United States Patent	12395395
Kind Code	B2
Date of Patent	August 19, 2025
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Doppler mode in a wireless network

Abstract

To receive data in data field of a PHY Protocol Data Unit (PPDU), wherein the data field includes mid-ambles, a number of mid-ambles and a number of data symbols included in the data field is determined. The number of mid-ambles is determined according to information in an HE-SIG-A field of the PPDU, information in an L-SIG field of the PPDU, and one or more predetermined values prescribed by a standard. The number of data symbols may be determined using the number of the mid-ambles, and the data received according to the number of mid-ambles and the number of data symbols.

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Appl. No.:	**18/529999**
Filed:	**December 05, 2023**

Prior Publication Data

Document Identifier	Publication Date
US 20240146597 A1	May. 02, 2024

Related U.S. Application Data

continuation parent-doc US 17891985 20220819 US 11870634 child-doc US 18529999
continuation parent-doc US 16924979 20200709 US 11457097 20220927 child-doc US 17891985
continuation parent-doc US 15978030 20180511 US 10749996 20200818 child-doc US 16924979
us-provisional-application US 62511914 20170526

Publication Classification

Int. Cl.: **H04L27/26** (20060101); **H04L5/00** (20060101); **H04L69/22** (20220101); **H04W74/00** (20090101)

U.S. Cl.:

CPC   **H04L27/2666** (20130101); **H04L5/0048** (20130101); **H04L27/2603** (20210101); **H04L27/2613** (20130101); **H04L27/26132** (20210101); **H04L69/22** (20130101); **H04W74/006** (20130101); H04L27/261 (20130101); H04L27/26134 (20210101)

Field of Classification Search

CPC: H04L (27/2666); H04L (5/0048); H04L (27/2603); H04L (27/2613); H04L (27/26132); H04L (69/22); H04L (27/261); H04L (27/26134); H04L (5/0096); H04L (5/006); H04L (5/0051); H04L (5/0085); H04L (27/2602); H04L (27/2646); H04W (74/006)

USPC: 370/254

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION (1) This application is a continuation of U.S. patent application Ser. No. 17/891,985, filed Aug. 19, 2022, which is a continuation of U.S. patent application Ser. No. 16/924,979, filed Jul. 9, 2020 and issued as U.S. Pat. No. 11,457,097 on Sep. 27, 2022, which is a continuation of U.S. patent application Ser. No. 15/978,030, filed May 11, 2018, and issued as U.S. Pat. No. 10,749,996 on Aug. 18, 2020, which claims the benefit of U.S. Provisional Patent Application No. 62/511,914, filed May 26, 2017, which are incorporated by reference herein in their entirety.

BACKGROUND

1. Technical Field

(1) The technology described herein relates generally to wireless networking. More particularly, the technology relates to determining parameters of a received transmission wherein mid-ambles are used to improve the reception of the transmission.

2. Description of the Related Art

(2) Wireless Local Area Network (WLAN) devices are currently being deployed in diverse environments. Some of these environments have large numbers of access points (APs) and non-AP stations in geographically limited areas. In addition, WLAN devices are increasingly required to support a variety of applications such as video, cloud access, and offloading. In particular, video traffic is expected to be the dominant type of traffic in many high efficiency WLAN deployments. With the real-time requirements of some of these applications, WLAN users demand improved performance in delivering their applications, including improved power consumption for battery-operated devices.

(3) A WLAN is being standardized by the IEEE (Institute of Electrical and Electronics Engineers) Part 11 under the name of "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications." A series of standards have been adopted as the WLAN evolved, including IEEE Std 802.11™-2012 (March 2012) (IEEE 802.11n). The IEEE Std 802.11 was subsequently amended by IEEE Std 802.11ae™-2012, IEEE Std 802.11aa™-2012, IEEE Std 802.11ad™-2012, and IEEE Std 802.11ac™-2013 (IEEE 802.11ac).

(4) Recently, an amendment focused on providing a High Efficiency (HE) WLAN in high-density scenarios is being developed by the IEEE 802.11ax task group. The 802.11ax amendment focuses on improving metrics that reflect user experience, such as average per station throughput, the 5th percentile of per station throughput of a group of stations, and area throughput. Improvements may be made to support environments such as wireless corporate offices, outdoor hotspots, dense residential apartments, and stadiums.

(5) In some environments, channel conditions may change during the communication of a data unit. For example, when non-AP stations are moving with respect to the AP, the Doppler effect may alter the channel conditions. In these environments, mid-ambles may be inserted in a data portion of a communication to allow channel estimation to be performed by the receiving device during the reception of the data portion. The presence of mid-ambles into the data portion may alter how the receiving device determines some of the parameters of the communication.

SUMMARY

(6) In an embodiment, a method performed by a wireless device comprises receiving a first portion of a PHY Protocol Data Unit (PPDU), the first portion including a Legacy Signal (L-SIG) field, decoding the L-SIG field, and determining a format of the PPDU using the first portion. In response to determining that the format of the PPDU is a High Efficiency (HE) format, the method performs receiving and decoding an HE Signal A (HE-SIG-A) field, and determining, using a Doppler field of the HE-SIG-A field, whether the PPDU includes mid-ambles. In response to determining that the PPDU includes mid-ambles, the method performs determining, according to the format of the PPDU and using first information determined using the HE-SIG-A field and second information determined using the L-SIG field, a number of mid-ambles N_{MA} indicating the number of mid-ambles included in a data field of the PPDU, determining, using the number of the mid-ambles N_{MA}, a number of data symbols N_{SYM} included in the data field of the PPDU, and receiving, using the number of mid-ambles N_{MA} and the number of data symbols N_{SYM}, the data field of the PPDU.

(7) In another embodiment, a wireless device comprises a receiver and a processor. The processor is configured to perform receiving, using the receiver, a first portion of a PHY Protocol Data Unit (PPDU), the first portion including a Legacy Signal (L-SIG) field, decoding the L-SIG field, and determining a format of the PPDU using the first portion. The processor is further configured to, in response to determining that the format of the PPDU is a High Efficiency (HE) format, perform receiving and decoding an HE Signal A (HE-SIG-A) field, and determining, using a Doppler field of the HE-SIG-A field, whether the PPDU includes mid-ambles. The processor is further configure to, in response to determining that the PPDU includes mid-ambles, perform determining, according to the format of the PPDU and using first information determined using the HE-SIG-A field and second information determined using the L-SIG field, a number of mid-ambles N_{MA} indicating the number of mid-ambles included in a data field of the PPDU, determining, using the number of the mid-ambles, a number of data symbols N_{SYM} included in the data field of the PPDU, and receiving, using the number of mid-ambles N_{MA} and the number of data symbols N_{SYM}, the data field of the PPDU.

(8) In embodiments, the first information includes a Packet Extension (PE) Disambiguity bit value $b_{PE-Disambiguity}$, a number of HE Long

Training Fields (HE-LTFs) value N.sub.HE-LTF, an HE-LTF duration including guard interval T.sub.HE-LTF, and a data symbol duration T.sub.SYM, and a mid-amble periodicity M.

(9) In embodiments, the first information further includes a preamble duration T.sub.PA according to the format of the PPDU, the HE-LTF duration T.sub.HE-LTF, and the number of HE-LTFs value N.sub.HE-LTF.

(10) In embodiments, the first information further includes a mid-amble duration T.sub.MA.

(11) In embodiments, the second information includes a Length field value L_LENGTH.

(12) In embodiments, determining the number of mid-ambles N.sub.MA includes determining the number of mid-ambles N.sub.MA according to:

(13) $N_{MA} =$ .Math. $\dfrac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + \beta + b_{PE\text{-}Disambiguity})}{T_{MA} + M \,.Math.\, T_{SYM}}$ .Math.

wherein m is 1 when the format of the PPDU is an HE Multi-User PPDU or HE Extended Range Single User PPDU format and m is 2 otherwise, and wherein β is an integer number greater than or equal to zero.

(14) In embodiments, determining the number of mid-ambles N.sub.MA includes determining the number of mid-ambles N.sub.MA according to:

(15) $N_{MA} =$ .Math. $\dfrac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + \beta + b_{PE\text{-}Disambiguity} + M)}{T_{MA} + M \,.Math.\, T_{SYM}}$ .Math.

wherein m is 1 when the format of the PPDU is an HE Multi-User PPDU or HE Extended Range Single User PPDU format and m is 2 otherwise, and wherein β is an integer number greater than or equal to zero.

(16) In embodiments, β is 1.

(17) In embodiments, receiving the data field comprises repeating, a number of times equal to the number of mid-ambles N.sub.MA, the steps of: receiving a plurality of consecutive data symbols, wherein the number of data symbols in the plurality of data symbols is equal to the mid-amble periodicity M, and receiving a mid-amble immediately following the plurality of consecutive data symbols. Then the embodiment receives a remaining 0 or more remaining consecutive data symbols, wherein the number of data symbols N.sub.remain is equal to:

N.sub.remain=N.sub.SYM−(M.Math.N.sub.MA)

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. **1** illustrates a wireless network, according to an embodiment.
(2) FIG. **2** is a schematic diagram of a wireless device, according to an embodiment.
(3) FIG. **3**A illustrates components of a wireless device configured to transmit data, according to an embodiment.
(4) FIG. **3**B illustrates components of a wireless device configured to receive data, according to an embodiment.
(5) FIG. **4** illustrates Inter-Frame Space (IFS) relationships.
(6) FIG. **5** illustrates a Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) based frame transmission procedure.
(7) FIG. **6**A illustrates a High Efficiency (HE) PHY Protocol Data Units (PPDU), according to an embodiment.
(8) FIG. **6**B shows a Table 1 disclosing additional properties of fields of the HE PPDU frame of FIG. **6**A, according to an embodiment.
(9) FIG. **7**A illustrates a format of a High Efficiency (HE) Single User (SU) PPDU according to an embodiment.
(10) FIG. **7**B illustrates a format of an HE Multi-User (MU) PPDU frame according to an embodiment.
(11) FIG. **7**C illustrates a format of an HE Extended Range (ER) SU PPDU according to an embodiment.
(12) FIG. **7**D illustrates a format of an HE Trigger-Based (TB) PPDU **700**D according to an embodiment.
(13) FIG. **8** illustrates a Trigger frame according to an embodiment.
(14) FIG. **9** illustrates a Common Info field according to an embodiment.
(15) FIG. **10** illustrates a User Info field according to an embodiment.
(16) FIG. **11** illustrates a PPDU used when the Doppler subfield is set to 1, according to an embodiment.
(17) FIG. **12** illustrates signaling of a PPDU format according to an embodiment.
(18) FIG. **13** illustrates a process, according to an embodiment, for determining a mid-amble periodicity M according to format of a PPDU.
(19) FIG. **14** illustrates a process, according to another embodiment, for determining a mid-amble periodicity M according to format of a PPDU.
(20) FIG. **15** illustrates a process, according to another embodiment, for determining a mid-amble periodicity M according to format of a PPDU.
(21) FIG. **16** illustrates a process, according to another embodiment, for determining a mid-amble periodicity M according to format of a PPDU.
(22) FIG. **17** illustrates a PPDU including mid-ambles according to an embodiment.
(23) FIG. **18** illustrates a PPDU including mid-ambles according to an embodiment.
(24) FIG. **19** illustrates features of a PPDU including mid-ambles according to another embodiment.
(25) FIG. **20** illustrates a PPDU including mid-ambles according to another embodiment.
(26) FIG. **21** illustrates a process, according to an embodiment, for receiving a PPDU having a data field that includes mid-ambles.
(27) FIG. **22** illustrates a process, according to an embodiment, for receiving a data field of a PPDU including mid-ambles.

DETAILED DESCRIPTION

(28) The technology described herein relates generally to wireless networking. More particularly, the technology relates to communication of PHY Protocol Data Units (PPDUs) including data fields wherein the data field include mid-ambles.

(29) In the following detailed description, certain illustrative embodiments have been illustrated and described. As those skilled in the art would realize, these embodiments are capable of modification in various different ways without departing from the scope of the present disclosure. Accordingly, the drawings and description are to be regarded as illustrative in nature and not restrictive. Like reference numerals designate like elements in the specification.

(30) FIG. **1** illustrates a wireless network according to an embodiment. The wireless networks includes an infrastructure Basic Service Set (BSS) **100** of a Wireless Local Area Networks (WLAN). In an 802.11 WLAN, the BSS provides the basic organizational unit and typically includes an Access Point (AP) and one or more associated stations (STAs).

(31) The first BSS **100** includes an Access Point **102** (also referred to as AP) wirelessly communicating with first, second, third, and fourth wireless devices (or stations) **104**, **106**, **108**, and **110** (also referred to as stations STA1, STA2, STA3, and STA4, respectively). The wireless devices may each include a medium access control (MAC) layer and a physical (PHY) layer according to an IEEE 802.11 standard.

(32) Although FIG. **1** shows the first BSS **100** including only the first to fourth stations STA1 to STA4, embodiments are not limited thereto and may comprise BSSs including any number of stations.

(33) The AP **102** is a station, that is, a STA, configured to control and coordinate functions of the BSS **100**. The AP **102** may transmit information to a single station selected from the plurality of stations STA1 to STA4 in the first BSS **100** using a single frame, or may simultaneously transmit information to two or more of the stations STA1 to STA4 in the first BSS **100** using either a single Orthogonal Frequency Division Multiplexing (OFDM) broadcast frame, a single OFDM Multi-User Multi-Input-Multi-Output (MU-MIMO) transmission, a single Orthogonal Frequency Division Multiple Access (OFDMA) frame, or a single MU-MIMO OFDMA frame.

(34) The stations STA1 to STA4 may each transmit data to the AP **102** using a single frame, or transmit information to and receive information from each other using a single frame. Two or more of the stations STA1 to STA4 may simultaneously transmit data to the AP **102** using an Uplink (UL) OFDMA frame, an UL MU-MIMO frame, or an UL MU-MIMO OFDMA frame.

(35) In another embodiment, the AP **102** may be absent and the stations STA1 to STA4 may be in an ad-hoc network.

