STS parameter may be set to any value, subject to the constraint of the previous sentence, regardless of the value of the Supported VHT-MCS and NSS Set field of the VHT Capabilities element at either the transmitter or recipient of the NDP.

The destination of a VHT NDP is equal to the RA of the immediately preceding VHT NDP Announcement frame.

The source of a VHT NDP is equal to the TA of the immediately preceding VHT NDP Announcement frame.

10.35 Mesh forwarding framework

10.35.1 General

The term *mesh forwarding* refers to forwarding of MSDUs and MMPDUs on paths determined by the mesh path selection between mesh STAs at the link layer. The mesh paths are contained in the forwarding information. The forwarding information, for instance, the lifetime of a mesh path, may be updated as a consequence of mesh forwarding.

The forwarding of MSDUs and MMPDUs within an MBSS is described in 10.35.3, 10.35.4, 10.35.5, and 10.35.8. The forwarding of MSDUs and MMPDUs between the MBSS and the DS at proxy mesh gates is described in 14.11.3.

17.3 OFDM PHY

17.3.1 Introduction

Subclause 17.3 provides a convergence procedure in which PSDUs are converted to and from PPDU. During transmission, the PSDU shall be provided with a PHY preamble and header to create the PPDU. At the receiver, the PHY preamble and header are processed to aid in demodulation and delivery of the PSDU.

17.3.2 PPDU format

17.3.2.1 General

Figure 17-1 shows the format for the PPDU including the OFDM PHY preamble, OFDM PHY header, PSDU, tail bits, and pad bits. The PHY header contains the following fields: LENGTH, RATE, a reserved bit, an even parity bit, and the SERVICE field. In terms of modulation, the LENGTH, RATE, reserved bit, and parity bit (with 6 zero tail bits appended) constitute a separate single OFDM symbol, denoted SIGNAL, which is transmitted with the most robust combination of BPSK modulation and a coding rate of $R = 1/2$. The SERVICE field of the PHY header and the PSDU (with 6 zero tail bits and pad bits appended), denoted as DATA, are transmitted at the data rate described in the RATE field and may constitute multiple OFDM symbols. The tail bits in the SIGNAL symbol enable decoding of the RATE and LENGTH fields immediately after the reception of the tail bits. The RATE and LENGTH fields are required for decoding the DATA part of the packet. In addition, the CCA mechanism is augmented by predicting the duration of the packet from the contents of the RATE and LENGTH fields, even if the data rate is not supported by the STA. Each of these fields is described in detail in 17.3.3, 17.3.4, and 17.3.5.

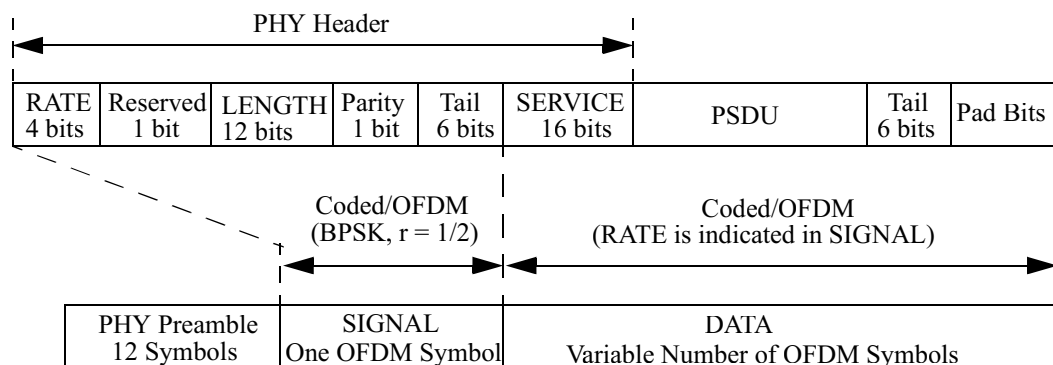


Figure 17-1—PPDU format

17.3.2.2 Overview of the PPDU encoding process

The encoding process is composed of many detailed steps, which are described fully in later subclauses, as noted below. The following overview intends to facilitate understanding the details of the convergence procedure:

- Produce the PHY Preamble field, composed of 10 repetitions of a “short training sequence” (used for AGC convergence, diversity selection, timing acquisition, and coarse frequency acquisition in the receiver) and two repetitions of a “long training sequence” (used for channel estimation and fine frequency acquisition in the receiver), preceded by a guard interval (GI). Refer to 17.3.3 for details.
- Produce the PHY header field from the RATE, LENGTH, and SERVICE fields of the TXVECTOR by filling the appropriate bit fields. The RATE and LENGTH fields of the PHY header are encoded by a convolutional code at a rate of $R = 1/2$, and are subsequently mapped onto a single BPSK

encoded OFDM symbol, denoted as the SIGNAL symbol. In order to facilitate a reliable and timely detection of the RATE and LENGTH fields, 6 zero tail bits are inserted into the PHY header. The encoding of the SIGNAL field into an OFDM symbol follows the same steps for convolutional encoding, interleaving, BPSK modulation, pilot insertion, Fourier transform, and prepending a GI as described subsequently for data transmission with BPSK-OFDM modulated at coding rate 1/2. The contents of the SIGNAL field are not scrambled. Refer to 17.3.4 for details.

- c) Calculate from RATE field of the TXVECTOR the number of data bits per OFDM symbol (N_{DBPS}), the coding rate (R), the number of bits in each OFDM subcarrier (N_{BPSC}), and the number of coded bits per OFDM symbol (N_{CBPS}). Refer to 17.3.2.3 for details.
- d) Append the PSDU to the SERVICE field of the TXVECTOR. Extend the resulting bit string with zero bits (at least 6 bits) so that the resulting length is a multiple of N_{DBPS} . The resulting bit string constitutes the DATA part of the packet. Refer to 17.3.5.4 for details.
- e) If the TXVECTOR parameter CH_BANDWIDTH_IN_NON_HT is not present, initiate the scrambler with a pseudorandom nonzero seed and generate a scrambling sequence. If the TXVECTOR parameter CH_BANDWIDTH_IN_NON_HT is present, construct the first 7 bits of the scrambling sequence from CH_BANDWIDTH_IN_NON_HT, DYN_BANDWIDTH_IN_NON_HT (if present), and a pseudorandom integer constrained such that the first 7 bits of the scrambling sequence are not all 0s; then set the scrambler state to these 7 bits and generate the remainder of the scrambling sequence. XOR the scrambling sequence with the extended string of data bits. Refer to 17.3.5.5 for details.
- f) Replace the six scrambled zero bits following the data with six nonscrambled zero bits. (Those bits return the convolutional encoder to the zero state and are denoted as tail bits.) Refer to 17.3.5.3 for details.
- g) Encode the extended, scrambled data string with a convolutional encoder ($R = 1/2$). Omit (puncture) some of the encoder output string (chosen according to “puncturing pattern”) to reach the “coding rate” corresponding to the TXVECTOR parameter RATE. Refer to 17.3.5.6 for details.
- h) Divide the encoded bit string into groups of N_{CBPS} bits. Within each group, perform an “interleaving” (reordering) of the bits according to a rule corresponding to the TXVECTOR parameter RATE. Refer to 17.3.5.7 for details.
- i) Divide the resulting coded and interleaved data string into groups of N_{BPSC} bits. For each of the bit groups, convert the bit group into a complex number according to the modulation encoding tables. Refer to 17.3.5.8 for details.
- j) Divide the complex number string into groups of 48 complex numbers. Each such group is associated with one OFDM symbol. In each group, the complex numbers are numbered 0 to 47 and mapped hereafter into OFDM subcarriers numbered –26 to –22, –20 to –8, –6 to –1, 1 to 6, 8 to 20, and 22 to 26. The subcarriers –21, –7, 7, and 21 are skipped and, subsequently, used for inserting pilot subcarriers. The 0 subcarrier, associated with center frequency, is omitted and filled with the value 0. Refer to 17.3.5.10 for details.
- k) Four subcarriers are inserted as pilots into positions –21, –7, 7, and 21. The total number of the subcarriers is 52 ($48 + 4$). Refer to 17.3.5.9 for details.
- l) For each group of subcarriers –26 to 26, convert the subcarriers to time domain using inverse Fourier transform. Prepend to the Fourier-transformed waveform a circular extension of itself thus forming a GI, and truncate the resulting periodic waveform to a single OFDM symbol length by applying time domain windowing. Refer to 17.3.5.10 for details.
- m) Append the OFDM symbols one after another, starting after the SIGNAL symbol describing the RATE and LENGTH fields. Refer to 17.3.5.10 for details.
- n) Upconvert the resulting “complex baseband” waveform to an RF according to the center frequency of the operating channel and transmit. Refer to 17.3.2.5 and 17.3.8.2 for details.

19.2.6 TXSTATUS parameters

The parameters listed in Table 19-4 are defined as part of the TXSTATUS parameter list in the PHY-TXSTART.confirm(TXSTATUS) service primitive.

Table 19-4—TXSTATUS parameter

Parameter	Value
TIME_OF_DEPARTURE	0 to $2^{32}-1$. The locally measured time when the first frame energy is sent by the transmitting port, in units equal to $1/\text{TIME_OF_DEPARTURE_ClockRate}$. This parameter is present only if <code>TIME_OF_DEPARTURE_REQUESTED</code> is true in the corresponding request.
TIME_OF_DEPARTURE_ClockRate	0 to $2^{16}-1$. The clock rate, in units of MHz, is used to generate the <code>TIME_OF_DEPARTURE</code> value. This parameter is present only if <code>TIME_OF_DEPARTURE_REQUESTED</code> is true in the corresponding request.
TX_START_OF_FRAME_OFFSET	0 to $2^{32}-1$. An estimate of the offset (in 10 ns units) from the point in time at which the start of the preamble corresponding to the frame was transmitted at the transmit antenna connector to the point in time at which this primitive is issued to the MAC.

19.3 HT PHY

19.3.1 Introduction

Subclause 19.3 provides a procedure in which PSDUs are converted to and from PPDU. During transmission, the PSDU is processed (i.e., scrambled and coded) and appended to the PHY preamble to create the PPDU. At the receiver, the PHY preamble is processed to aid in demodulation and delivery of the PSDU.

Two preamble formats are defined. For HT-mixed format operation, the preamble has a non-HT portion and an HT portion. The non-HT portion of the HT-mixed format preamble enables detection of the PPDU and acquisition of carrier frequency and timing by both HT STAs and STAs that are compliant with Clause 17 and/or Clause 18. The non-HT portion of the HT-mixed format preamble also consists of the SIGNAL field defined in Clause 17 and is thus decodable by STAs compliant with Clause 17 and Clause 18 as well as HT STAs.

The HT portion of the HT-mixed format preamble enables estimation of the MIMO channel to support demodulation of the HT data by HT STAs. The HT portion of the HT-mixed format preamble also includes the HT-SIG field, which supports HT operation. The SERVICE field is prepended to the PSDU.

For HT-greenfield operation, compatibility with Clause 17 and Clause 18 STAs is not required. Therefore, the non-HT portions of the preamble are not included in the HT-greenfield format preamble.

19.3.2 PPDU format

Two formats are defined for the PPDU: HT-mixed format and HT-greenfield format. These two formats are called *HT formats*. Figure 19-1 shows the non-HT format⁴⁸ and the HT formats. There is also an MCS 32 format (specified in 19.3.11.11.5) used for MCS 32 that provides the lowest rate in a 40 MHz channel. In

⁴⁸ The non-HT format is shown related to the terminology of this subclause. The non-HT PPDU format is defined in 17.3.3 and 17.3.2.

addition to the HT formats, there is a non-HT duplicate format (specified in 19.3.11.12) that duplicates the 20 MHz non-HT packet in two 20 MHz halves of a 40 MHz channel.

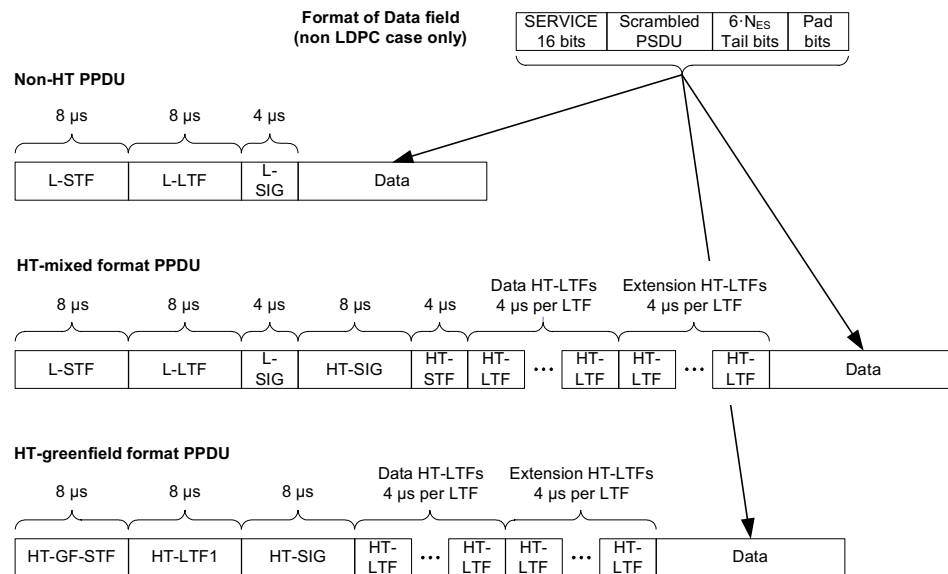


Figure 19-1—PPDU format

The elements of the PPDU are summarized in Table 19-5.

Table 19-5—Elements of the HT PPDU

Element	Description
L-STF	Non-HT Short Training field
L-LTF	Non-HT Long Training field
L-SIG	Non-HT SIGNAL field
HT-SIG	HT SIGNAL field
HT-STF	HT Short Training field
HT-GF-STF	HT-Greenfield Short Training field
HT-LTF1	First HT Long Training field (Data)
HT-LTFs	Additional HT Long Training fields (Data and Extension)
Data	The Data field includes the PSDU

The HT-SIG, HT-STF, HT-GF-STF, HT-LTF1, and HT-LTFs exist only in HT packets. In non-HT packets only the L-STF, L-LTF, L-SIG, and Data fields exist.

In both HT-mixed format and HT-greenfield format frames, there are two types of HT-LTFs: Data HT-LTFs (HT-DLTFs) and Extension HT-LTFs (HT-ELTFs). HT-DLTFs are always included in HT PPDU to provide the necessary reference for the receiver to form a channel estimate that allows it to demodulate the data

portion of the frame. The number of HT-DLTFs, $N_{HT-DLTF}$, may be 1, 2, or 4 and is determined by the number of space-time streams being transmitted in the frame (see Table 19-13). HT-ELTFs provide additional reference in sounding PPDU's so that the receiver can form an estimate of additional dimensions of the channel beyond those that are used by the data portion of the frame. The number of HT-ELTFs, $N_{HT-ELTF}$, may be 0, 1, 2, or 4 (see Table 19-14). PHY preambles in which HT-DLTFs are followed by HT-ELTFs are referred to as *staggered preambles*. The HT-mixed format and HT-greenfield format frames shown in Figure 19-1 both contain staggered preambles for illustrative purposes.

Transmissions of frames with TXVECTOR parameter NO_SIG_EXTN equal to false are followed by a period of no transmission for a duration of aSignalExtension. See 10.3.8.

A Signal Extension shall be present in a transmitted PPDU, based on the parameters of the TXVECTOR, when the NO_SIG_EXTN parameter is equal to false and either of the following is true:

- The FORMAT parameter is equal to HT_MF or HT_GF.
- The FORMAT parameter is equal to NON_HT, and the NON_HT_MODULATION parameter is equal to ERP-OFDM, or NON_HT_DUP_OFDM.

A Signal Extension shall be assumed to be present (for the purpose of timing of PHY-RXEND.indication and PHY-CCA.indication primitives, as described below and in 19.3.21) in a received PPDU when either of the following is true, based on the determined parameter values of the RXVECTOR:

- The FORMAT parameter is equal to HT_MF or HT_GF.
- The FORMAT parameter is equal to NON_HT, and the NON_HT_MODULATION parameter is equal to ERP-OFDM, or NON_HT_DUP_OFDM.