(36) FIG. **1** shows a first Down-Link (DL) transmission **114** and a first Up-Link (UL) transmission **112** of the first BSS **100**.

(37) Each of the stations STA1 to STA4 and the AP **102** includes a processor and one or more transceiver circuits, and may further include a user interface and a display device.

(38) The processor is configured to generate a frame to be transmitted through a wireless network, to process a frame received through the wireless network, and to execute protocols of the wireless network. The processor may perform some or all of its functions by executing computer programming instructions stored on a non-transitory computer-readable medium.

(39) The transceiver represents a unit functionally connected to the processor, and designed to transmit and receive a frame through the wireless network. The transceiver may include a single component that performs the functions of transmitting and receiving, or two separate components each performing one of such functions.

(40) The processor and transceiver of the stations STA1 to STA4 and the AP **102** may be respectively implemented using hardware components, software components, or both.

(41) The first AP **102** may be or include a WLAN router, a stand-alone Access Point, a WLAN bridge, a Light-Weight Access Point (LWAP) managed by a WLAN controller, and the like. In addition, a device such as a personal computer, tablet computer, or cellular phone may configured to be able to operate as the AP **102**, such as when a cellular phone is configured to operate as a wireless "hot spot."

(42) Each of the stations STA1 to STA4 may be or may include a desktop computer, a laptop computer, a tablet PC, a wireless phone, a mobile phone, a smart phone, an e-book reader, a Portable Multimedia Player (PMP), a portable game console, a navigation system, a digital camera, a Digital Multimedia Broadcasting (DMB) player, a digital audio recorder, a digital audio player, a digital picture recorder, a digital picture player, a digital video recorder, a digital video player, and the like.

(43) The present disclosure may be applied to WLAN systems according to IEEE 802.11 standards but embodiments are not limited thereto.

(44) In IEEE 802.11 standards, frames exchanged between stations (including access points) are classified into management frames, control frames, and data frames. A management frame may be a frame used for exchanging management information that is not forwarded to a higher layer of a communication protocol stack. A control frame may be a frame used for controlling access to a medium. A data frame may be a frame used for transmitting data to be forwarded to the higher layer of the communication protocol stack.

(45) A type and subtype of a frame may be identified using a type field and/or a subtype field included in a control field of the frame, as prescribed in the applicable standard.

(46) FIG. **2** illustrates a schematic block diagram of a wireless device **200** according to an embodiment. The wireless or WLAN device **200** may be included in the AP **102** or any of the stations STA1 to STA4 in FIG. **1**. The WLAN device **200** includes a baseband processor **210**, a radio frequency (RF) transceiver **240**, an antenna unit **250**, a storage device (e.g., memory) **232**, one or more input interfaces **234**, and one or more output interfaces **236**. The baseband processor **210**, the memory **232**, the input interfaces **234**, the output interfaces **236**, and the RF transceiver **240** may communicate with each other via a bus **260**.

(47) The baseband processor **210** performs baseband signal processing, and includes a MAC processor **212** and a PHY processor **222**. The baseband processor **210** may utilize the memory **232**, which may include a non-transitory computer readable medium having software (e.g., computer programing instructions) and data stored therein.

(48) In an embodiment, the MAC processor **212** includes a MAC software processing unit **214** and a MAC hardware processing unit **216**. The MAC software processing unit **214** may implement a first plurality of functions of the MAC layer by executing MAC software, which may be included in the software stored in the memory **232**. The MAC hardware processing unit **216** may implement a second plurality of functions of the MAC layer in special-purpose hardware. However, the MAC processor **212** is not limited thereto. For example, the MAC processor **212** may be configured to perform the first and second plurality of functions entirely in software or entirely in hardware according to an implementation.

(49) The PHY processor **222** includes a transmitting signal processing unit (SPU) **224** and a receiving SPU **226**. The PHY processor **222** implements a plurality of functions of the PHY layer. These functions may be performed in software, hardware, or a combination thereof according to an implementation.

(50) Functions performed by the transmitting SPU **224** may include one or more of Forward Error Correction (FEC) encoding, stream parsing into one or more spatial streams, diversity encoding of the spatial streams into a plurality of space-time streams, spatial mapping of the space-time streams to transmit chains, inverse Fourier Transform (iFT) computation, Cyclic Prefix (CP) insertion to create a Guard Interval (GI), and the like. Functions performed by the receiving SPU **226** may include inverses of the functions performed by the transmitting SPU **224**, such as GI removal, Fourier Transform computation, and the like.

(51) The RF transceiver **240** includes an RF transmitter **242** and an RF receiver **244**. The RF transceiver **240** is configured to transmit first information received from the baseband processor **210** to the WLAN, and provide second information received from the WLAN to the baseband processor **210**.

(52) The antenna unit **250** includes one or more antennas. When Multiple-Input Multiple-Output (MIMO) or Multi-User MIMO (MU-MIMO) is used, the antenna unit **250** may include a plurality of antennas. In an embodiment, the antennas in the antenna unit **250** may operate as a beam-formed antenna array. In an embodiment, the antennas in the antenna unit **250** may be directional antennas, which may be fixed or steerable.

(53) The input interfaces **234** receive information from a user, and the output interfaces **236** output information to the user. The input interfaces **234** may include one or more of a keyboard, keypad, mouse, touchscreen, microphone, and the like. The output interfaces **236** may include one or more of a display device, touch screen, speaker, and the like.

(54) As described herein, many functions of the WLAN device **200** may be implemented in either hardware or software. Which functions are implemented in software and which functions are implemented in hardware will vary according to constraints imposed on a design. The constraints may include one or more of design cost, manufacturing cost, time to market, power consumption, available semiconductor technology, and so on.

(55) As described herein, a wide variety of electronic devices, circuits, firmware, software, and combinations thereof may be used to implement the functions of the components of the WLAN device **200**. Furthermore, the WLAN device **200** may include other components, such as application processors, storage interfaces, clock generator circuits, power supply circuits, and the like, which have been omitted in the interest of brevity.

(56) FIG. **3**A illustrates components of a wireless device configured to transmit data according to an embodiment, including a Transmitting (Tx) SPU (TxSP) **324**, an RF transmitter **342**, and an antenna **352**. In an embodiment, the TxSP **324**, the RF transmitter **342**, and the antenna **352** correspond to the transmitting SPU **224**, the RF transmitter **242**, and an antenna of the antenna unit **250** of FIG. **2**, respectively.

(57) The TxSP **324** includes an encoder **300**, an interleaver **302**, a mapper **304**, an inverse Fourier transformer (IFT) **306**, and a guard interval (GI) inserter **308**.

(58) The encoder **300** receives and encodes input data DATA. In an embodiment, the encoder **300** includes a forward error correction (FEC) encoder. The FEC encoder may include a binary convolutional code (BCC) encoder followed by a puncturing device. The FEC encoder may include a low-density parity-check (LDPC) encoder.

(59) The TxSP **324** may further include a scrambler for scrambling the input data before the encoding is performed by the encoder **300** to reduce the probability of long sequences of 0 s or 1 s. When the encoder **300** performs the BCC encoding, the TxSP **324** may further include an encoder parser

for demultiplexing the scrambled bits among a plurality of BCC encoders. If LDPC encoding is used in the encoder, the TxSP **324** may not use the encoder parser.

(60) The interleaver **302** interleaves the bits of each stream output from the encoder **300** to change an order of bits therein. The interleaver **302** may apply the interleaving only when the encoder **300** performs the BCC encoding, and otherwise may output the stream output from the encoder **300** without changing the order of the bits therein.

(61) The mapper **304** maps the sequence of bits output from the interleaver **302** to constellation points. If the encoder **300** performed LDPC encoding, the mapper **304** may also perform LDPC tone mapping in addition to the constellation mapping.

(62) When the TxSP **324** performs a MIMO or MU-MIMO transmission, the TxSP **324** may include a plurality of interleavers **302** and a plurality of mappers **304** according to a number of spatial streams (NSS) of the transmission. The TxSP **324** may further include a stream parser for dividing the output of the encoder **300** into blocks and may respectively send the blocks to different interleavers **302** or mappers **304**. The TxSP **324** may further include a space-time block code (STBC) encoder for spreading the constellation points from the spatial streams into a number of space-time streams (NSTS) and a spatial mapper for mapping the space-time streams to transmit chains. The spatial mapper may use direct mapping, spatial expansion, or beamforming.

(63) The IFT **306** converts a block of the constellation points output from the mapper **304** (or, when MIMO or MU-MIMO is performed, the spatial mapper) to a time domain block (i.e., a symbol) by using an inverse discrete Fourier transform (IDFT) or an inverse fast Fourier transform (IFFT). If the STBC encoder and the spatial mapper are used, the IFT **306** may be provided for each transmit chain.

(64) When the TxSP **324** performs a MIMO or MU-MIMO transmission, the TxSP **324** may insert cyclic shift diversities (CSDs) to prevent unintentional beamforming. The TxSP **324** may perform the insertion of the CSD before or after the IFT **306**. The CSD may be specified per transmit chain or may be specified per space-time stream. Alternatively, the CSD may be applied as a part of the spatial mapper.

(65) When the TxSP **324** performs a MIMO or MU-MIMO transmission, some blocks before the spatial mapper may be provided for each user.

(66) The GI inserter **308** prepends a GI to each symbol produced by the IFT **306**. Each GI may include a Cyclic Prefix (CP) corresponding to a repeated portion of the end of the symbol that the GI precedes. The TxSP **324** may optionally perform windowing to smooth edges of each symbol after inserting the GI.

(67) The RF transmitter **342** converts the symbols into an RF signal and transmits the RF signal via the antenna **352**. When the TxSP **324** performs a MIMO or MU-MIMO transmission, the GI inserter **308** and the RF transmitter **342** may be provided for each transmit chain.

(68) FIG. **3B** illustrates components of a wireless device configured to receive data according to an embodiment, including a Receiver (Rx) SPU (RxSP) **326**, an RF receiver **344**, and an antenna **354**. In an embodiment, the RxSP **326**, RF receiver **344**, and antenna **354** may correspond to the receiving SPU **226**, the RF receiver **244**, and an antenna of the antenna unit **250** of FIG. **2**, respectively.

(69) The RxSP **326** includes a GI remover **318**, a Fourier transformer (FT) **316**, a demapper **314**, a deinterleaver **312**, and a decoder **310**.

(70) The RF receiver **344** receives an RF signal via the antenna **354** and converts the RF signal into symbols. The GI remover **318** removes the GI from each of the symbols. When the received transmission is a MIMO or MU-MIMO transmission, the RF receiver **344** and the GI remover **318** may be provided for each receive chain.

(71) The FT **316** converts each symbol (that is, each time domain block) into a frequency domain block of constellation points by using a discrete Fourier transform (DFT) or a fast Fourier transform (FFT). The FT **316** may be provided for each receive chain.

(72) When the received transmission is the MIMO or MU-MIMO transmission, the RxSP **326** may include a spatial demapper for converting the respective outputs of the FTs **316** of the receiver chains to constellation points of a plurality of space-time streams, and an STBC decoder for despreading the constellation points from the space-time streams into one or more spatial streams.

(73) The demapper **314** demaps the constellation points output from the FT **316** or the STBC decoder to bit streams. If the received transmission was encoded using the LDPC encoding, the demapper **314** may further perform LDPC tone demapping before performing the constellation demapping.

(74) The deinterleaver **312** deinterleaves the bits of each stream output from the demapper **314**. The deinterleaver **312** may perform the deinterleaving only when the received transmission was encoded using the BCC encoding, and otherwise may output the stream output by the demapper **314** without performing deinterleaving.

(75) When the received transmission is the MIMO or MU-MIMO transmission, the RxSP **326** may use a plurality of demappers **314** and a plurality of deinterleavers **312** corresponding to the number of spatial streams of the transmission. In this case, the RxSP **326** may further include a stream deparser for combining the streams output from the deinterleavers **312**.

(76) The decoder **310** decodes the streams output from the deinterleaver **312** or the stream deparser. In an embodiment, the decoder **312** includes an FEC decoder. The FEC decoder may include a BCC decoder or an LDPC decoder.

(77) The RxSP **326** may further include a descrambler for descrambling the decoded data. When the decoder **310** performs the BCC decoding, the RxSP **326** may further include an encoder deparser for multiplexing the data decoded by a plurality of BCC decoders. When the decoder **310** performs the LDPC decoding, the RxSP **326** may not use the encoder deparser.

(78) Before making a transmission, wireless devices such as wireless device **200** will assess the availability of the wireless medium using Clear Channel Assessment (CCA). If the medium is occupied, CCA may determine that it is busy, while if the medium is available, CCA determines that it is idle.

(79) The PHY entity for IEEE Std 802.11 is based on Orthogonal Frequency Division Multiplexing (OFDM) or Orthogonal Frequency Division Multiple Access (OFDMA). In either OFDM or OFDMA Physical (PHY) layers, a STA is capable of transmitting and receiving Physical Layer Protocol Data Units (PPDUs) that are compliant with the mandatory PHY specifications. A PHY specification defines a set of Modulation and Coding Schemes (MCS) and a maximum number of spatial streams. Some PHY entities define downlink (DL) and uplink (UL) Multi-User (MU) transmissions having a maximum number of space-time streams (STS) per user and employing up to a predetermined total number of STSs.

(80) FIG. **4** illustrates Inter-Frame Space (IFS) relationships. FIG. **4** illustrates a Short IFS (SIFS), a Point Coordination Function (PCF) IFS (PIFS), a Distributed Coordination Function (DCF) IFS (DIFS), and an Arbitration IFSs corresponding to an Access Category (AC) 'i' (AIFS[i]). FIG. **4** also illustrates a slot time.

(81) A data frame is used for transmission of data forwarded to a higher layer. The WLAN device transmits the data frame after performing backoff if a DIFS has elapsed during which DIFS the medium has been idle.

(82) A management frame is used for exchanging management information, which is not forwarded to the higher layer. Subtype frames of the management frame include a beacon frame, an association request/response frame, a probe request/response frame, and an authentication request/response frame.