A PPDU containing a Signal Extension is called a *signal extended PPDU*. When transmitting a signal extended PPDU, the PHY-TXEND.indication primitive shall be emitted a period of aSignalExtension after the end of the last symbol of the PPDU. When receiving a signal extended PPDU, the PHY-RXEND.indication primitive shall be emitted a period of aSignalExtension after the end of the last symbol of the PPDU.

19.3.3 Transmitter block diagram

HT-mixed format and HT-greenfield format transmissions can be generated using a transmitter consisting of the following blocks:

- a) *Scrambler* scrambles the data to reduce the probability of long sequences of 0s or 1s; see 19.3.11.3.
- b) *Encoder parser*, if BCC encoding is to be used, demultiplexes the scrambled bits among N_{ES} (number of BCC encoders for the Data field) BCC encoders, in a round robin manner.
- c) *FEC encoders* encode the data to enable error correction. An FEC encoder may include a binary convolutional encoder followed by a puncturing device, or it may include an LDPC encoder.
- d) *Stream parser* divides the outputs of the encoders into blocks that are sent to different interleaver and mapping devices. The sequence of the bits sent to an interleaver is called a *spatial stream*.
- e) *Interleaver* interleaves the bits of each spatial stream (changes order of bits) to prevent long sequences of adjacent noisy bits from entering the BCC decoder. Interleaving is applied only when BCC encoding is used.
- f) *Constellation mapper* maps the sequence of bits in each spatial stream to constellation points (complex numbers).
- g) *STBC encoder* spreads constellation points from N_{SS} spatial streams into N_{STS} space-time streams using a space-time block code. STBC is used only when $N_{SS} < N_{STS}$; see 19.3.11.9.2.

- h) *Spatial mapper* maps space-time streams to transmit chains. This may include one of the following:
 - 1) *Direct mapping*: Constellation points from each space-time stream are mapped directly onto the transmit chains (one-to-one mapping).
 - 2) *Spatial expansion*: Vectors of constellation points from all of the space-time streams are expanded via matrix multiplication to produce the input to all of the transmit chains.
 - 3) *Beamforming*: Similar to spatial expansion, each vector of constellation points from all of the space-time streams is multiplied by a matrix of steering vectors to produce the input to the transmit chains.
- i) *Inverse discrete Fourier transform (IDFT)* converts a block of constellation points to a time domain block.
- j) *Cyclic shift (CSD) insertion* is where the insertion of the cyclic shifts prevents unintentional beamforming. CSD insertion may occur before or after the IDFT. There are three cyclic shift types as follows:
 - 1) A cyclic shift specified per transmitter chain with the values defined in Table 19-9 (a possible implementation is shown in Figure 19-2).
 - 2) A cyclic shift specified per space-time stream with the values defined in Table 19-10 (a possible implementation is shown in Figure 19-3).
 - 3) A cyclic shift $M_{CSD}(k)$ that may be applied as a part of the spatial mapper; see 19.3.11.11.2.
- k) *GI insertion* prepends to the symbol a circular extension of itself.
- l) *Windowing* optionally smooths the edges of each symbol to increase spectral decay.

Figure 19-2 and Figure 19-3 show example transmitter block diagrams. In particular, Figure 19-2 shows the transmitter blocks used to generate the HT-SIG of the HT-mixed format PPDU. These transmitter blocks are also used to generate the non-HT portion of the HT-mixed format PPDU, except that the BCC encoder and interleaver are not used when generating the L-STF and L-LTFs. Figure 19-3 shows the transmitter blocks used to generate the Data field of the HT-mixed format and HT-greenfield format PDUs. A subset of these transmitter blocks consisting of the constellation mapper and CSD blocks, as well as the blocks to the right of, and including, the spatial mapping block, are also used to generate the HT-STF, HT-GF-STF, and HT-LTFs. The HT-greenfield format SIGNAL field is generated using the transmitter blocks shown in Figure 19-2, augmented by additional CSD and spatial mapping blocks.

19.3.4 Overview of the PPDU encoding process

The encoding process is composed of the steps described below. The following overview is intended to facilitate an understanding of the details of the convergence procedure:

- a) Determine the number of transmit chains, N_{TX} , from the N_TX field of the TXVECTOR. Produce the PHY preamble training fields for each of the N_{TX} transmit chains based on the FORMAT, NUM_EXTEN_SS, CH_BANDWIDTH, and MCS parameters of the TXVECTOR. The format and relative placement of the PHY preamble training fields vary depending on the frame format being used, as indicated by these parameters. Apply cyclic shifts. Determine spatial mapping to be used for HT-STF and HT-LTFs in HT-mixed format frame and HT-GF-STF and HT-LTFs in HT-greenfield format frame from the EXPANSION_MAT parameter of the TXVECTOR. Refer to 19.3.9 for details.
- b) Construct the PHY preamble SIGNAL fields from the appropriate fields of the TXVECTOR by adding tail bits, applying convolutional coding, formatting into one or more OFDM symbols, applying cyclic shifts, applying spatial processing, calculating an inverse Fourier transform for each OFDM symbol and transmit chain, and prepending a cyclic prefix or GI to each OFDM symbol in each transmit chain. The number and placement of the PHY preamble SIGNAL fields depend on the frame format being used. Refer to 19.3.9.3.5, 19.3.9.4.3, and 19.3.9.5.4.

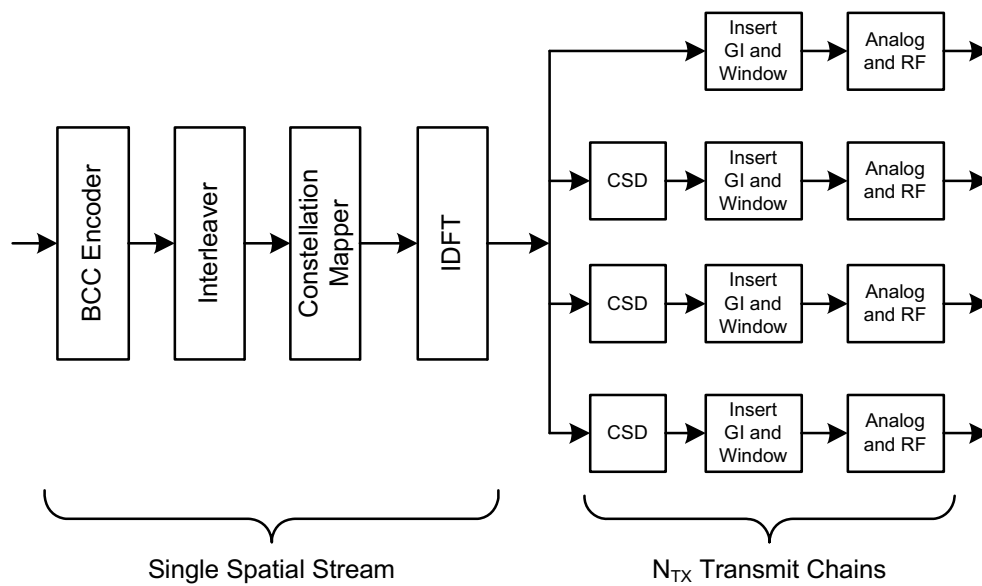
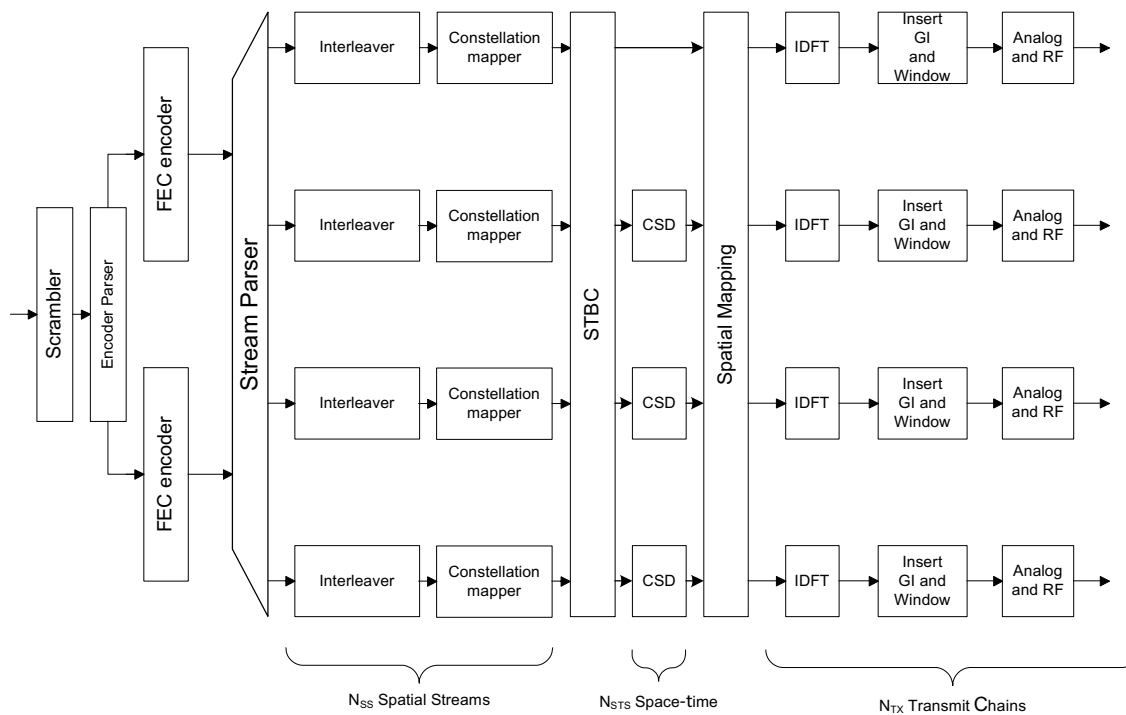


Figure 19-2—Transmitter block diagram 1



NOTES

- There might be 1 or 2 FEC encoders when BCC encoding is used.
- The stream parser might have 1, 2, 3 or 4 outputs.
- When LDPC encoding is used, the interleavers are not used
- When STBC is used, the STBC block has more outputs than inputs.
- When spatial mapping is used, there might be more transmit chains than space-time streams.
- The number of inputs to the spatial mapper might be 1, 2, 3, or 4.

Figure 19-3—Transmitter block diagram 2

- c) Concatenate the PHY preamble training and SIGNAL fields for each transmit chain one field after another, in the appropriate order, as described in 19.3.2 and 19.3.7.
- d) Use the MCS and CH_BANDWIDTH parameters of the TXVECTOR to determine the number of data bits per OFDM symbol (N_{DBPS}), the coding rate (R), the number of coded bits in each OFDM subcarrier (N_{BPCS}), and the number of coded bits per OFDM symbol (N_{CBPS}). Determine the number of encoding streams (N_{ES}) from the MCS, CH_BANDWIDTH, and FEC_CODING parameters of the TXVECTOR. Refer to 19.3.11.4 for details.
- e) Append the PSDU to the SERVICE field (see 19.3.11.2). If BCC encoding is to be used, as indicated by the FEC_CODING parameter of the TXVECTOR, tail bits are appended to the PSDU. If a single BCC encoder is used (i.e., when the value of N_{ES} is 1), the bit string is extended by 6 zero bits. If two BCC encoders are used (i.e., when the value of N_{ES} is 2), the bit string is extended by 12 zero bits. The number of symbols, N_{SYM} , is calculated according to Equation (19-32), and if necessary, the bit string is further extended with zero bits so that the resulting length is a multiple of $N_{SYM} \times N_{DBPS}$, as described in 19.3.11. If LDPC encoding is to be used, as indicated by the FEC_CODING parameter of the TXVECTOR, the resulting bit string is padded, if needed, by repeating coded bits rather than using zero bits, as given in the encoding procedure of 19.3.11.7.5. The number of resulting symbols is given by Equation (19-41), and the number of repeated coded bits used for padding is given by Equation (19-42). The resulting bit string constitutes the DATA part of the packet.
- f) Initiate the scrambler with a pseudorandom nonzero seed, generate a scrambling sequence, and exclusive-OR (XOR) it with the string of data bits, as described in 17.3.5.5.
- g) If BCC encoding is to be used, replace the scrambled zero bits that served as tail bits (6 bits if the value of N_{ES} is 1, or 12 bits if the value of N_{ES} is 2) following the data with the same number of nonscrambled zero bits, as described in 17.3.5.3. (These bits return the convolutional encoder to the zero state.)
- h) If BCC encoding is to be used and the value of N_{ES} is 2, divide the scrambled data bits between two BCC encoders by sending alternating bits to the two different encoders, as described in 19.3.11.5.
- i) If BCC encoding is to be used, encode the extended, scrambled data string with a rate 1/2 convolutional encoder (see 17.3.5.6). Omit (puncture) some of the encoder output string (chosen according to puncturing pattern) to reach the coding rate, R , corresponding to the TXVECTOR parameters MCS or L_DATARATE. Refer to 19.3.11.6 for details. If LDPC encoding is to be used, encode the scrambled data stream according to 19.3.11.7.5.
- j) Parse the coded bit stream that results from the BCC encoding or LDPC encoding into N_{SS} spatial streams, where the value of N_{SS} is determined from the MCS parameter of the TXVECTOR. See 19.3.11.8.2 for details.
- k) Divide each of the N_{SS} encoded and parsed spatial streams of bits into groups of $N_{CBPSS}(i)$ bits. If BCC encoding is to be used, within each spatial stream and group, perform an interleaving (reordering) of the bits according to a rule corresponding to $N_{BPSCS}(i)$, where i is the index of the spatial stream. Refer to 19.3.6 for details.
- l) For each of the N_{SS} encoded, parsed, and interleaved spatial streams, divide the resulting coded and interleaved data string into groups of $N_{BPSCS}(i)$ bits, where i is the index of the spatial stream. For each of the bit groups, convert the bit group into a complex number according to the modulation encoding tables. Refer to 17.3.5.8 for details.

- m) Divide the complex number string for each of the resulting N_{SS} spatial streams into groups of N_{SD} complex numbers, where the value of N_{SD} is determined from the CH_OFFSET parameter of TXVECTOR and the CH_BANDWIDTH parameter of TXVECTOR. Each such group is associated with one OFDM symbol in one spatial stream. In each group, the complex numbers are indexed 0 to $N_{SD} - 1$, and these indices have an associated one-to-one correspondence with subcarrier indices via the mapping function $M^r(k)$ as described in 19.3.11.11, 19.3.11.11.3, 19.3.11.11.4, 19.3.11.11.5, and 19.3.11.12.
- n) If STBC is to be applied, as indicated by the STBC parameter in the TXVECTOR, operate on the complex number associated with each data subcarrier in sequential pairs of OFDM symbols as described in 19.3.11.9.2 to generate N_{STS} OFDM symbols for every N_{SS} OFDM symbols associated with the N_{SS} spatial streams. If STBC is not to be used, the number of space-time streams is the same as the number of spatial streams, and the sequences of OFDM symbols in each space-time stream are composed of the sequences of OFDM symbols in the corresponding spatial stream. In each group of N_{SD} resulting complex numbers in each space-time stream, the complex numbers indexed 0 to $N_{SD} - 1$ are mapped onto OFDM subcarriers via the mapping function $M^r(k)$ as described in 19.3.11.11, 19.3.11.11.3, 19.3.11.11.4, 19.3.11.11.5, and 19.3.11.12.
- o) Determine whether 20 MHz or 40 MHz operation is to be used from the CH_BANDWIDTH parameter of the TXVECTOR. Specifically, when CH_BANDWIDTH is HT_CBW20 or NON_HT_CBW20, 20 MHz operation is to be used. When CH_BANDWIDTH is HT_CBW40 or NON_HT_CBW40, 40 MHz operation is to be used. For 20 MHz operation (with the exception of non-HT formats), insert four subcarriers as pilots into positions -21 , -7 , 7 , and 21 . The total number of the subcarriers, N_{ST} , is 56. For 40 MHz operation (with the exception of MCS 32 and non-HT duplicate format), insert six subcarriers as pilots into positions -53 , -25 , -11 , 11 , 25 , and 53 , resulting in a total of $N_{ST} = 114$ subcarriers. See 19.3.11.11.5 for pilot locations when using MCS 32 and 19.3.11.12 for pilot locations when using non-HT duplicate format. The pilots are modulated using a pseudorandom cover sequence. Refer to 19.3.11.10 for details. For 40 MHz operation, apply a $+90^\circ$ phase shift to the complex value in each OFDM subcarrier with an index greater than 0, as described in 19.3.11.11.4, 19.3.11.11.5, and 19.3.11.12.
- p) Map each of the complex numbers in each of the N_{ST} subcarriers in each of the OFDM symbols in each of the N_{STS} space-time streams to the N_{TX} transmit chain inputs. For direct-mapped operation, $N_{TX} = N_{STS}$, and there is a one-to-one correspondence between space-time streams and transmit chains. In this case, the OFDM symbols associated with each space-time stream are also associated with the corresponding transmit chain. Otherwise, a spatial mapping matrix associated with each OFDM subcarrier, as indicated by the EXPANSION_MAT parameter of the TXVECTOR, is used to perform a linear transformation on the vector of N_{STS} complex numbers associated with each subcarrier in each OFDM symbol. This spatial mapping matrix maps the vector of N_{STS} complex numbers in each subcarrier into a vector of N_{TX} complex numbers in each subcarrier. The sequence of N_{ST} complex numbers associated with each transmit chain (where each of the N_{ST} complex numbers is taken from the same position in the N_{TX} vector of complex numbers across the N_{ST} subcarriers associated with an OFDM symbol) constitutes an OFDM symbol associated with the corresponding transmit chain. For details, see 19.3.11.11. Spatial mapping matrices may include cyclic shifts, as described in 19.3.11.11.2.
- q) If the CH_BANDWIDTH and CH_OFFSET parameters of the TXVECTOR indicate that upper or lower 20 MHz are to be used in 40 MHz, move the complex numbers associated with subcarriers -28 to 28 in each transmit chain to carriers 4 to 60 in the upper channel or -60 to -4 in the lower