(83) A control frame is used for controlling access to the medium. Subtype frames of the control frame include a request to send (RTS) frame, a clear to send (CTS) frame, and an acknowledgement (ACK) frame.

(84) When the control frame is not a response frame of another frame, the WLAN device transmits the control frame after performing backoff if a DIFS has elapsed during which DIFS the medium has been idle. When the control frame is the response frame of another frame, the WLAN device transmits the control frame after a SIFS has elapsed without performing backoff or checking whether the medium is idle.

(85) A WLAN device that supports a Quality of Service (QoS) functionality (that is, a QoS station) may transmit the frame after performing backoff if an AIFS for an associated access category (AC), (AIFS[AC]), has elapsed. When transmitted by the QoS station, any of the data frame, the management frame, and the control frame which is not the response frame may use the AIFS[AC] of the AC of the transmitted frame.

(86) A WLAN device may perform a backoff procedure when the WLAN device that is ready to transfer a frame finds the medium busy. In addition,

a WLAN device operating according to the IEEE 802.11n and 802.11ac standards may perform the backoff procedure when the WLAN device infers that a transmission of a frame by the WLAN device has failed.

(87) The backoff procedure includes determining a random backoff time composed of N backoff slots, each backoff slot having a duration equal to a slot time and N being an integer number greater than or equal to zero. The backoff time may be determined according to a length of a Contention Window (CW). In an embodiment, the backoff time may be determined according to an AC of the frame. All backoff slots occur following a DIFS or Extended IFS (EIFS) period during which the medium is determined to be idle for the duration of the period.

(88) When the WLAN device detects no medium activity for the duration of a particular backoff slot, the backoff procedure shall decrement the backoff time by the slot time. When the WLAN determines that the medium is busy during a backoff slot, the backoff procedure is suspended until the medium is again determined to be idle for the duration of a DIFS or EIFS period. The WLAN device may perform transmission or retransmission of the frame when the backoff timer reaches zero.

(89) The backoff procedure operates so that when multiple WLAN devices are deferring and execute the backoff procedure, each WLAN device may select a backoff time using a random function, and the WLAN device selecting the smallest backoff time may win the contention, reducing the probability of a collision.

(90) FIG. **5** illustrates a Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) based frame transmission procedure for avoiding collision between frames in a channel according to an embodiment. FIG. **5** shows a first station STA1 transmitting data, a second station STA2 receiving the data, and a third station STA3 that may be located in an area where a frame transmitted from the STA1, a frame transmitted from the second station STA2, or both can be received. The stations STA1, STA2, and STA3 may be WLAN devices.

(91) The STA1 may determine whether the channel is busy by carrier sensing. The STA1 may determine the channel occupation based on an energy level in the channel or an autocorrelation of signals in the channel, or may determine the channel occupation by using a network allocation vector (NAV) timer.

(92) After determining that the channel is not used by other devices (that is, that the channel is IDLE) during a DIFS (and performing backoff if required), the STA1 may transmit a Ready-To-Send (RTS) frame to the second station STA2. Upon receiving the RTS frame, after a SIFS the second station STA2 may transmit a Clear-To-Send (CTS) frame as a response of the RTS frame. If Dual-CTS is enabled and the second station STA2 is an AP, the AP may send two CTS frames in response to the RTS frame: a first CTS frame in the legacy non-HT format, and a second CTS frame in the HT format.

(93) When the third station STA3 receives the RTS frame, it may set a NAV timer of the third station STA3 for a transmission duration of subsequently transmitted frames (for example, a duration of SIFS+CTS frame duration+SIFS+data frame duration+SIFS+ACK frame duration) using duration information included in the RTS frame. When the third station STA3 receives the CTS frame, it may set the NAV timer of the third station STA3 for a transmission duration of subsequently transmitted frames using duration information included in the CTS frame. Upon receiving a new frame before the NAV timer expires, the third station STA3 may update the NAV timer of the third station STA3 by using duration information included in the new frame. The third station STA3 does not attempt to access the channel until the NAV timer expires.

(94) When the STA1 receives the CTS frame from the second station STA2, it may transmit a data frame to the second station STA2 after SIFS elapses from a time when the CTS frame has been completely received. Upon successfully receiving the data frame, the second station STA2 may transmit an ACK frame as a response of the data frame after SIFS elapses.

(95) When the NAV timer expires, the third station STA3 may determine whether the channel is busy using the carrier sensing. Upon determining that the channel is not used by other devices during a DIFS after the NAV timer has expired, the third station STA3 may attempt to access the channel after a contention window according to a backoff process elapses.

(96) When Dual-CTS is enabled, a station that has obtained a transmission opportunity (TXOP) and that has no data to transmit may transmit a CF-End frame to cut short the TXOP. An AP receiving a CF-End frame having a Basic Service Set Identifier (BSSID) of the AP as a destination address may respond by transmitting two more CF-End frames: a first CF-End frame using Space Time Block Coding (STBC) and a second CF-End frame using non-STBC. A station receiving a CF-End frame resets its NAV timer to 0 at the end of the PPDU containing the CF-End frame.

(97) FIG. **5** shows the second station STA2 transmitting an ACK frame to acknowledge the successful reception of a frame by the recipient.

(98) The PHY entity for IEEE Std 802.11 is based on Orthogonal Frequency Division Multiplexing (OFDM) or Orthogonal Frequency Division Multiple Access (OFDMA). In either OFDM or OFDMA Physical (PHY) layers, a STA is capable of transmitting and receiving PHY Protocol Data Units (PPDUs) that are compliant with the mandatory PHY specifications.

(99) A PHY entity may provide support for 20 MHz, 40 MHz, 80 MHz, and 160 MHz contiguous channel widths and support for an 80+80 MHz non-contiguous channel width. Each channel includes a plurality of subcarriers, which may also be referred to as tones.

(100) A PHY entity may define fields denoted as Legacy Signal (L-SIG), Signal A (SIG-A), and Signal B (SIG-B) within which some necessary information about PHY Service Data Unit (PSDU) attributes are communicated. For example, a High Efficiency (HE) PHY entity may define an L-SIG field, an HE Signal A (HE-SIG-A) field, and an HE Signal B (HE-SIG-B) field.

(101) The descriptions below, for sake of completeness and brevity, refer to OFDM-based 802.11 technology. Unless otherwise indicated, a station refers to a non-AP HE STA, and an AP refers to an HE AP.

(102) In the IEEE Std 802.11ac, SIG-A and SIG-B fields are called VHT SIG-A and VHT SIG-B fields. Hereinafter, IEEE Std 802.11ax SIG-A and SIG-B fields are respectively referred to as HE-SIG-A and HE-SIG-B fields.

(103) FIG. **6**A illustrates an HE PPDU **600** according to an embodiment. A transmitting station generates the HE PPDU frame **600** and transmits it to one or more receiving stations. The receiving stations receive, detect, and process the HE PPDU frame **600**.

(104) The HE PPDU frame **600** includes a Legacy Short Training Field (L-STF) **602**, a Legacy (i.e., a Non-High Throughput (Non-HT)) Long Training Field (L-LTF) **604**, a Legacy Signal (L-SIG) field **606**, which together comprise a legacy preamble **601** and a Repeated L-SIG field (RL-SIG) **608**. The L-STF **604** of the HE PPDU has a periodicity of 0.8 μs with 10 periods.

(105) The HE PPDU frame **600** also includes an HE Signal A (HE-SIG-A) field **610**, an HE Signal B (HE-SIG-B) field **612**, an HE-STF **614**, an HE-LTF **616**, and an HE-Data field **618**. In an embodiment, the HE PPDU frame **600** includes a plurality of HE-SIG-B fields **612** corresponding to different channels, and respective pluralities of HE-STFs **614**, HE-LTFs **616**, and HE-Data fields **618** corresponding to different channels or resource units.

(106) The legacy preamble **601**, the RL-SIG field **608**, the HE-SIG-A field **610**, and the HE-SIG-B field **612** when present, comprise a first part of the HE PPDU frame **600**. In an embodiment, the first part of the HE PPDU frame **600** is decoded using a 64-element Discrete Fourier Transform (DFT), having a basic subcarrier spacing of 312.5 KHz.

(107) The HE-SIG-A field **610** is duplicated on each 20 MHz segment after the legacy preamble to indicate common control information. The HE-SIG-A field **610** includes a plurality of OFDM HE-SIG-A symbols **620** each having a duration (including a Guard Interval (GI)) of 4 μs. A number of the HE-SIG-A symbols **620** in the HE-SIG-A field **610** is determined as either 2 or 4 depending on a type of the HE PPDU **600**. In an embodiment, an HE-SIG-A field **610** of an HE Extended Range Single User (SU) PPDU include 4 HE-SIG-A symbols **620**, and HE-SIG-A fields **610** of other types of HE PPDU include 2 HE-SIG-A symbols **620**.

(108) The HE-SIG-B field **612** is included in HE Multi-User (MU) PPDU(s). The HE-SIG-B field **612** includes a plurality of OFDM HE-SIG-B symbols **622** each having a duration including a GI of 4 μs. In embodiments, one or more of HE SU PPDUs, HE Tigger-based PPDUs, and HE Extended Range SU PPDUs do not include the HE-SIG-B field **612**. A number of the HE-SIG-B symbols **622** in the HE-SIG-B field **612** is indicated by N.sub.HE-SIGB in the HE-SIG-A field **610** and is variable.

(109) When the HE PPDU **600** has a bandwidth of 40 MHz or more, the HE-SIG-B field **612** may be transmitted in first and second HE-SIG-B channels 1 and 2. The HE-SIG-B field in the HE-SIG-B channel 1 is referred to as the HE-SIG-B1 field, and the HE-SIG-B field in the HE-SIG-B channel 2 is referred to as the HE-SIG-B2 field. The HE-SIG-B1 field and the HE-SIG-B2 field are communicated using different 20 MHz bandwidths of the HE PPDU **600**, and may contain different information. Within this document, the term "HE-SIG-B field" may refer to an HE-SIG-B field of a 20 MHz PPDU, or to either or both of an HE-SIG-B1 field or HE-SIG-B2 field of a 40 MHz or more PPDU.

(110) An HE-STF **614** of a non-trigger-based PPDU has a periodicity of 0.8 µs with 5 periods. A non-trigger-based PPDU is a PPDU that is not sent in response to a trigger frame. An HE-STF **614** of a trigger-based PPDU has a periodicity of 1.6 µs with 5 periods. Trigger-based PPDUs include UL PPDUs sent in response to respective trigger frames.

(111) The HE-LTF **616** includes one or more OFDM HE-LTF symbols **626** each having a duration of 12.8 µs plus a Guard Interval (GI). The HE PPDU frame **600** may support a 2×LTF mode and a 4×LTF mode. In the 2×LTF mode, an HE-LTF symbol **626** excluding a Guard Interval (GI) is equivalent to modulating every other tone in an OFDM symbol of 12.8 µs excluding the GI, and then removing the second half of the OFDM symbol in a time domain. A number of the HE-LTF symbols **626** in the HE-LTF field **616** is indicated by N.sub.HE-LTF, and is equal to 1, 2, 4, 6, or 8.

(112) The HE-Data field **618** includes one or more OFDM HE-Data symbols **628** each having a duration of 12.8 µs plus a Guard Interval (GI). A number of the HE-Data symbols **628** in the HE-Data field **618** is indicated by N.sub.DATA and is variable.

(113) FIG. **6**B shows a Table 1 indicating additional properties of the fields of the HE PPDU frame **600** of FIG. **6**A, according to an embodiment.

(114) The descriptions below, for sake of completeness and brevity, refer to OFDMA-based 802.11 technology. Unless otherwise indicated, a station refers to a non-AP HE STA, and an AP refers to an HE AP.

(115) In this disclosure, multi-user (MU) transmission refers to cases that multiple frames are transmitted to or from multiple STAs simultaneously using different resources, wherein examples of different resources are different frequency resources in OFDMA transmission and different spatial streams in MU-MIMO transmission. Therefore, DL-OFDMA, DL-MU-MIMO, UL-OFDMA, and UL-MU-MIMO are examples of MU transmission.

(116) For several reasons, the IEEE Std 802.11ax may require more protection mechanisms for MU transmission than the DL MU-MIMO defined in the IEEE Std 802.11ac. The first reason is that the IEEE Std 802.11ax operation scenario is different, in that it encompasses denser wireless environments and outdoor support. Also, the coverage of an IEEE Std 802.11ax BSS may be physically larger compared to an IEEE Std 802.11ac BSS. Both of these factors create a need for more robust protection mechanisms.

(117) The second reason is that IEEE Std 802.11ax supports not only DL MU transmission but also UL MU transmission. In the case of UL MU transmission, as the number of frames that might be transmitted from each STA are larger, it requires more protection from other nearby transmitting STAs. Another reason is that in an IEEE Std 802.11ax environment, an AP may want to have more control of the medium by use of scheduled access mechanisms, which may involve more frequent use of OFDMA/MU-MIMO transmissions.

(118) UL MU PPDUs (MU-MIMO or OFDMA) are sent as a response to a Trigger frame sent by the AP. The Trigger frame may have enough STA specific information and respective assigned resource units to identify the STAs which are supposed to transmit UL MU PPDUs.

(119) Four HE PPDU formats, illustrated in FIGS. **7**A through **7**D, are defined by the IEEE Std 802.11ax: HE SU PPDU, HE MU PPDU, HE extended range SU PPDU and HE trigger-based (TB) PPDU. Elements in FIGS. **7**A through **7**D having reference characters of the form 7xx are substantially similar to elements of FIG. **6**A having reference characters of the form 6xx, and descriptions thereof are therefore omitted for brevity. The frames shown in FIGS. **7**A through **7**D also include a Packet Extension (PE) **730**.

(120) FIG. **7**A illustrates a format of a High Efficiency (HE) Single User (SU) PPDU **700**A according to an embodiment. The HE SU PPDU **700**A is used for SU transmission and in this format the HE-SIG-A field **710** is not repeated. The HE SU PPDU **700**A does not have an HE-SIG-B field.