channel. Note that this shifts the signal in frequency from the center of the 40 MHz channel to +10 MHz or –10 MHz offset from the center of the 40 MHz channel. The complex numbers in the other subcarriers are set to 0.

- r) For each group of N_{ST} subcarriers and each of the N_{TX} transmit chains, convert the subcarriers to time domain using IDFT. Prepend to the Fourier-transformed waveform a circular extension of itself, thus forming a GI, and truncate the resulting periodic waveform to a single OFDM symbol length by applying time domain windowing. Determine the length of the GI according to the GI_TYPE parameter of the TXVECTOR. Refer to 19.3.11.11 and 19.3.11.12 for details. When beamforming is not used, it is sometimes possible to implement the cyclic shifts in the time domain.
- s) Append the OFDM symbols associated with each transmit chain one after another, starting after the final field of the PHY preamble. Refer to 19.3.2 and 19.3.7 for details.
- t) Upconvert the resulting complex baseband waveform associated with each transmit chain to an RF signal according to the center frequency of the desired channel and transmit. Refer to 19.3.7 for details. The transmit chains are connected to antenna elements according to ANTENNA_SET of the TXVECTOR if ASEL is applied.

19.3.5 Modulation and coding scheme (MCS)

The MCS is a value that determines the modulation, coding, and number of spatial channels. It is a compact representation that is carried in the HT-SIG. Rate-dependent parameters for the full set of MCSs are shown in Table 19-27 through Table 19-41 (in 19.5). These tables give rate-dependent parameters for MCSs with indices 0 to 76. MCSs with indices 0 to 7 and 32 have a single spatial stream; MCSs with indices 8 to 31 have multiple spatial streams using equal modulation (EQM) on all of the streams; MCSs with indices 33 to 76 have multiple spatial streams using unequal modulation (UEQM) on the spatial streams. MCS indices 77 to 127 are reserved.

Table 19-27 through Table 19-30 show rate-dependent parameters for EQM MCSs for one, two, three, and four streams for 20 MHz operation. Table 19-31 through Table 19-34 show rate-dependent parameters for EQM MCSs in one, two, three, and four streams for 40 MHz operation. The same EQM MCSs are used for 20 MHz and 40 MHz operation. Table 19-35 shows rate-dependent parameters for the 40 MHz, 6 Mb/s MCS 32 format.

The remaining tables, Table 19-36 to Table 19-41, show rate-dependent parameters for the MCSs with UEQM of the spatial streams for use with $N_{SS} > 1$.

UEQM MCSs are detailed in the following tables:

- Table 19-36 through Table 19-38 are for 20 MHz operation.
- Table 19-39 through Table 19-41 are for 40 MHz operation.

An HT STA shall support all equal modulation (EQM) rates for one spatial stream (MCSs 0 to 7) using a 20 MHz channel width. An HT AP that is not a VHT AP shall support all EQM rates for two spatial streams (MCSs 8 to 15) using a 20 MHz channel width. All other MCSs and modes are optional, specifically including transmit and receive support of 400 ns GI, operation in 40 MHz, and support of MCSs with indices 16 to 76.

19.3.6 Timing-related parameters

Table 19-6 defines the timing-related parameters.

Table 19-6—Timing-related constants

Parameter	TXVECTOR CH_BANDWIDTH			
	NON_HT_CBW20	HT_CBW_20	HT_CBW40 or NON_HT_CBW40	
			HT format	MCS 32 and non-HT duplicate
N_{SD} : Number of complex data numbers	48	52	108	48
N_{SP} : Number of pilot values	4	4	6	4
N_{ST} : Total number of subcarriers See NOTE 1	52	56	114	104
N_{SR} : Highest data subcarrier index	26	28	58	58
Δ_F : Subcarrier frequency spacing	312.5 kHz (20 MHz/64)	312.5 kHz	312.5 kHz (40 MHz/128)	
T_{DFT} : IDFT/DFT period	3.2 μ s	3.2 μ s	3.2 μ s	
T_{GI} : Guard interval duration	0.8 μ s = $T_{DFT}/4$	0.8 μ s	0.8 μ s	
T_{GI2} : Double guard interval	1.6 μ s	1.6 μ s	1.6 μ s	
T_{GIS} : Short guard interval duration	N/A	0.4 μ s = $T_{DFT}/8$	0.4 μ s See NOTE 2	
T_{L-STF} : Non-HT short training sequence duration	8 μ s = $10 \times T_{DFT}/4$	8 μ s	8 μ s	
$T_{HT-GF-STF}$: HT-greenfield short training field duration	N/A	8 μ s = $10 \times T_{DFT}/4$	8 μ s See NOTE 2	
T_{L-LTF} : Non-HT long training field duration	8 μ s = $2 \times T_{DFT} + T_{GI2}$	8 μ s	8 μ s	
T_{SYM} : Symbol interval	4 μ s = $T_{DFT} + T_{GI}$	4 μ s	4 μ s	
T_{SYMS} : Short GI symbol interval	N/A	3.6 μ s = $T_{DFT} + T_{GIS}$	3.6 μ s See NOTE 2	
T_{L-SIG} : Non-HT SIGNAL field duration	4 μ s = T_{SYM}	4 μ s	4 μ s	
T_{HT-SIG} : HT SIGNAL field duration	N/A	8 μ s = $2T_{SYM}$	8 μ s See NOTE 2	
T_{HT-STF} : HT short training field duration	N/A	4 μ s	4 μ s See NOTE 2	

Table 19-6—Timing-related constants (continued)

Parameter	TXVECTOR CH_BANDWIDTH			
	NON_HT_CBW20	HT_CBW_20	HT_CBW40 or NON_HT_CBW40	
			HT format	MCS 32 and non-HT duplicate
$T_{HT-LTF1}$: First HT long training field duration	N/A	4 μ s in HT-mixed format, 8 μ s in HT-greenfield format	4 μ s in HT-mixed format, 8 μ s in HT-greenfield format See NOTE 2	
$T_{HT-LTFs}$: Second, and subsequent, HT long training fields duration	N/A	4 μ s	4 μ s See NOTE 2	
NOTE 1— $N_{ST} = N_{SD} + N_{SP}$ except in the cases of MCS 32 and non-HT duplicate, where the number of data subcarriers differs from the number of complex data numbers, and the number of pilot subcarriers differs from the number of pilot values. In those cases, data numbers and pilot values are replicated in upper and lower 20 MHz portions of 40 MHz signal to make a total of 104 subcarriers.				
NOTE 2—Not applicable in non-HT formats.				
NOTE 3—N/A = Not applicable.				

Table 19-7 defines parameters used frequently in Clause 19.

Table 19-7—Frequently used parameters

Symbol	Explanation
N_{CBPS}	Number of coded bits per symbol
$N_{CBPSS}(i)$	Number of coded bits per symbol per the i -th spatial stream
N_{DBPS}	Number of data bits per symbol
N_{BPSC}	Number of coded bits per single carrier
$N_{BPSCS}(i)$	Number of coded bits per single carrier for spatial stream i
N_{RX}	Number of receive chains
N_{STS}	Number of space-time streams
N_{SS}	Number of spatial streams
N_{ESS}	Number of extension spatial streams
N_{TX}	Number of transmit chains
N_{ES}	Number of BCC encoders for the Data field
N_{HT-LTF}	Number of HT Long Training fields (see 19.3.9.4.6)
$N_{HT-DLTF}$	Number of Data HT Long Training fields
$N_{HT-ELTF}$	Number of Extension HT Long Training fields
R	Coding rate

19.3.7 Mathematical description of signals

For the description of the convention on mathematical description of signals, see 17.3.2.5.

In the case of either a 20 MHz non-HT format (TXVECTOR parameter FORMAT equal to NON_HT, MODULATION parameter equal to one of {ERP-OFDM, OFDM}) transmission or a 20 MHz HT format (TXVECTOR parameter FORMAT equal to HT_MF or HT_GF, CH_BANDWIDTH equal to HT_CBW_20) transmission, the channel is divided into 64 subcarriers. In the 20 MHz non-HT format, the signal is transmitted on subcarriers -26 to -1 and 1 to 26 , with 0 being the center (dc) carrier. In the 20 MHz HT format, the signal is transmitted on subcarriers -28 to -1 and 1 to 28 .

In the case of the 40 MHz HT format, a 40 MHz channel is used. The channel is divided into 128 subcarriers. The signal is transmitted on subcarriers -58 to -2 and 2 to 58 .

In the case of 40 MHz HT upper format or 40 MHz HT lower format, the upper or lower 20 MHz is divided into 64 subcarriers. The signal is transmitted on subcarriers -60 to -4 in the case of a 40 MHz HT lower format transmission and on subcarriers 4 to 60 in the case of a 40 MHz HT upper format transmission.

In the case of the MCS 32 and non-HT duplicate formats, the same data are transmitted over two adjacent 20 MHz channels. In this case, the 40 MHz channel is divided into 128 subcarriers, and the data are transmitted on subcarriers -58 to -6 and 6 to 58 .

The transmitted signal is described in complex baseband signal notation. The actual transmitted signal is related to the complex baseband signal by the relation shown in Equation (19-1).

$$r_{RF}(t) = \text{Re}\{r(t)\exp(j2\pi f_c t)\} \quad (19-1)$$

where

f_c is the center frequency of the carrier

The transmitted RF signal is derived by modulating the complex baseband signal, which consists of several fields. The timing boundaries for the various fields are shown in Figure 19-4.

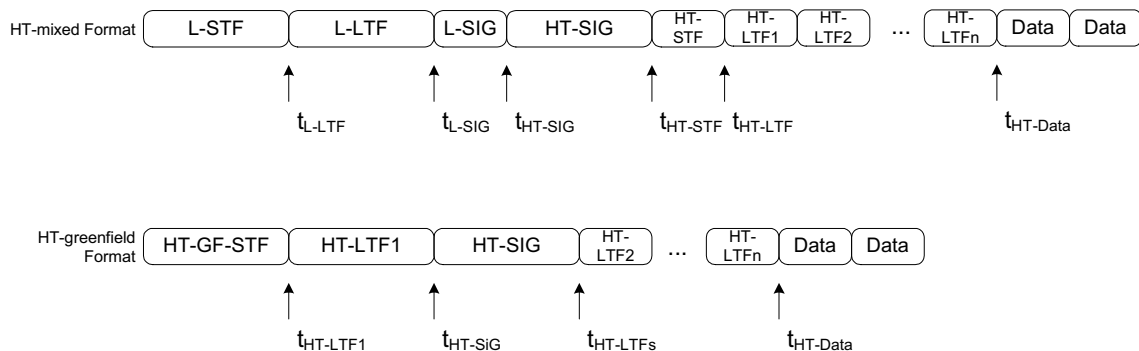


Figure 19-4—Timing boundaries for PPDU fields

The time offset, t_{Field} , determines the starting time of the corresponding field.

In HT-mixed format, the signal transmitted on transmit chain i_{TX} shall be as shown in Equation (19-2).

$$\begin{aligned}
 r_{PPDU}^{(i_{TX})}(t) = & r_{L-STF}^{(i_{TX})}(t) + r_{L-LTF}^{(i_{TX})}(t - t_{L-LTF}) \\
 & + r_{L-SIG}^{(i_{TX})}(t - t_{L-SIG}) + r_{HT-SIG}^{(i_{TX})}(t - t_{HT-SIG}) + r_{HT-STF}^{(i_{TX})}(t - t_{HT-STF}) \\
 & + \sum_{i_{LTF}=1}^{N_{HTLTF}} r_{HT-LTF}^{(i_{TX}, i_{LTF})}(t - t_{HT-LTF} - (i_{LTF} - 1)T_{HT-LTFs}) + r_{HT-DATA}^{(i_{TX})}(t - t_{HT-DATA})
 \end{aligned} \tag{19-2}$$

where

$$\begin{aligned}
 t_{L-LTF} &= T_{L-STF} \\
 t_{L-SIG} &= t_{L-LTF} + T_{L-LTF} \\
 t_{HT-SIG} &= t_{L-SIG} + T_{L-SIG} \\
 t_{HT-STF} &= t_{HT-SIG} + T_{HT-SIG} \\
 t_{HT-LTF} &= t_{HT-STF} + T_{HT-STF} \\
 t_{HT-Data} &= t_{HT-LTF} + N_{HT-LTF} \cdot T_{HT-LTFs}
 \end{aligned}$$

In the case of HT-greenfield format, the transmitted signal on transmit chain i_{TX} shall be as shown in Equation (19-3).

$$\begin{aligned}
 r_{PPDU}^{(i_{TX})}(t) = & r_{HT-GF-STF}^{(i_{TX})}(t) + r_{HT-LTF1}^{(i_{TX})}(t - t_{HT-LTF1}) \\
 & + r_{HT-SIG}^{(i_{TX})}(t - t_{HT-SIG}) \\
 & + \sum_{i_{LTF}=2}^{N_{HTLTF}} r_{HT-LTF}^{(i_{TX}, i_{LTF})}(t - t_{HT-LTFs} - (i_{LTF} - 2)T_{HT-LTFs}) \\
 & + r_{HT-DATA}^{(i_{TX})}(t - t_{HT-DATA})
 \end{aligned} \tag{19-3}$$

where

$$\begin{aligned}
 t_{HT-LTF1} &= T_{HT-GF-STF} \\
 t_{HT-SIG} &= t_{HT-LTF1} + T_{HT-LTF1} \\
 t_{HT-LTFs} &= t_{HT-SIG} + T_{HT-SIG} \\
 t_{HT-Data} &= t_{HT-LTFs} + (N_{HT-LTF} - 1) \cdot T_{HT-LTFs}
 \end{aligned}$$

Each baseband waveform, $r_{Field}^{(i_{TX})}(t)$, is defined via the discrete Fourier transform (DFT) per OFDM symbol as shown in Equation (19-4).

$$r_{Field}^{(i_{TX})}(t) = \frac{1}{\sqrt{N_{Field}^{Tone} \cdot N_{TX}}} w_{T_{Field}}(t) \sum_k \Upsilon_k X_k^{(i_{TX})} \exp(j2\pi k \Delta_F t) \tag{19-4}$$

This general representation holds for all fields. A suggested definition of the windowing function, $w_{T_{\text{Field}}}(t)$, is given in 17.3.2.5. The frequency domain symbols $X_k^{(i_{TX})}$ represent the output of any spatial processing in subcarrier k for transmit chain i_{TX} required for the field.