(121) FIG. **7**B illustrates a format of an HE Multi-User (MU) PPDU frame **700**B according to an embodiment. This format is used for MU transmissions that are not a response of a Trigger frame. An HE-SIG-B field **712** is present in this format. A number of symbols in the HE-SIG-B field **712** may be determined according to information in the HE-SIG-A field **710** (for example, an HE-SIG-B compression indication), a bandwidth of the PPDU frame **700**B, and a number of User fields indicated in a Common field of the HE-SIG-B field **712** when the Common field is present in the HE-SIG-B field **712**.

(122) FIG. **7**C illustrates a format of an HE Extended Range (ER) SU PPDU **700**C according to an embodiment. This format is used for SU transmission and in this format the HE-SIG-A field **710** is repeated (as first and second HE-SIG-A field **710-1** and **710-2**).

(123) FIG. **7**D illustrates a format of an HE Trigger-Based (TB) PPDU **700**D according to an embodiment.

(124) FIG. **8** illustrates a Trigger frame **800** according to an embodiment. The Trigger frame **800** is used to allocate resources for a UL MU transmission and to solicit the UL MU transmission to be performed after (as a response to) the PPDU that carries the Trigger frame. The Trigger frame also carries other information required by the responding STAs to send the UL MU transmission.

(125) The Trigger frame **800** includes a Frame Control field **802**, a Duration field **804**, a Receiver Address (RA) field **806**, a Transmitter Address (TA) field **808**, a Common Info field **810**, on or more User Info fields **812-**x, optional Padding **814**, and a Frame Check Sequence (FCS) field **816**.

(126) A value of the Frame Control field **802** indicates that the Trigger frame **800** is a trigger frame. A value of the Duration field **804** indicates a length of the Trigger frame **800**. A value of the RA field **806** of the Trigger frame is the address of a recipient station or a broadcast address corresponding to one or more recipient stations. A value of a TA field **804** of the Trigger frame is an address of the station transmitting the Trigger frame.

(127) FIG. **9** illustrates a Common Info field **910** according to an embodiment. The Common info field **910** is suitable for use as the Common info field **810** of the Trigger frame **800** of FIG. **8**. The Common Info field **910** includes a Trigger Type subfield **922**, a Length subfield **924**, a Cascade Information subfield **926**, a Carrier Sense (CS) Required subfield **928**, a Bandwidth (BW) subfield **930**, a Guard Interval (GI) and Long Training Field (LTF) Type subfield **932**, a Number of HE-LTF Symbols subfield **936**, a Space-Time Bloc Coding subfield **938**, a Spatial Reuse subfield **946**, a Doppler subfield **948**, and a HE-SIG-A Reserved subfield **950**. In some Trigger frames, the Common Info field **910** also includes a Trigger-Dependent Common Info subfield **954**.

(128) The Trigger Type subfield **922** that indicates a type of the Trigger frame. Depending on the type of the Trigger frame, the Trigger frame can include the optional type-specific Trigger Dependent Common Info field **954** and (in each of the Per User Info field(s) of the Trigger frame) optional Type-specific Per User Info fields.

(129) The Length subfield **924** that indicates the value of an L-SIG Length field of an HE TB PPDU transmitted in response to the Trigger frame. The Cascade Indication subfield **926** when set to 1 indicates that a subsequent Trigger frame follows the current Trigger frame, and that otherwise has a value of 0.

(130) The CS Required subfield **928** being set to 1 indicates that station(s) identified in the Per User Info field(s) of the Trigger frame are required to use Energy Detect (ED) to sense the medium and to consider the medium state and a NAV in determining whether to respond to the Trigger frame. The CS Required subfield **928** being set to 0 indicates that the station(s) identified in the Per User Info field(s) are not required to consider the medium state or the NAV in determining whether to respond to the Trigger frame.

(131) The BW subfield **930** indicates a bandwidth in an HE-SIG-A field of an HE TB PPDU transmitted in response to the Trigger Frame. The CP and LTF Type subfield **932** indicates a CP and an HE-LTF type of the HE TB PPDU transmitted in response to the Trigger frame.

(132) The HE-SIG-A Reserved subfield **950** indicates contents of an HE-SIG-A field of the HE TB PPDU transmitted in response to the Trigger frame. In an embodiment, all values in the HE-SIG-A Reserved subfield are set to 1.

(133) A Spatial Reuse (SR) subfield **946** provides spatial reuse information. For a communication using a 20 MHz BW the SR subfield **946** provides

one SR field corresponding to entire 20 MHz, and the other 3 fields indicate identical values. For a communication using a 40 MHz BW the SR subfield **946** provides two SR field respectively corresponding to each 20 MHz, and the other 2 fields indicate identical values. For a communication using an 80 MHz BW the SR subfield **946** provides four SR field respectively corresponding to each 20 MHz. For a communication using a 160 MHz BW the SR subfield **946** provides four SR field respectively corresponding to each 40 MHz.

(134) The Doppler subfield **948** supports proper performance even in outdoor mobility use cases. When the Doppler subfield **948** indicates a first value (e.g., is set to 1), a PPDU transmitted in response to the Trigger frame including the Common Info field **90** includes Mid-amble fields made up of multiple HE-LTFs that are inserted every mid-amble periodicity (M) data symbols, as described below.

(135) In some embodiments of the present disclosure, the Common Info field **910** may include a Mid-amble Interval (M) field **952**, described below, indicating a number of data symbols between mid-ambles when the Doppler subfield **948** has a value of 1.

(136) FIG. **10** illustrates a User Info field **1012** according to an embodiment. The User Info field **1012** is suitable for use as any or all of the User Info fields **812**-*x* of the Trigger frame **800** of FIG. **8**. The User Info field **1012** includes an 12-bit User Identifier indicating an Association ID (AID12) subfield **1020**, a Resource Unit (RU) Allocation subfield **1022**, a Coding Type subfield **1024**, an MCS subfield **1026**, a Dual Carrier Modulation (DCM) subfield **1028**, and a Spatial Stream (SS) Allocation subfield **1030**. In some Trigger frames, the User Info field **1012** may include a Trigger-Dependent User Info subfield **1036**.

(137) A User Identifier (AID12) subfield **1020** indicates an Association Identifier (AID) of a station allocated a Resource Unit (RU) in which to transmit one or more MPDU(s) in the HE TB PPDU transmitted in response to the Trigger frame. The RU Allocation subfield **1022** indicating the RU to be used to transmit the HE TB PPDU of the station identified by User Identifier subfield. A first bit of the RU Allocation subfield **1022** may indicate whether the allocated RU is located in a primary or a non-primary 80 MHz. The mapping of the subsequent seven bits indices of the RU Allocation subfield **1022** to the RU allocation as one of RU according to the IEEE Std 802.11ax OFDMA numerology.

(138) The Coding Type subfield **1024** indicates a coding type of the HE TB PPDU transmitted in response to the Trigger frame of the station identified by the User Identifier subfield **1020**, and set to 0 for BCC and to 1 for LDPC. The MCS subfield **1026** indicates an MCS of the HE TB PPDU transmitted in response to the Trigger frame by the station identified by User Identifier field.

(139) The Dual Carrier Modulation (DCM) subfield **1028** indicates dual carrier modulation of the HE TB PPDU transmitted in response to the Trigger frame by the station identified by User Identifier field **1020**. A value of 1 indicates that the HE TB PPDU shall use DCM, and a value of 0 indicates that it shall not.

(140) The Spatial Stream (SS) Allocation subfield **1030** indicates spatial streams of the HE TB PPDU transmitted in response to the Trigger frame by the station identified by User Identifier field **1020**.

(141) FIG. **11** illustrates a PPDU **1100** used when the Doppler subfield **948** is set to 1, according to an embodiment. In the PPDU format **1100**, mid-amble fields made up of one or more HE-LTFs **1106**.sub.M inserted every mid-amble periodicity (M) data symbols of the transmission, as described below. The number of HE-LTFs **1106**.sub.M in each mid-amble field is equal to the number of HE-LTFs **1106**.sub.P in the preamble of the PPDU wherein HE-LTFs **1106**.sub.M and HE-LTFs **1106**.sub.P are defined as mid-amble HE-LTFs and preamble HE-LTFs, respectively.

(142) The PPDU **1100** includes a first part **1102** corresponding to the first part of the PPDU **600** of FIG. **6**. The first part **1102** is followed by an HE-STF **1104** and one or more preamble HE-LTFs **1106**.sub.P. The first part **1102**, HE-STF **1104**, and one or more preamble HE-LTFs **1106**.sub.P correspond to a preamble of the PPDU **1100**.

(143) After the preamble, the PPDU **1100** includes a first data portion **1108-1** including M data symbols. After the first data portion **1108-1**, the PPDU **1100** includes a first mid-amble including one or more mid-amble HE-LTFs **1106**.sub.M. The duration of the first mid-amble is a mid-amble duration T.sub.MA.

(144) After the first mid-amble, the PPDU **1100** includes a second data portion **1108-2** including M data symbols. After the second data portion **1108-2**, the PPDU **1100** includes a second mid-amble including one or more mid-amble HE-LTFs **1106**.sub.M. The duration of the second mid-amble is the mid-amble duration T.sub.MA.

(145) After the second mid-amble, the PPDU **1100** includes a third data portion **1108-3** including the remaining data symbols of the PPDU **1100**. After the third data portion **1108-3**, the PPDU **1100** includes a Packet Extension **1110**.

(146) In some embodiments of the present disclosure, the value of M is determined using information in a Common Info field of a Trigger frame soliciting the PPDU.

(147) FIG. **12** illustrates signaling of a PPDU format according to an embodiment. FIG. **12** illustrates first, second, and third PPDUs **1200***a*, **1200***b*, and **1200***c* each having a different format. Each PPDU includes at least an L-SIG field **1202**, a repeated L-SIG (RL-SIG) field **1204**, at least first and second HE-SIG-A symbols **1206-1** and **1206-2**, and an HE-STF **1210**. In a device operating according to IEEE Std 802.11ax, the device may detect the format of a PPDU based on a value of a Length field included in the L-SIG field **1202** and the rotated constellation of initial symbols of the HE-SIG-A field.

(148) In FIG. **12**, symbols having a horizontal bar beneath them are modulated using Binary Phase Shift Keying (BPSK). Symbols having a vertical bar beneath them are modulated using Quadrature Binary Phase Shift Keying (QBPSK), that is, rotated BPSK.

(149) If a value of the length field in the L-SIG field **1202** modulo 3 is equal to 1, the detected PPDU is either an HE SU PPDU (bit B**0** of the HE-SIG-A field=1) or an HE Trigger based PPDU (bit B**0** of the HE-SIG-A field=0). Accordingly, in FIG. **12**, PPDU **1200***a* is either an HE SU PPDU or an HE TB PPDU.

(150) If a value of the length field in the L-SIG field **1202** modulo 3 is equal to 2, the PPDU format is either an HE extended range SU PPDU (indicated by second HE-SIG-A symbols **1206-2** being modulated using QBPSK) or an HE MU PPDU (indicated by second HE-SIG-A symbols **1206-2** being modulated using BPSK). Accordingly, in FIG. **12**, PPDU **1200***b* is an HE extended range SU PPDU and includes third and fourth HE-SIG-A symbols **1206-3** and **1206-4** modulated using BPSK, and PPDU **1200***a* is a HE MU PPDU and includes an HE-SIG-B field **1208**, the HE-SIG-B field **1208** including a plurality of symbols.

(151) Embodiments include processes for inserting mid-ambles into a PPDU according to the PPDU format, and processes for determining where the mid-ambles are inserted in a PPDU once the PPDU format is detected. How the mid-ambles are inserted in an HE PPDU could be different depending on the format of the PPDU.

(152) Generally, information transmitted using higher data rates (e.g. higher MCS) is more vulnerable to detrimental effect associated with mobility environments. Therefore, introducing mid-amble field according to a small mid-amble periodicity M when higher MCS rates are used can enable compensation for phase drift and thereby improving performance.

(153) FIG. **13** illustrates a process **1300**, according to an embodiment, for determining a mid-amble periodicity M according to format of a PPDU. The process **1300** may be used, for example, when Doppler subfield of a Common info field of a Trigger frame is set to 1. In such a case, the process **1300** may be used to determine the mid-amble periodicity M of a PPDU transmitted in response to the Trigger frame.

(154) At S**1302**, the process **1300** determines whether the PPDU format is any one of an HE SU, HE SU ER, or HE UL MU format. For a received PPDU, the PPDU format may be determined according to one or more of a length in an L-SIG field, a modulation of a second symbol of an HE-SIG-A field, and a B**0** bit of the HE-SIG-A field. In response to the PPDU format being an HE SU, HE SU ER, or HE UL MU format, at S**1302** the process **1300** proceeds to S**1312**; otherwise, at S**1302** the process **1300** proceeds to S**1304**.

(155) At S**1304**, the process **1300** determines whether the PPDU format is a multi-user HE DL MU format. For a received PPDU, the PPDU format may be determined according to a length in an L-SIG field and a modulation of a second symbol of an HE-SIG-A field. In response to the PPDU format being a multi-user HE DL MU format, at S**1304** the process **1300** proceeds to S**1314**; otherwise, at S**1304** the process **1300** proceeds to

S**1306**.

(156) At S**1306**, the process **1300** determines whether the PPDU format is an HE Trigger-Based (TB) format for a PPDU. In response to the PPDU format being an HE TB format, at S**1306** the process **1300** proceeds to S**1316**; otherwise, at S**1306** the process **1300** exits.

(157) At S**1312**, the process **1300** determines the mid-amble periodicity M according to an MCS of the PPDU, and then exits.

(158) At S**1314**, the process **1300** determines the mid-amble periodicity M according to a highest MCS of the respective MCS values of the STA assigned to participate in the MU PPDU, and then exits.

(159) At S**1316**, the process **1300** determines the mid-amble periodicity M according to an a predetermined value, without regard to the values of assigned MCS in the Trigger frame that solicits the STAs to perform an UL MU transmission, and then exits.