The function Υ_k is used to represent a rotation of the upper tones in a 40 MHz channel as shown in Equation (19-5) and Equation (19-6).

$$\Upsilon_k = \begin{cases} 1, & k \leq 0, \text{ in a 40 MHz channel} \\ j, & k > 0, \text{ in a 40 MHz channel} \end{cases} \quad (19-5)$$

$$\Upsilon_k = 1, \text{ in a 20 MHz channel} \quad (19-6)$$

The $1/\sqrt{N_{\text{Field}}^{\text{Tone}} \cdot N_{TX}}$ scale factor in Equation (19-4) causes the total power of the time domain signal as summed over all transmit chains to be either 1 or lower than 1 when required. Table 19-8 summarizes the various values of $N_{\text{Field}}^{\text{Tone}}$.

Table 19-8—Value of tone scaling factor $N_{\text{Field}}^{\text{Tone}}$

Field	$N_{\text{Field}}^{\text{Tone}}$, see NOTE 1	
	20 MHz	40 MHz
L-STF	12	24
HT-GF-STF	12	24
L-LTF	52	104
L-SIG	52	104
HT-SIG	52/56, see NOTE 2	104/114, see NOTE 2
HT-STF	12	24
HT-LTF	56	114
HT-DATA	56	114
MCS 32	—	104
Non-HT Duplicate	—	104
NOTE 1—The numbers in the table refer only to the value of $N_{\text{Field}}^{\text{Tone}}$ as it appears in Equation (19-4) and in subsequent specification of various fields. This value might be different from the actual number of tones being transmitted.		
NOTE 2—The values 56 and 114 are for HT-greenfield format; the values 52 and 104 are for HT-mixed format.		

19.3.8 Transmission in the upper/lower 20 MHz of a 40 MHz channel

When transmitting in the upper/lower 20 MHz portion of a 40 MHz channel, the mathematical definition of transmission shall follow that of a 20 MHz channel with f_c in Equation (19-1) replaced by $f_c \pm 10$ MHz.

21. Very high throughput (VHT) PHY specification

21.1 Introduction

21.1.1 Introduction to the VHT PHY

Clause 21 specifies the PHY entity for a very high throughput (VHT) orthogonal frequency division multiplexing (OFDM) system.

In addition to the requirements in Clause 21, a VHT STA shall be capable of transmitting and receiving PPDU's that are compliant with the mandatory PHY specifications defined in Clause 19.

The VHT PHY is based on the HT PHY defined in Clause 19, which in turn is based on the OFDM PHY defined in Clause 17. The VHT PHY extends the maximum number of space-time streams supported to eight and provides support for downlink multi-user (MU) transmissions. A downlink MU transmission supports up to four users with up to four space-time streams per user with the total number of space-time streams not exceeding eight.

NOTE—MU transmission is different from VHT SU group addressed transmission.

The VHT PHY provides support for 20 MHz, 40 MHz, 80 MHz, and 160 MHz contiguous channel widths and support for 80+80 MHz noncontiguous channel width.

The VHT PHY data subcarriers are modulated using binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), 16-quadrature amplitude modulation (16-QAM), 64-QAM, and 256-QAM. Forward error correction (FEC) coding (convolutional or LDPC coding) is used with coding rates of 1/2, 2/3, 3/4, and 5/6.

A VHT STA shall support the following features:

- Non-HT and non-HT duplicate formats (transmit and receive) for all channel widths supported by the VHT STA
- HT-mixed format (transmit and receive)
- VHT format (transmit and receive)
- 20 MHz, 40 MHz, and 80 MHz channel widths
- Single spatial stream VHT-MCSs 0 to 7 (transmit and receive) in all supported channel widths
- Binary convolutional coding

A VHT STA may support the following features:

- HT-greenfield format (transmit and receive)
- 2 or more spatial streams (transmit and receive)
- 400 ns short guard interval (transmit and receive)
- Beamforming sounding (by sending a VHT NDP)
- Responding to transmit beamforming sounding (by providing compressed beamforming feedback)
- STBC (transmit and receive)
- LDPC (transmit and receive)
- VHT MU PPDU's (transmit and receive)
- Support for 160 MHz channel width
- Support for 80+80 MHz channel width
- VHT-MCSs 8 and 9 (transmit and receive)

21.1.2 Scope

The services provided to the MAC by the VHT PHY consist of the following protocol functions:

- a) A function that defines a method of mapping the PSDUs into a framing format (PPDU) suitable for sending and receiving PSDUs between two or more STAs.
- b) A function that defines the characteristics and method of transmitting and receiving data through a wireless medium between two or more STAs. Depending on the PPDU format, these STAs support a mixture of VHT, Clause 19 and Clause 17 PHYs.

21.1.3 VHT PHY functions

21.1.3.1 General

The VHT PHY contains two functional entities: the PHY function and the physical layer management function (i.e., the PLME). Both of these functions are described in detail in 21.3 and 21.4.

The VHT PHY service is provided to the MAC through the PHY service primitives defined in Clause 8. The VHT PHY service interface is described in 21.2.

21.1.3.2 PHY management entity (PLME)

The PLME performs management of the local PHY functions in conjunction with the MLME.

21.1.3.3 Service specification method

The models represented by figures and state diagrams are intended to be illustrations of the functions provided. It is important to distinguish between a model and a real implementation. The models are optimized for simplicity and clarity of presentation, but do not necessarily reflect any particular implementation.

The service of a layer is the set of capabilities that it offers to a user in the next higher layer. Abstract services are specified here by describing the service primitives and parameters that characterize each service. This definition is independent of any particular implementation.

21.1.4 PPDU formats

The structure of the PPDU transmitted by a VHT STA is determined by the TXVECTOR parameters as defined in Table 21-1.

In a VHT STA the FORMAT parameter determines the overall structure of the PPDU and can take one of the following values:

- Non-HT format (NON_HT), based on Clause 17 and including non-HT duplicate format.
- HT-mixed format (HT_MF) as specified in Clause 19.
- HT-greenfield format (HT_GF) as specified in Clause 19.
- VHT format (VHT). PPDU of this format contain a preamble compatible with Clause 17 and Clause 19 STAs. The non-VHT portion of the VHT format preamble (the parts of VHT preamble preceding the VHT-SIG-A field) is defined so that it can be decoded by these STAs.

NOTE—Required support for these formats is defined in 11.40, 19.1.1, and 21.1.1.

A VHT PPDU can be further categorized as a VHT SU PPDU or a VHT MU PPDU. A VHT PPDU using a group ID value of 0 or 63 is a VHT SU PPDU and either carries only one PSDU or no PSDU. A VHT PPDU

21.3 VHT PHY

21.3.1 Introduction

This subclause provides the procedure by which PSDUs are converted to and from transmissions on the wireless medium.

During transmission, a PSDU (in the SU case) or one or more PSDUs (in the MU case) are processed (i.e., scrambled and coded) and appended to the PHY preamble to create the PPDU. At the receiver, the PHY preamble is processed to aid in the detection, demodulation, and delivery of the PSDU.

Pre-VHT modulated fields refer to the L-STF, L-LTF, L-SIG, and VHT-SIG-A fields, while VHT modulated fields refer to the VHT-STF, VHT-LTF, VHT-SIG-B, and Data fields (see Figure 21-17).

21.3.2 VHT PPDU format

A single PPDU format is defined for this PHY: the VHT PPDU format. Figure 21-4 shows the VHT PPDU format.

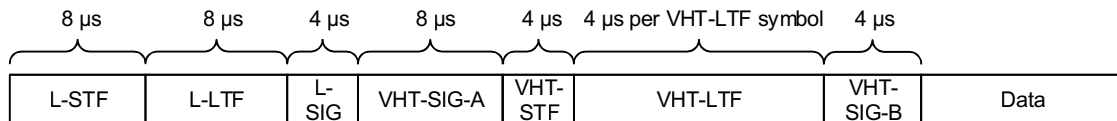


Figure 21-4—VHT PPDU format

The fields of the VHT PPDU format are summarized in Table 21-4.

Table 21-4—Fields of the VHT PPDU

Field	Description
L-STF	Non-HT Short Training field
L-LTF	Non-HT Long Training field
L-SIG	Non-HT SIGNAL field
VHT-SIG-A	VHT Signal A field
VHT-STF	VHT Short Training field
VHT-LTF	VHT Long Training field
VHT-SIG-B	VHT Signal B field
Data	The Data field carrying the PSDU(s)

The VHT-SIG-A, VHT-STF, VHT-LTF, and VHT-SIG-B fields exist only in VHT PPDU. In a VHT NDP the Data field is not present. The number of symbols in the VHT-LTF field, N_{VHTLTF} , can be either 1, 2, 4, 6, or 8 and is determined by the total number of space-time streams across all users being transmitted in the VHT PPDU (see Table 21-13).

21.3.8.3 VHT portion of VHT format preamble

21.3.8.3.1 Introduction

The VHT portion of the VHT format preamble consists of the VHT-SIG-A, VHT-STF, VHT-LTF, and VHT-SIG-B fields.

21.3.8.3.2 Cyclic shift for VHT modulated fields

The cyclic shift values defined in this subclause apply to the VHT-STF, VHT-LTF, VHT-SIG-B, and Data fields of the VHT PPDU. The cyclic shift values defined in 21.3.8.2.1 apply to VHT-SIG-A field in the VHT format preamble.

Throughout the VHT modulated fields of the preamble, cyclic shifts are applied to prevent unintended beamforming when correlated signals are transmitted in multiple space-time streams. The same cyclic shift is also applied to these streams during the transmission of the Data field of the VHT PPDU. The cyclic shift value $T_{CS, VHT}(n)$ for the VHT modulated fields for space-time stream n out of $N_{STS, total}$ total space-time streams is shown in Table 21-11.

Table 21-11—Cyclic shift values for the VHT modulated fields of a PPDU

$T_{CS, VHT}(n)$ values for the VHT modulated fields of a PPDU								
Total number of space-time streams ($N_{STS, total}$)	Cyclic shift for space-time stream n (ns)							
	1	2	3	4	5	6	7	8
1	0	—	—	—	—	—	—	—
2	0	−400	—	—	—	—	—	—
3	0	−400	−200	—	—	—	—	—
4	0	−400	−200	−600	—	—	—	—
5	0	−400	−200	−600	−350	—	—	—
6	0	−400	−200	−600	−350	−650	—	—
7	0	−400	−200	−600	−350	−650	−100	—
8	0	−400	−200	−600	−350	−650	−100	−750

In a VHT MU PPDU, the cyclic shifts are applied sequentially across the space-time streams as follows: the cyclic shift of the space-time stream number m of user u is given by $T_{CS, VHT}(M_u + m)$ of the row corresponding to $N_{STS, total}$ in Table 21-11.

$$r_{\text{VHT-STF}}^{(i_{\text{seg}}, i_{\text{TX}})}(t) = \frac{1}{\sqrt{N_{\text{VHT-STF}}^{\text{Tone}} N_{\text{STS}, \text{total}}}} w_{T_{\text{VHT-STF}}}(t) \cdot \sum_{k=-N_{\text{SR}}}^{N_{\text{SR}}} \sum_{u=0}^{N_{\text{user}}-1} \sum_{m=1}^{N_{\text{STS}, u}} \left(\left[Q_k^{(i_{\text{seg}})} \right]_{i_{\text{TX}}, (M_u + m)} Y_{k, \text{BW}}^{\text{VHTS}_k} \cdot \exp(j2\pi k \Delta_F(t - T_{\text{CS}, \text{VHT}}(M_u + m))) \right) \quad (21-33)$$

where

$N_{\text{VHT-STF}}^{\text{Tone}}$ has the value given in Table 21-8

$T_{\text{CS}, \text{VHT}}(n)$ is given in Table 21-11

$Q_k^{(i_{\text{seg}})}$ is defined in 21.3.10.11.1

$Y_{k, \text{BW}}$ is defined in Equation (21-14), Equation (21-15), Equation (21-16), and Equation (21-17)

21.3.8.3.5 VHT-LTF definition

The VHT Long Training field (VHT-LTF) field provides a means for the receiver to estimate the MIMO channel between the set of constellation mapper outputs (or, if STBC is applied, the STBC encoder outputs) and the receive chains. The transmitter provides training for $N_{\text{STS}, \text{total}}$ space-time streams (spatial mapper inputs) used for the transmission of the PSDU(s). For each tone, the MIMO channel that can be estimated is an $N_{\text{RX}} \times N_{\text{STS}, \text{total}}$ matrix. A VHT transmission has a preamble that contains VHT-LTF symbols, where the data tones of each VHT-LTF symbol are multiplied by entries belonging to a matrix $P_{\text{VHT-LTF}}$, to enable channel estimation at the receiver. The pilot tones of each VHT-LTF symbol are multiplied by the entries of a matrix $R_{\text{VHT-LTF}}$ defined in the following text. The multiplication of the pilot tones in the VHT-LTF symbol by the $R_{\text{VHT-LTF}}$ matrix instead of the $P_{\text{VHT-LTF}}$ matrix allows receivers to track phase and frequency offset during MIMO channel estimation using the VHT-LTF. The number of VHT-LTF symbols, $N_{\text{VHT-LTF}}$, is a function of the total number of space-time streams $N_{\text{STS}, \text{total}}$ as shown in Table 21-13. As a result the VHT-LTF field consists of one, two, four, six or eight symbols.

Table 21-13—Number of VHT-LTFs required for different numbers of space-time streams

$N_{\text{STS}, \text{total}}$	N_{VHTLTF}
1	1
2	2
3	4
4	4
5	6
6	6
7	8
8	8

After the PHY is configured using the PHYCONFIG_VECTOR parameter GROUP_ID_MANAGEMENT, the following lookup tables are populated:

- a) Group ID to Membership Status, denoted by MembershipStatusInGroupID[g] for $1 \leq g \leq 62$
- b) Group ID to User Position, denoted by UserPositionInGroupID[g] for $1 \leq g \leq 62$

When a STA receives a VHT MU PPDU where the Group ID field in VHT-SIG-A has the value k and where MembershipStatusInGroupID[k] is equal to 1, then the number of space-time streams for that STA is indicated in the MU[UserPositionInGroupID[k]] NSTS field in VHT-SIG-A. The space-time streams of different users are ordered in accordance to user position values, i.e., the space-time streams for the user in user position 0 come first, followed by the space-time streams for the user in position 1, followed by the space-time streams for the user in position 2, and followed by the space-time streams for the user in position 3.

A STA is also able to identify the space-time streams intended for other STAs that act as interference. VHT-LTF symbols in the VHT MU PPDU are used to measure the channel for the space-time streams intended for the STA and can also be used to measure the channel for the interfering space-time streams. To successfully demodulate the space-time streams intended for the STA, the STA may use the channel state information for all space-time streams to reduce the effect of interfering space-time streams.

If a STA finds that it is not a member of the group, or the STA is a member of the group but the corresponding MU NSTS field in VHT-SIG-A indicates that there are zero space-time streams for the STA in the PPDU, then the STA may elect to not process the remainder of the PPDU.

21.3.12 VHT preamble format for sounding PPDUs

NDP is the only VHT sounding format.

The format of a VHT NDP PPDU is shown in Figure 21-28.

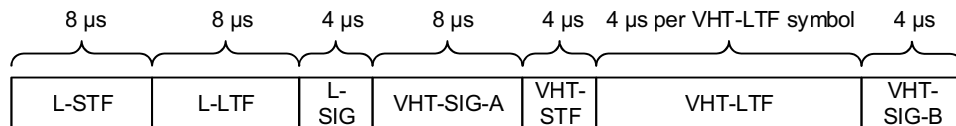


Figure 21-28—VHT NDP format

NOTE—The number of VHT-LTF symbols in the NDP is determined by the SU NSTS field in VHT-SIG-A.

The VHT NDP PPDU has the following properties:

- Uses the VHT PPDU format but without the Data field.
- Is a VHT SU PPDU as indicated by the VHT-SIG-A field.
- Has the data bits of the VHT-SIG-B field set to a fixed bit pattern (see 21.3.8.3.6).

21.3.13 Regulatory requirements

Wireless LANs (WLANs) implemented in accordance with this standard are subject to equipment certification and operating requirements established by regional and national regulatory administrations. The PHY specification establishes minimum technical requirements for interoperability, based upon established regulations at the time this standard was issued. These regulations are subject to revision or may be superseded. Requirements that are subject to local geographic regulations are annotated within the PHY specification. Regulatory requirements that do not affect interoperability are not addressed in this standard. Implementers are referred to the regulatory sources in Annex D for further information. Operation in