(160) In an embodiment, the mid-amble periodicity M for Trigger-Based PPDUs could be signaled for all STAs participating in the TB PPDU in a field of the Trigger frame soliciting the TB PPDU, as previously described with respect to FIG. **9**.

(161) Referring to FIG. **9**, when the Doppler subfield **948** is set to a first state (e.g., 1), the mid-amble periodicity (M) subfield **952** has a value corresponding to a number of data symbols between mid-ambles. When the Doppler subfield **948** is set to a second state (e.g., 0), the mid-amble periodicity (M) subfield **952** is reserved.

(162) FIG. **14** illustrates a process **1400**, according to another embodiment, for determining a mid-amble periodicity M according to format of a PPDU. The process **1400** may be used, for example, when Doppler subfield of a Common info field of a Trigger frame is set to 1. In such a case, the process **1500** may be used to determine the mid-amble periodicity M of a PPDU transmitted in response to the Trigger frame.

(163) At S**1402**, the process **1400** determines whether the PPDU format is either the HE SU or HE SU ER format. In response to the PPDU format being either the HE SU or HE SU ER format, at S**1402** the process **1400** proceeds to S**1412**; otherwise, at S**1402** the process **1400** proceeds to S**1404**.

(164) At S**1404**, the process **1400** determines whether the PPDU format is a multi-user HE MU format (either UL or DL). In response to the PPDU format being a multi-user HE MU format, at S**1404** the process **1400** proceeds to S**1414**; otherwise, at S**1404** the process **1400** proceeds to S**1406**.

(165) At S**1406**, the process **1400** determines whether the PPDU format is an HE TB format for a PPDU. In response to the PPDU format being an HE TB format, at S**1406** the process **1400** proceeds to S**1416**; otherwise, at S**1406** the process **1400** exits.

(166) At S**1412**, the process **1400** determines the mid-amble periodicity M according to an MCS of the PPDU, and then exits.

(167) At S**1414**, the process **1400** determines the mid-amble periodicity M according to a highest MCS of the respective MCS values of the STA assigned to participate in the MU PPDU, and then exits. At S**1414**, when only one STA is assigned to participate in an MU PPDU (for example, an UL MU PPDU), the process **1400** determines the mid-amble periodicity M according to an MCS of the only one STA, and then exits.

(168) At S**1416**, the process **1400** determines the mid-amble periodicity M according to a predetermined value, without regard to the values of assigned MCS in the Trigger frame that solicits the STAs to perform an UL MU transmission, and then exits.

(169) FIG. **15** illustrates a process **1500**, according to another embodiment, for determining a mid-amble periodicity M according to format of a PPDU.

(170) At S**1502**, the process **1500** determines whether the PPDU format is either the HE SU or HE SU ER format. In response to the PPDU format being either the HE SU or HE SU ER format, at S**1502** the process **1500** proceeds to S**1512**; otherwise, at S**1502** the process **1500** proceeds to S**1504**.

(171) At S**1504**, the process **1500** determines whether the PPDU format is a multi-user HE MU format (either UL or DL). In response to the PPDU format being a multi-user HE MU format, at S**1504** the process **1500** proceeds to S**1516**; otherwise, at S**1504** the process **1500** proceeds to S**1506**.

(172) At S**1506**, the process **1500** determines whether the PPDU format is an HE Trigger-Based (TB) format for a PPDU. In response to the PPDU format being an HE TB format, at S**1506** the process **1500** proceeds to S**1516**; otherwise, at S**1506** the process **1500** exits.

(173) At S**1512**, the process **1500** determines the mid-amble periodicity M according to an MCS of the PPDU, and then exits.

(174) At S**1516**, the process **1500** determines the mid-amble periodicity M according to a predetermined value, regardless of any MCS values, and then exits.

(175) FIG. **16** illustrates a process **1600**, according to another embodiment, for determining a mid-amble periodicity M according to a format of a PPDU. The process **1600** may be used when a Doppler subfield indicates the presence of mid-ambles in the PPDU.

(176) At S**1602**, the process **1600** determines whether the PPDU format is a first format. In an embodiment, the first format includes the HE SU format. In an embodiment, the first format includes the HE ER SU format. In an embodiment, the first format includes the single-user HE UL MU format. In response to the PPDU format being the first format, at S**1602** the process **1600** proceeds to S**1612**; otherwise, at S**1602** the process **1600** proceeds to S**1604**.

(177) At S**1604**, the process **1600** determines whether the PPDU format is a second format. In an embodiment, the second format includes the HE MU format. In an embodiment, the second format includes the HE DL MU format for more than one user. In response to the PPDU format being the second format, at S**1604** the process **1600** proceeds to S**1614**; otherwise, at S**1604** the process **1600** proceeds to S**1606**.

(178) At S**1606**, the process **1600** determines whether the PPDU format is a third format. In an embodiment, the third format includes the HE TB format. In an embodiment, the third format includes the HE MU format. In response to the PPDU format being the third format, at S**1606** the process **1600** proceeds to S**1616**; otherwise, at S**1606** the process **1600** proceeds to S**1608**.

(179) At S**1608**, the process **1600** determines whether the PPDU format is a fourth format. In an embodiment, the fourth format includes the HE TB format. In response to the PPDU format being the fourth format, at S**1608** the process **1600** proceeds to S**1618**; otherwise, at S**1608** the process **1600** exits.

(180) At S**1612**, the process **1600** determines the mid-amble periodicity M according to an MCS of the PPDU, and then exits.

(181) At S**1614**, the process **1600** determines the mid-amble periodicity M according to a highest values of MCS values of all assigned STAs in the PPDU. In an embodiment, only one STA could be assigned. The process **1600** then exits.

(182) At S**1616**, the process **1600** determines the mid-amble periodicity M according to a predetermined value, regardless of any MCS values, and then exits.

(183) At S**1618**, the process **1600** determines the mid-amble periodicity M according to a value indicated in a frame that solicits the STAs to send the PPDU in response to the frame, and then exits. In an embodiment, the soliciting frame could be a Trigger frame.

(184) In a first embodiment, for any of an HE SU PPDU, HE SU extended range PPDU, and UL HE PPDU for one user transmission, when a Doppler subfield is set to a first state that indicates that the PPDU is transmitted with mid-ambles, the HE PPDU format is considered in determining the mid-amble periodicity M. A transmitter inserts a Mid-amble field after every mid-amble periodicity M OFDM data symbols encoded according to an MCS value of the PPDU. Each mid-amble fields may be used to perform channel estimation for data symbols that follow the mid-amble field. When receiving the PPDU, once a receiver decodes an MCS value in a PHY preamble of the PPDU correctly, the location and length of Mid-amble field(s) can be determined.

(185) In a DL MU transmission with STAs assigned with different MCS values, the mid-amble fields might not be lined up for the resource block allocated to the respective STAs, and as a result an FFT window may not line up across resource blocks, which may increase implementation complexity. The MCS values for each assigned STA may be determined by all of the all STAs because the HE-SIG-B field that communicates the MCS values to the STAs is not beamformed.

(186) In an embodiment, for DL HE MU PPDUs targeted for more than one user, when the Doppler subfield is set to a first state that indicates that the PPDU is transmitted with mid-ambles, the HE PPDU format is considered in determining the mid-amble periodicity M. A transmitter inserts a

Mid-amble field after every mid-amble periodicity M OFDM data symbol according to a maximum MCS value among the STAs participating in the DL HE MU PPDU. Each mid-amble fields may be used to perform channel estimation for data symbols that follow the mid-amble field. When receiving the PPDU, once a receiver decodes all the MCS values for each STA correctly, the location and length of Mid-amble field(s) can be determined based on maximum MCS value among the STAs.

(187) In an UL MU transmission with STAs assigned with different MCS values, the mid-amble fields might not be lined up for the resource block allocated to the respective STAs, and as a result an FFT window may not line up across resource blocks, which may increase implementation complexity. Implementation of an AP may be made easier if all mid-amble feeds from all users in an UL MU transmission end at a same point.

(188) In an embodiment, for UL HE MU PPDUs, when the Doppler subfield is set to a first state that indicates that the PPDU is transmitted with mid-ambles, the HE PPDU format is considered in determining the mid-amble periodicity M for HE trigger-based (TB) PPDUs of the UL HE MU transmission. Each STA determines all MCS values in each user info field of the Trigger frame. A responding STA inserts a Mid-amble field on every mid-amble periodicity M data symbols based on the maximum MCS value among assigned STAs. When the AP receives the HE TB PPDUs from the assigned STAs, the location and length of Mid-amble field can be determined according to the maximum MCS value among assigned STAs.

(189) In an embodiment, for UL HE MU PPDUs, when the Doppler subfield of a received Trigger frame is set to a first state that indicates that the PPDU is transmitted with mid-ambles, the HE PPDU format is considered in determining the mid-amble periodicity M for HE TB PPDUs transmitted in response to the Trigger frame. The mid-amble periodicity M has a predetermined value, and therefore each STA does not need to see all MCS values in each user info field of the Trigger frame. A responding STA inserts Mid-amble field after the pre-determined mid-amble periodicity M data symbols regardless of MCS values assigned for STAs in UL transmission. When AP receives the HE TB PPDUs from assigned STAs, the location and length of Mid-amble field can be expected based on the pre-determined mid-amble periodicity M value.

(190) FIG. **17** illustrates a PPDU **1700** including mid-ambles according to an embodiment. The PPDU **100** includes a preamble **1702**, first, second, and third data portions **1706-1**, **1706-2**, and **1706-3**, first and second mid-ambles **1708-1** and **1708-2**, and a Packet Extension (PE) **1710**. The first data portion **1706-1** starts with a first data symbol **1706S1** followed by a second data symbol **1706S2**, and ends with a seventh data symbol **1706S7**. The second data portion **1706-2** starts with an eighth data symbol **1706S8**. In the illustrative example shown, the mid-amble periodicity M is equal to 7.

(191) A first channel estimation **1722-1** is performed using the preamble **1702** to produce parameters for a first equalization **1724-1** to be performed on the symbols of the first data portion **1706-1**. A second channel estimation **1722-2** is performed using the first mid-amble **1708-1** to produce parameters for a second equalization **1724-2** to be performed on the symbols of the second data portion **1706-2**. A third channel estimation **1722-3** is performed using the second mid-amble **1708-2** to produce parameters for a third equalization **1724-3** to be performed on the symbols of the third data portion **1706-3**.

(192) For IEEE Std 802.11 devices, a Space-Time Block Coding STBC process has been implemented to provide stable performance in edge areas of an AP's coverage. STBC operation pairs two OFDM symbols and transmits the paired symbols in consecutive time slots, and a receiver decodes the paired symbols together. For example, when the PPDU **1700** is transmitted using STBC, the first data symbol **1706S1** is paired with the second data symbol **1706S2**, the third, with the fourth, and so on.

(193) But the paired seventh data symbol **1706S8** and eighth data symbol **1706S8** are separated by the first mid-amble **1708-1**. As a result, the system needs to wait to get the new channel information from the second channel estimation **1722-2** in order to decode the two OFDM symbol together, and needs to have a two times bigger buffer size in order to store the two different channel information together (here, the results of the first channel estimation **1722-1** using the preamble **1702** and the results of the second channel estimation **1722-2** using the first mid-amble **1708-1**).

(194) In an embodiment, when STBC is enabled and a Doppler subfield is set to a first state to indicate the transmitted PPDU includes one or more mid-amble fields, a transmitter inserts Mid-amble fields after every mid-amble periodicity M OFDM data symbols of a PPDU. If a mid-amble field is located between two OFDM symbols paired for STBC operation, the mid-amble field is shifted to the location after the two paired OFDM symbols.

(195) In another embodiment, when STBC is enabled and a Doppler subfield is set to a first state to indicate the transmitted PPDU includes one or more mid-amble fields, a transmitter inserts Mid-amble fields after every mid-amble periodicity M OFDM data symbols of a PPDU. If a Mid-amble field is located between two OFDM symbols to be paired for STBC operation the Mid-amble field is shifted to the location before the two paired OFDM symbols.

(196) In either embodiment, when receiving the PPDU, once a receiver decodes a STBC value in the PHY preamble of the PPDU correctly, the location and length of Mid-amble field can be determined.

(197) In another embodiment, the value of the mid-amble periodicity M is always an even number, and as a result the Mid-amble field always occurs before or after two OFDM data symbols paired for STBC operation, and never occurs between the paired symbols.

(198) When a transmitter sends data of APEP_LENGTH bytes in an HE PPDU wherein the Doppler subfield is set to the first state (e.g. 1) indicating the presence of one or more mid-ambles, the data in transmitted in a number of OFDM data symbols N.sub.SYM. Depending on the coding scheme, the number of data symbols N.sub.SYM, can be determined by: for BCC:

(199) $N_{SYM} = m_{STBC} \cdot \left\lceil \frac{8 \cdot \text{APEP\_LENGTH} + N_{Tail} + N_{Service}}{m_{STBC} N_{DBPS}} \right\rceil$ Eq. 1 for LDPC:

(200) $N_{SYM} = m_{STBC} \cdot \left\lceil \frac{8 \cdot \text{APEP\_LENGTH} + N_{Service}}{m_{STBC} N_{DBPS}} \right\rceil$ Eq. 2

wherein m.sub.STBC is 2 when STBC is used and 1 otherwise, N.sub.DBPS is a number of data bits per OFDM symbol, N.sub.Tail is a number of tail bits (6), and N.sub.Service is a number of service bits (16).

(201) Given N.sub.SYM, the transmitter sets a value of Length field in L-SIG to:

(202) $N_{SYM} = m_{STBC} \cdot \left\lceil \frac{\text{TXTIME} - SE - 20}{4} \right\rceil \times 3 - 3 - m$ Eq. 3

wherein:

(203) $\text{TXTIME} = 20 + T_{PA} + N_{SYM} T_{SYM} + N_{MA} T_{MA} + T_{PE} + SE, T_{MA} = N_{HE\text{-}LTF} T_{HE\text{-}LTF} (+ T_{HE\text{-}STF})$,

and $N_{MA} = \begin{cases} \lfloor N_{SYM} / M \rfloor \\ 0 \end{cases}$

when the Doppler subfield indicates the first state (1),
when the Doppler subfield indicates the second state (0).

and wherein N.sub.MA is the number of mid-ambles, M is the mid-amble periodicity, SE is 0 us when the transmission is in a 5 GHz band and is 6 us when the transmission is in a 2.4 GHz band, T.sub.PA is duration of HE preamble as described with respect to FIGS. **7**A through **7**D, T.sub.SYM is duration of a OFDM data symbol, T.sub.PE is duration of Packet Extension (which Packet Extensions consists of random values whose average power is that same as the average power of the OFDM data symbols and secures additional receive processing time), and m is 1 for an HE MU PPDU or HE ER SU PPDU, and 2 otherwise. T.sub.MA is duration of Mid-amble field, which in an embodiment may include a duration of a HE-STF T.sub.HE-STF, and in another embodiment may not include the duration of a HE-STF T.sub.HE-STF.

(204) When a receiver receives an HE PPDU, it needs to determine how many OFDM data symbols, N.sub.SYM, are transmitted and what amount of time, T.sub.PE, can be secured for RX processing.

(205) In an embodiment, a device receiving an HE PPDU determines a number of OFDM symbols used for decoding data symbols of the HE PPDU by finding a number of OFDM data symbols (N.sub.SYM) that satisfies the following equations:

(206) $N_{MA} = \begin{cases} \lfloor N_{SYM} / M \rfloor & \text{when a Doppler subfield indicates} \\ & \text{a mid-amble exists,} \\ 0 & \text{otherwise.} \end{cases}$ Eq. 4

$N_{SYM} = \lfloor (\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - N_{MA} T_{MA}) / T_{SYM} \rfloor - b_{PE\text{-}Disambiguity}$ Eq. 5

wherein b.sub.PE-Disambiguity is the value of a PE Disambiguity bit in the HE-SIG-A field of the PPDU. Once N.sub.SYM is obtained, T.sub.PE is calculated by:

(207) $T_{PE} = \lceil \dfrac{(\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - N_{MA} T_{MA}) - N_{SYM} T_{SYM}}{4} \rceil \times 4$ Eq. 6

(208) Accordingly, in PPDUs wherein one or more mid-amble fields exist, the receiver may determine the number of OFDM data symbols N.sub.SYM using Equation 5, but the number of mid-ambles N.sub.MA in Equation 5 is a function of N.sub.SYM. As a result the number of OFDM symbols N.sub.SYM cannot be directly calculated by the receiver, and implementation of the determination of the number of OFDM data symbols N.sub.SYM in received PPDUs including one or more mid-ambles can increase the system complexity compared to the case where a mid-amble field is not included in the PPDU Eliminating the circular dependency of Equations 4 and 5 is difficult because of, for example, the non-linear elements of the equations, such as the floor operations (i.e., $\lfloor x \rfloor$) is each equation.

(209) Embodiments reduce the complexity of a device configured to receive HE PPDUs including mid-ambles by using novel processes for determining the number of OFDM symbols N.sub.SYM used for data symbols and the Packet Extension duration T.sub.PE of the received HE PPDU.

(210) In order to determine the number of OFDM data symbols N.sub.SYM at a receiving device, the use of Equation 5 might be considered. But Equation 5 requires that the value of the number of mid-ambles N.sub.MA be known, and Equation 4 establishes that the number of mid-ambles N.sub.MA is a function of the number of OFDM data symbols N.sub.SYM. Therefore the number of OFDM data symbols N.sub.SYM cannot be directly calculated using Equation 5 when a Doppler subfield of an HE-SIG-A field of the PPDU being received is set to the first state (e.g. 1), indicating that one or more mid-ambles are present. Accordingly a new equation and new assumptions are needed to determine N.sub.SYM. The new equations may be derived as follows:

(211) Step A1) the floor function can be eliminated from Equation 4 by restating Equation 4 as shown below, using an additional unknown variable no: for some n.sub.0, $0 \leq n.sub.0 \leq M-1$,

(212) $N_{MA} = \frac{N_{SYM} - n_0}{M} \Rightarrow N_{SYM} = M \cdot N_{MA} + n_0$. Eq. 7

(213) Step A2) the floor function can be eliminated from Equation 5 by restating Equation 5 as shown below using an additional unknown variable α: for some α, $0 \leq \alpha < 1$,

(214) $0 \leq (\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - N_{MA} T_{MA}) / T_{SYM} = N_{SYM} + b_{PE\text{-}Disambiguity} + \alpha$. Eq. 8

(215) Step A3) from Step A1 and Step A2, the following equations can be derived:

(216) $(\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - N_{MA} T_{MA}) = T_{SYM}(M \cdot N_{MA} + n_0 + b_{PE\text{-}Disambiguity} + \alpha)$. Eq. 9

$N_{MA} = \dfrac{(\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}) - T_{SYM}(n_0 + b_{PE\text{-}Disambiguity} + \alpha)}{T_{MA} + M \cdot T_{SYM}}$ Eq. 10

(217) Step A4) from the above, minimum and maximum possible values of n.sub.0 and a may be used to determine minimum (N.sub.MA_MIN) and maximum (N.sub.MA_MAX) possible values for the number of mid-ambles N.sub.MA: assume α=0, n.sub.0=0:

(218) $N_{MA\_MAX} = \dfrac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM} b_{PE\text{-}Disambiguity}}{T_{MA} + M \cdot T_{SYM}}$ Eq. 11 assume α=1, n.sub.0=M−1:

(219) $N_{MA\_MIN} = \dfrac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(b_{PE\text{-}Disambiguity} + M)}{T_{MA} + M \cdot T_{SYM}}$ Eq. 12 and note that:

$N.sub.MA\_MIN < N.sub.MA < N.sub.MA\_MAX$ Eq. 13

(220) Step A5) from the above, determine an equation for (N.sub.MA_MAX−N.sub.MA_MIN) to determine the scope of the range of possible values for the number of mid-ambles N.sub.MA:

(221) $(N_{MA\_MAX} - N_{MA\_MIN}) = \frac{M \cdot T_{SYM}}{T_{MA} + M \cdot T_{SYM}}$, which is < 1 Eq. 14

(222) Because the difference between N.sub.MA_MAX and N.sub.MA_MIN is less than one and N.sub.MA_MAX is greater than N.sub.MA_MIN, floor(N.sub.MA_MAX)=ceiling(N.sub.MA_MIN/N). Relying on this and on the number of mid-ambles N.sub.MA being a positive integer between N.sub.MA_MAX and N.sub.MA_MIN,

(223) $N_{MA} = \text{floor}(N_{MA\_MAX}) = \text{ceiling}(N_{MA\_MIN})$ Eq. 15

$N_{MA} = \lfloor \dfrac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM} b_{PE\text{-}Disambiguity}}{T_{MA} + M \cdot T_{SYM}} \rfloor = \lceil \dfrac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(b_{PE\text{-}Disambiguity} + M)}{T_{MA} + M \cdot T_{SYM}} \rceil$ Eq. 16

(224) In an embodiment in accordance with Equation 16, a process of identifying a number of OFDM data symbols N.sub.SYM and a Packet Extension duration T.sub.PE from a received HE PPDU first determines a number of mid-ambles N.sub.MA when the Doppler subfield indicates that mid-ambles are present in the received HE PPDU according to:

(225) $N_{MA} = \lfloor \dfrac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM} \lceil b_{PE\text{-}Disambiguity} \rceil}{T_{MA} + M \cdot T_{SYM}} \rfloor$ Eq. 17

When the Doppler subfield indicates that mid-ambles are not present in the HE PPDU, the number of mid-ambles N.sub.MA is 0. Unlike a process relying on Equation 4, the process using Equation 17 to determine the number of mid-ambles N.sub.MA does not need to first determine the value N.sub.SYM in order to do so.

(226) Once the number of mid-ambles N.sub.MA is determined, the process may determine the number of OFDM data symbols N.sub.SYM according to Equation 5 and the Packet Extension duration T.sub.PE may be determined according to Equation 6.

(227) In another embodiment in accordance with Equation 16, a process of identifying a number of OFDM data symbols N.sub.SYM and a Packet Extension duration T.sub.PE from a received HE PPDU determines a number of mid-ambles N.sub.MA when the Doppler subfield indicates that mid-ambles are present in an HE PPDU according to:

(228) $N_{MA} = \lceil \dfrac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(b_{PE\text{-}Disambiguity} + M)}{T_{MA} + M \cdot T_{SYM}} \rceil$ Eq. 18

When the Doppler subfield indicates that mid-ambles are not present in the HE PPDU, the number of mid-ambles N.sub.MA is 0. The process using Equation 18 to determine the number of mid-ambles N.sub.MA does not need to first determine the value of N.sub.SYM in order to do so.

(229) Once the number of mid-ambles N_{MA} is determined, the process may determine the number of OFDM data symbols N_{SYM} according to Equation 5 and the Packet Extension duration T_{PE} may be determined according to Equation 6.

(230) The analysis that led to Equations 17 and 18 can be generalized to cover other similar relationships between the number of mid-ambles N_{MA} and the number of OFDM data symbols N_{SYM}.

(231) For example, the relationship of Equation 4 would indicate two 2 mid-ambles when the number of OFDM data symbols N_{SYM} is equal to twice the mid-amble periodicity M. This would produce a PPDU as shown in FIG. 18.

(232) FIG. 18 illustrates a PPDU 1800 according to an embodiment. Elements of FIG. 18 having reference characters of the form 18XX or 18XX-X are similar to elements of FIG. 17 having respective reference characters of the form 17XX or 17XX-X, and descriptions thereof are omitted for brevity.

(233) The PPDU 1800 includes 2.Math.M OFDM data symbols, where M is the mid-amble periodicity. As a result, a mid-amble 1808-1 is inserted after the first M OFDM data symbols, and because the embodiment was according to Equation 4, another (unnecessary) mid-amble 1826 was inserted after the last OFDM data symbol. The mid-amble 1826 is unnecessary because the Packet Extension (PE) 1810 is not an OFDM symbols to be decoded, and therefore the third channel estimation 1822-3 and third equalization 1824-3 are not needed.

(234) In an embodiment, to prevent the insertion of this unnecessary mid-amble, a transmitter determines the number of OFDM data symbols N_{SYM} used in a HE PPDU according to Equation 1 or Equation 2, as appropriate, and the Length field of the L-SIG of the HE PPDU according to Equation 3.

(235) Then, instead of determining the number of mid-ambles N_{MA} according to Equation 4 above, the transmitter may determine a number of mid-ambles N_{MA} according to:

(236) $$N_{MA} = \begin{cases} .Math.\ (N_{SYM} - 1)/M\ .Math. & \text{when Doppler subfield indicates mid-amble exists,} \\ 0 & \text{otherwise.} \end{cases} \quad \text{Eq.}\ 19$$

(237) When a receiver receives the HE PPDU, it needs to derive how many OFDM data symbols N_{SYM}, that will be decoded to produce data, are being transmitted in the received HE PPDU and what amount of additional time, the Packet Extension duration T_{PE}, is being provided for receive processing. Equations for doing so may be derived as follows:

(238) Step B1) the floor function can be eliminated from Equation 19 by restating Equation 19 as shown below using an additional unknown variable n_0: for some n_0, $0 \le n_0 \le M-1$,

(239) $$N_{MA} = \frac{N_{SYM} - 1 - n_0}{M} \qquad N_{SYM} = M\ .Math.\ N_{MA} + 1 + n_0\ . \quad \text{Eq.}\ 20$$

(240) Step B2) the floor function can be eliminated from Equation 5 by restating Equation 5 as shown below using an additional unknown variable α: for some α, $0 \le \alpha < 1$,

(241) $$0\ (\tfrac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - N_{MA} T_{MA})/T_{SYM} = N_{SYM} + b_{PE\text{-}Disambiguity} + \quad . \quad \text{Eq.}\ 21$$

(242) Step B3) from Step B1 and Step B2, the following equations can be derived:

(243) $$(\tfrac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - N_{MA} T_{MA}) = T_{SYM}(M\ .Math.\ N_{MA} + 1 + n_0 + b_{PE\text{-}Disambiguity} +\ ). \quad \text{Eq.}\ 22$$

$$N_{MA} = \frac{(\tfrac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}) - T_{SYM}(1 + n_0 + b_{PE\text{-}Disambiguity} +\ )}{T_{MA} + M\ .Math.\ T_{SYM}} \quad \text{Eq.}\ 23$$

(244) Step B4) from the above, minimum and maximum possible values of n_0 and α may be used to determine minimum (N_{MA_MIN}) and maximum (N_{MA_MAX}) possible values for the number of mid-ambles N_{MA}: assume α=0, n_0=0:

(245) $$N_{MA\_MAX} = \frac{\tfrac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + b_{PE\text{-}Disambiguity})}{T_{MA} + M\ .Math.\ T_{SYM}} \quad \text{Eq.}\ 24 \quad \text{assume α=1, } n_0 = M-1:$$

(246) $$N_{MA\_MIN} = \frac{\tfrac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + b_{PE\text{-}Disambiguity} + M)}{T_{MA} + M\ .Math.\ T_{SYM}} \quad \text{Eq.}\ 25 \quad \text{and note that:}$$

$N_{MA\_MIN} < N_{MA} < N_{MA\_MAX}$ Eq. 26

(247) Step B5) from the above, determine an equation for ($N_{MA\_MAX} - N_{MA\_MIN}$) to determine the scope of the range of possible values for the number of mid-ambles N_{MA}:

(248) $$(N_{MA\_MAX} - N_{MA\_MIN}) = \frac{M\ .Math.\ T_{SYM}}{T_{MA} + M\ .Math.\ T_{SYM}}, \text{which is} < 1 \quad \text{Eq.}\ 27$$

(249) Because the difference between N_{MA_MAX} and N_{MA_MIN} is less than one and N_{MA_MAX} is greater than N_{MA_MIN}, floor(N_{MA_MAX})=ceiling(N_{MA_MIN}). Relying on this and that the number of mid-ambles N_{MA} must be a positive integer between N_{MA_MAX} and N_{MA_MIN},

(250) $$N_{MA} = \text{floor}(N_{MA\_MAX}) = \text{ceiling}(N_{MA\_MIN}) \quad \text{Eq.}\ 28$$

$$N_{MA} = .Math.\ \frac{\tfrac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + b_{PE\text{-}Disambiguity})}{T_{MA} + M\ .Math.\ T_{SYM}}\ .Math. = .Math.\ \frac{\tfrac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + b_{PE\text{-}Disambiguity} + M)}{T_{MA} + M\ .Math.\ T_{SYM}}\ .Math. \quad \text{Eq.}\ 29$$

(251) In an embodiment in accordance with Equation 29, a process of identifying a number of OFDM data symbols N_{SYM} and a Packet Extension duration T_{PE} from a received HE PPDU first determines a number of mid-ambles N_{MA} when the Doppler subfield indicates that mid-ambles are present in an HE PPDU according to:

(252) $$N_{MA} = .Math.\ \frac{\tfrac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + b_{PE\text{-}Disambiguity})}{T_{MA} + M\ .Math.\ T_{SYM}}\ .Math. \quad \text{Eq.}\ 30$$

When the Doppler subfield indicates that mid-ambles are not present in the HE PPDU, the number of mid-ambles N_{MA} is 0. Unlike a process relying on Equation 4, the process using Equation 30 to determine the number of mid-ambles N_{MA} does not need to first determine the value N_{SYM} in order to do so.

(253) Once the number of mid-ambles N_{MA} is determined, the process may determine the number of OFDM data symbols N_{SYM} according to Equation 5 and the Packet Extension duration T_{PE} determined according to Equation 6.

(254) In another embodiment in accordance with Equation 29, a process of identifying a number of OFDM data symbols N_{SYM} and a Packet Extension duration T_{PE} from a received HE PPDU determines a number of mid-ambles N_{MA} when the Doppler subfield indicates that mid-ambles are present in an HE PPDU according to:

(255) $$N_{MA} = .Math.\ \frac{\tfrac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + b_{PE\text{-}Disambiguity} + M)}{T_{MA} + M\ .Math.\ T_{SYM}}\ .Math. \quad \text{Eq.}\ 31$$

When the Doppler subfield indicates that mid-ambles are not present in the HE PPDU, the number of mid-ambles N_{MA} is 0. The process using Equation 31 to determine the number of mid-ambles N_{MA} does not need to first determine the value of N_{SYM} in order to do so.

(256) Once the number of mid-ambles N_{MA} is determined, the process may determine the number of OFDM data symbols N_{SYM} according to Equation 5 and the Packet Extension duration T_{PE} determined according to Equation 6.

(257) Generalizing from FIG. 18, FIG. 20 illustrates a PPDU 2000 according to an embodiment. Elements of FIG. 20 having reference characters of the form 20XX or 20XX-X are similar to elements of FIG. 17 having respective reference characters of the form 17XX or 17XX-X, and descriptions thereof are omitted for brevity.

(258) The illustrative PPDU 2000 includes 2M+β OFDM data symbols, where M is the mid-amble periodicity. In the example shown, β=1. As a result, a mid-amble 2008-1 is inserted after the first M OFDM data symbols, and because the embodiment was according to Equation 4 (or Equation

19), another (unnecessary) mid-amble **2026** before the last OFDM data symbol **2006**-2M+1 and the PE **2010**. The mid-amble **2026** is unnecessary because the equalization necessary to decode the last OFDM data symbol **2006**-2M+1 is probably substantially the same as the equalization needed to receive the second-to-the-last OFDM data symbol **2006**-2M and the Packet Extension (PE) **2010** is not an OFDM symbols to be decoded. Therefore, the third channel estimation **2022**-3 and third equalization **2024**-3 are not needed, which means the unnecessary mid-amble **2026** is not needed.

(259) In an embodiment, to prevent the insertion of the unnecessary mid-amble **2026**, a transmitter determines the number of OFDM symbols N.sub.SYM used for encoding data symbols in a HE PPDU according to Equation 1 or Equation 2, as appropriate, and the Length field of the L-SIG of the HE PPDU according to Equation 3.

(260) Then, instead of determining the number of mid-ambles N.sub.MA according to Equations 4 or 19, above, the transmitter may determine a number of mid-ambles N.sub.MA according to:

(261) $N_{MA} = \{ \begin{array}{ll} \lceil (N_{SYM} - \gamma - 1)/M \rceil & \text{when Doppler subfield indicates mid-ambles,} \\ 0 & \text{otherwise.} \end{array}$ $\quad$ Eq. 19A

thereby preventing the insertion of another mid-amble when only M+β OFDM data symbols remain to be transmitted, 0≤β<M after a last mid-amble. In an embodiment, β=1. Equivalently, because for any positive integers y and z, $\lfloor y/z \rfloor \equiv \lfloor (y+1)/z \rfloor - 1$, Equation 19A is equivalent to:

(262) $N_{MA} = \{ \begin{array}{ll} \lfloor (N_{SYM} - \gamma)/M \rfloor - 1 & \text{when Doppler subfield indicates mid-ambles,} \\ 0 & \text{otherwise.} \end{array}$ $\quad$ Eq. 19B

(263) When a receiver receives the HE PPDU, it needs to derive how many OFDM data symbols, N.sub.SYM, are being transmitted in the HE-PPDU and what amount of additional time, the PE duration T.sub.PE, has been provided for receive processing. Equations for doing so may be derived as follows:

(264) Step C1) the ceiling function can be eliminated from Equation 19B by restating Equation 19B as shown below using an additional unknown variable n.sub.0: for some n.sub.0, 0≤n.sub.0≤M−1,

(265) $0 \quad N_{MA} = \frac{N_{SYM} - \gamma + n_0}{M} - 1 \quad N_{SYM} = M \cdot N_{MA} + M + \gamma - n_0.$ $\quad$ Eq. 20B

(266) Step C2) the floor function can be eliminated from Equation 5 by restating Equation 5 as shown below using an additional unknown variable α: for some α, 0≤α<1,

(267) $(\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - N_{MA} T_{MA})/T_{SYM} = N_{SYM} + b_{PE\text{-}Disambiguity} + \alpha.$ $\quad$ Eq. 21B

(268) Step C3) from Step C1 and Step C2, the following equations can be derived:

(269) $(\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - N_{MA} T_{MA}) = T_{SYM}(M \cdot N_{MA} + M + \gamma - n_0 + b_{PE\text{-}Disambiguity} + \alpha).$ $\quad$ Eq. 22B

$N_{MA} = \frac{(\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}) - T_{SYM}(M + \gamma - n_0 + b_{PE\text{-}Disambiguity} + \alpha)}{T_{MA} + M \cdot T_{SYM}}$ $\quad$ Eq. 23B

(270) Step C4) from the above, minimum and maximum possible values of n.sub.0 and α may be used to determine minimum (N.sub.MA_MIN) and maximum (N.sub.MA_Max) possible values for the number of mid-ambles N.sub.MA: assume α=1, n.sub.0=M−1:

(271) $N_{MA\_MAX} = \frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + \gamma + b_{PE\text{-}Disambiguity})}{T_{MA} + M \cdot T_{SYM}}$ $\quad$ Eq. 24B $\quad$ assume α=0, n.sub.0=0:

(272) $N_{MA\_MIN} = \frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + b_{PE\text{-}Disambiguity} + \gamma + M)}{T_{MA} + M \cdot T_{SYM}}$ $\quad$ Eq. 25B $\quad$ and note that:

N.sub.MA_MIN<N.sub.MA<N.sub.MA_MAX $\quad$ Eq. 26B

(273) Step C5) from the above, determine an equation for (N.sub.MA_MAX−N.sub.MA_MIN) to determine the scope of the range of possible values for the number of mid-ambles N.sub.MA:

(274) $(N_{MA\_MAX} - N_{MA\_MIN}) = \frac{M \cdot T_{SYM}}{T_{MA} + M \cdot T_{SYM}}$, which is < 1 $\quad$ Eq. 27B

(275) Because the difference between N.sub.MA_MAX and N.sub.MA_MIN is less than one and N.sub.MA_MAX is greater than N.sub.MA_MIN, floor(N.sub.MA_MAX)=ceiling(N.sub.MA_MIN). Relying on this and that the number of mid-ambles N.sub.MA must be a positive integer between N.sub.MA_MAX and N.sub.MA_MIN,

(276) $N_{MA} = \text{floor}(N_{MA\_MAX}) = \text{ceiling}(N_{MA\_MIN})$ $\quad$ Eq. 28B

$N_{MA} = \lfloor \frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + \gamma + b_{PE\text{-}Disambiguity})}{T_{MA} + M \cdot T_{SYM}} \rfloor = \lceil \frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + \gamma + b_{PE\text{-}Disambiguity} + M)}{T_{MA} + M \cdot T_{SYM}} \rceil$ $\quad$ Eq. 29B

(277) In an embodiment in accordance with Equation 29B, a process of identifying a number of OFDM data symbols N.sub.SYM and a Packet Extension duration T.sub.PE from a HE PPDU being received first determines a number of mid-ambles N.sub.MA when the Doppler subfield indicates that mid-ambles are present in an HE PPDU according to:

(278) $N_{MA} = \lfloor \frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + \gamma + b_{PE\text{-}Disambiguity})}{T_{MA} + M \cdot T_{SYM}} \rfloor$ $\quad$ Eq. 30B

When the Doppler subfield indicates that mid-ambles are not present in the HE PPDU, the number of mid-ambles N.sub.MA is 0. Unlike a process relying on Equation 4, the process using Equation 30B to determine the number of mid-ambles N.sub.MA does not need to first determine the value of N.sub.SYM in order to do so.

(279) Once the number of mid-ambles N.sub.MA is determined, the process may determine the number of OFDM data symbols N.sub.SYM according to Equation 5 and the Packet Extension duration T.sub.PE may be determined according to Equation 6.

(280) In another embodiment in accordance with Equation 29B, a process of identifying a number of OFDM data symbols N.sub.SYM and a Packet Extension duration T.sub.PE from a received HE PPDU determines a number of mid-ambles N.sub.MA when the Doppler subfield indicates that mid-ambles are present in an HE PPDU according to:

(281) $N_{MA} = \lceil \frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + \gamma + b_{PE\text{-}Disambiguity} + M)}{T_{MA} + M \cdot T_{SYM}} \rceil$ $\quad$ Eq. 31B

When the Doppler subfield indicates that mid-ambles are not present in the HE PPDU, the number of mid-ambles N.sub.MA is 0. The process using Equation 31B to determine the number of mid-ambles N.sub.MA does not need to first determine the value of N.sub.SYM in order to do so.

(282) Once the number of mid-ambles N.sub.MA is determined, the process may determine the number of OFDM data symbols N.sub.SYM according to Equation 5 and the Packet Extension duration T.sub.PE may be determined according to Equation 6.

(283) For example, given β=0, each number of mid-ambles N.sub.MA from Eq. 1, Eq. 3 and Eq. 4 provides exactly the same value at the TX side. Equations 19 and 19B generate the same value for the number of mid-ambles N.sub.MA at the receive side.

(284) For another example, given β=1, at the TX side, substituting in 1 for β in Equation 19B gives:

(285) $N_{MA} = \{ \begin{array}{ll} \lfloor (N_{SYM} - \gamma - 1)/M \rfloor - 1 & \text{when Doppler subfield indicates mid-ambles,} \\ 0 & \text{otherwise.} \end{array}$ $\quad$ Eq. 19C

and at the receive side, when β=1, the number of mid-ambles N.sub.MA is determined by either:

(286) 0 $N_{MA} = $ .Math. $\frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(2 + b_{PE\text{-}Disambiguity})}{T_{MA} + M .\text{Math.} T_{SYM}}$ .Math. Eq. 30C orby

$N_{MA} = $ .Math. $\frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(2 + b_{PE\text{-}Disambiguity} + M)}{T_{MA} + M .\text{Math.} T_{SYM}}$ .Math. Eq. 31C

(287) Note that when β=1, the number of mid-ambles N.sub.MA is 0 or a positive integer according to the definition wherein the number of mid-ambles N.sub.MA is the number of mid-amble inserted on every M except two cases. There is no mid-amble inserted after the last OFDM data symbol if mod(N.sub.SYM, N.sub.MA)=0, and at the end of an HE PPDU, if mod(N.sub.SYM, N.sub.MA)=1, there is also no mid-amble inserted before the last OFDM data symbol. In an embodiment, β is a predetermined value.

(288) In another embodiment, a process determines a number of OFDM data symbols N.sub.SYM and a Packet-extension duration T.sub.PE for a received HE PPDU as follows:

(289) When Doppler information for the HE PPDU indicates that one or more mid-ambles exist in the HE PPDU, the process determines a number of mid-ambles N.sub.MA according to:

(290) $N_{MA} = $ .Math. $\frac{.\text{Math.} \left(\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}\right) / T_{SYM} .\text{Math.} - b_{PE\text{-}Disambiguity} + 1}{T_{MA} / T_{SYM} + M}$ .Math. . Eq. 32

or according to:

(291) $N_{MA} = $ .Math. $\frac{.\text{Math.} \left(\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}\right) / T_{SYM} .\text{Math.} - b_{PE\text{-}Disambiguity} + 1 - M}{T_{MA} / T_{SYM} + M}$ .Math. Eq. 33

Otherwise, when the Doppler information indicates no mid-ambles exist in the HE PPDU, the number of mid-ambles N.sub.MA=0.

(292) The process then determines an estimated number of OFDM symbols T_N.sub.SYM used to decode data according to either:

(293)

$T_N_{SYM} = $ .Math. $\left(\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}\right) / T_{SYM}$ .Math. $- b_{PE\text{-}Disambiguity} - $ .Math. $\frac{T_{MA}}{T_{SYM}}$ .Math. .Math. $\frac{.\text{Math.} \left(\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}\right) / T_{SYM} .\text{Math.} - b_{PE\text{-}Disambiguity}}{T_{MA} / T_{SYM} + M}$

or

$T_N_{SYM} = $ .Math. $\left(\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}\right) / T_{SYM}$ .Math. $- b_{PE\text{-}Disambiguity} - $ .Math. $\frac{T_{MA}}{T_{SYM}}$ .Math. .Math. $\frac{.\text{Math.} \left(\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}\right) / T_{SYM} .\text{Math.} - b_{PE\text{-}Disambiguity}}{T_{MA} / T_{SYM} + M}$

(294) The estimated number of OFDM symbols T_N.sub.SYM needs to be verified by determining whether T_T.sub.PE is less than 0 to obtain a final value for N.sub.SYM.

(295) $T_T_{PE} = $ .Math. $\frac{\left(\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - N_{MA} T_{MA}\right) - T\_N_{SYM} T_{SYM}}{4}$ .Math. $\times 4$ Eq. 36 $N_{SYM} = \begin{cases} T\_N_{SYM} - 1 & \text{when } T\_T_{PE} < 0, \\ T\_N_{SYM} & \text{otherwise}. \end{cases}$ Eq. 37

The PE duration T.sub.PE is then determined according to Equation 6, above.

(296) The equations 34-37 above, used to determine T_N.sub.SYM and N.sub.SYM above, are derived as follows in light of FIG. **19**.

(297) FIG. **19** illustrates features of a PPDU **1900** including a mid-amble **1908** according to an embodiment. The PPDU **1900** also includes an L-SIG field **1902**, an HE Preamble **1904**, first and second portions of a Data field **1906-1** and **1906-2**, and a Packet Extension (PE) **1910**. A duration of the HE Preamble **1904** is indicated by T.sub.PA. A combined duration of the mid-ambles of the PPDU is indicated by T.sub.HE_MIDAMBLE. A duration of the PE **1910** is indicated by T.sub.PE.

(298) A length from the end of the L-SIG field **1902** to beyond an end of the PPDU is equal to a value L_LENGTH of a length field of the L-SIG field **1902** plus a number of Service bits (16) at the beginning of the first portion of the Data field **1906-1** plus a number of Tail bits (6) at the end of the last (here, second) portion of the Data field **1906-2** plus m, m is 1 for an HE MU PPDU or HE ER SU PPDU, and 2 otherwise.

(299) In order to get N.sub.SYM at the receive side, the equation below is used when Doppler information is set to the first state (e.g. 1) which indicates that the Mid-Amble exists:

(300) $\frac{L_LENGTH + m + 3}{3} \times 4 = T_{PA} + N_{SYM} T_{SYM} + N_{MA} T_{MA} + T_{PE} + T_{SYM} b_{PE\text{-}Disambiguity} + $ Eq. 38 $0 \le \ < 4, 0 \le T_{PE} + \ < T_{SYM}$

(301) Step D1) from Equation 38 it follows that:

(302) $N_{SYM} T_{SYM} + N_{MA} T_{MA} + T_{SYM} b_{PE\text{-}Disambiguity} = \frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - (T_{PE} +)$ Eq. 39

.Math. $N_{SYM} + N_{MA} \frac{T_{MA}}{T_{SYM}} + b_{PE\text{-}Disambiguity}$ .Math. $= $ .Math. $\frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - (T_{PE} +)}{T_{SYM}}$ .Math. Eq. 40

$N_{SYM} + $ .Math. $N_{MA} \frac{T_{MA}}{T_{SYM}}$ .Math. $= $ .Math. $\frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}}{T_{SYM}} - \frac{T_{PE} + }{T_{SYM}}$ .Math. $- b_{PE\text{-}Disambiguity}$ Eq. 41

(303) Because T.sub.PE is not known without N.sub.SYM in a receiver of an HE PPDU, ((T.sub.PE+α)/T.sub.SYM) is temporarily ignored, and the impact of this term will be verified later. As shown in Equation 42, below, N.sub.SYM is replaced with T_N.sub.SYM as a temporary number of OFDM data symbol:

(304) $T_N_{SYM} + $ .Math. $N_{MA} \frac{T_{MA}}{T_{SYM}}$ .Math. $= $ .Math. $\frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}}{T_{SYM}}$ .Math. $- b_{PE\text{-}Disambiguity}$ Eq. 42

(305) Step D2) from the above:

$T\_N.\text{sub.SYM} = M .\text{Math.} N.\text{sub.MA} + n.\text{sub.0}, 0 \le n.\text{sub.0}, 0 \le M-1$ Eq. 43

(306) Step D3) from Step D1 and Step D2:

(307) $N_{MA} \frac{T_{MA}}{T_{SYM}} = $ .Math. $\frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}}{T_{SYM}}$ .Math. $- b_{PE\text{-}Disambiguity} - T_N_{SYM} + $, Eq. 44 $0 \le \ < 1$

$\frac{T_N_{SYM} - n_0}{M} \cdot \frac{T_{MA}}{T_{SYM}} = $ .Math. $\frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}}{T_{SYM}}$ .Math. $- b_{PE\text{-}Disambiguity} - T_N_{SYM} + $ Eq. 45

$T\_N_{SYM} = \frac{M}{T_{MA} / T_{SYM} + M}$ .Math. $\left(\frac{T_{MA} / T_{SYM}}{M} .\text{Math.} n_0 + .\text{Math.} \frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}}{T_{SYM}} .\text{Math.} - b_{PE\text{-}Disambiguity} + \right)$ Eq. 45

(308) Step D4) from Step D2 and Step D3,

(309) $N_{MA} = \frac{T\_N_{SYM} - n_0}{M}$ Eq. 46 $N_{MA} = \frac{1}{T_{MA} / T_{SYM} + M}$ .Math. $\left(.\text{Math.} \frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}}{T_{SYM}} .\text{Math.} - b_{PE\text{-}Disambiguity} + \ - n_0\right)$ Eq. 47 $0 \le \alpha < 1, 0 \le n.\text{sub.0} \le M-1$

(310) Step D5) find minimum value and maximum value of the number of mid-ambles N.sub.MA to find the boundary: Assuming α=1,n.sub.0=0,

(311) 0 $\text{Max} N_{MA} = \frac{1}{T_{MA} / T_{SYM} + M}$ .Math. $\left(.\text{Math.} \frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}}{T_{SYM}} .\text{Math.} - b_{PE\text{-}Disambiguity} + 1\right)$ Eq. 48 Assuming α=0,n.sub.0=M−1,

(312) $\text{Min} N_{MA} = \frac{1}{T_{MA} / T_{SYM} + M}$ .Math. $\left(.\text{Math.} \frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}}{T_{SYM}} .\text{Math.} - b_{PE\text{-}Disambiguity} - M + 1\right)$ Eq. 49

$\frac{1}{T_{MA} / T_{SYM} + M}$ .Math. $\left(.\text{Math.} \frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}}{T_{SYM}} .\text{Math.} - b_{PE\text{-}Disambiguity} - M + 1\right) < N_{MA} < \frac{1}{T_{MA} / T_{SYM} + M}$ .Math. $\left(.\text{Math.} \frac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA}}{T_{SYM}} .\text{Math.} - b_{PE\text{-}I}\right.$

(313) Step D6) check (Max N.sub.MA−Min N.sub.MA) to see the range of N.sub.MA:

(314) $(\text{Max} N_{MA} - \text{Min} N_{MA}) = \frac{M}{T_{MA} / T_{SYM} + M} < 1$ Eq. 51

Since the number of mid-ambles N.sub.MA is supposed to be a positive integer within 0<(MaxN.sub.MA−MinN.sub.MA)<1, N.sub.NA should be one positive integer, so floor(MaxN.sub.M)=ceil(MinN.sub.M):

(315)
$$N_{MA} = \left\lfloor \frac{1}{T_{MA}/T_{SYM}+M} \left(\left\lceil \frac{\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA}}{T_{SYM}} \right\rceil - b_{PE\text{-}Disambiguity} + 1 \right) \right\rfloor \qquad Eq.52$$

$$= \left\lfloor \frac{1}{T_{MA}/T_{SYM}+M} \left(\left\lceil \frac{\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA}}{T_{SYM}} \right\rceil - b_{PE\text{-}Disambiguity} - M + 1 \right) \right\rfloor$$

Then, from the above equations,

(316) $T\_N_{SYM} = \left\lceil \frac{\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA}}{T_{SYM}} \right\rceil - b_{PE\text{-}Disambiguity} - \left\lfloor N_{MA}\frac{T_{MA}}{T_{SYM}} \right\rfloor \qquad Eq.53$

$$T\_N_{SYM} = \left\lceil (\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA})/T_{SYM} \right\rceil - b_{PE\text{-}Disambiguity} - \left\lfloor \frac{T_{MA}}{T_{SYM}} \left\lfloor \frac{\left\lceil (\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA})/T_{SYM} \right\rceil - b_{PE\text{-}Disambiguity} + 1 - M}{T_{MA}/T_{SYM}+M} \right\rfloor \right\rfloor$$

Or

$$T\_N_{SYM} = \left\lceil (\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA})/T_{SYM} \right\rceil - b_{PE\text{-}Disambiguity} - \left\lfloor \frac{T_{MA}}{T_{SYM}} \left\lfloor \frac{\left\lceil (\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA})/T_{SYM} \right\rceil - b_{PE\text{-}Disambiguity} + 1}{T_{MA}/T_{SYM}+M} \right\rfloor \right\rfloor$$

(317) In another embodiment, a process determined the number of OFDM data symbols N.sub.SYM and a Packet-extension duration T.sub.PE for a received HE PPDU is determined as follows:

(318) When Doppler information for the HE PPDU indicates that one or more mid-ambles exist in the HE PPDU, the process determines a number of mid-ambles N.sub.MA according to:

(319) $N_{MA} = \left\lfloor \frac{\left\lceil (\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA})/T_{SYM} \right\rceil - b_{PE\text{-}Disambiguity}}{T_{MA}/T_{SYM}+M} \right\rfloor \qquad Eq.56$

or according to:

(320) $N_{MA} = \left\lfloor \frac{\left\lceil (\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA})/T_{SYM} \right\rceil - b_{PE\text{-}Disambiguity} - M}{(T_{MA}/T_{SYM}+M)} \right\rfloor \qquad Eq.56$

Otherwise, when the Doppler information indicates no mid-ambles exist in the HE PPDU, the number of mid-ambles N.sub.MA=0.

(321) The process then determines an estimated number of OFDM symbols T_N.sub.SYM used to decode data according to either:

(322)

$$T\_N_{SYM} = \left\lceil (\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA})/T_{SYM} \right\rceil - b_{PE\text{-}Disambiguity} - \left\lfloor \frac{T_{MA}}{T_{SYM}} \left\lfloor \frac{\left\lceil (\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA})/T_{SYM} \right\rceil - b_{PE\text{-}Disambiguity} - M}{T_{MA}/T_{SYM}+M} \right\rfloor \right\rfloor$$

or

$$T\_N_{SYM} = \left\lceil (\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA})/T_{SYM} \right\rceil - b_{PE\text{-}Disambiguity} - \left\lfloor \frac{T_{MA}}{T_{SYM}} \left\lfloor \frac{\left\lceil (\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA})/T_{SYM} \right\rceil - b_{PE\text{-}Disambigu}}{T_{MA}/T_{SYM}+M} \right\rfloor \right\rfloor$$

(323) The estimated number of OFDM symbols T_N.sub.SYM needs to be verified by determining whether T_T.sub.PE is less than 0 to obtain a final value for N.sub.SYM.

(324) $T\_T_{PE} = \left\lceil \frac{(\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA} - N_{MA}T_{MA}) - T\_N_{SYM}T_{SYM}}{4} \right\rceil \times 4 \quad Eq.59$ $\qquad N_{SYM} = \begin{cases} T\_N_{SYM} - 1 & when\ T\_T_{PE} < 0, \\ T\_N_{SYM} & otherwise. \end{cases} \quad Eq.60$

The PE duration T.sub.PE is then determined according to Equation 6, above.

(325) The equations 57-60 above used to determine T_N.sub.SYM and N.sub.SYM above are derived as follows: In order to get N.sub.SYM at the receive side, the equation below is used when Doppler information is set to the first state (e.g. 1) which indicates that the Mid-Amble exists:

(326) $\frac{L\_LENGTH+m+3}{3}\times 4 = T_{PA} + N_{SYM}T_{SYM} + N_{MA}T_{MA} + T_{PE} + T_{SYM}b_{PE\text{-}Disambiguity} + \alpha \quad Eq.61 \quad 0 \le \alpha < 4, 0 \le T_{PE} + \alpha < T_{SYM}$

(327) Step E1) from Equation 61 it follows that:

(328) $0 \le N_{SYM}T_{SYM} + N_{MA}T_{MA} + T_{SYM}b_{PE\text{-}Disambiguity} = \frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA} - (T_{PE} + \alpha) \quad Eq.62$

$\left\lfloor N_{SYM} + N_{MA}\frac{T_{MA}}{T_{SYM}} + b_{PE\text{-}Disambiguity} \right\rfloor = \left\lfloor \frac{\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA} - (T_{PE}+\alpha)}{T_{SYM}} \right\rfloor \quad Eq.63$

$N_{SYM} + \left\lfloor N_{MA}\frac{T_{MA}}{T_{SYM}} \right\rfloor = \left\lfloor \frac{\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA}}{T_{SYM}} - \frac{T_{PE}+\alpha}{T_{SYM}} \right\rfloor - b_{PE\text{-}Disambiguity} \quad Eq.63$

(329) Since T.sub.PE is not known without N.sub.SYM in a receiver of an HE PPDU, ((T.sub.PE+α)/T.sub.SYM) is temporarily ignored, and the impact of this term will be verified later. As shown in Equation 42, below, N.sub.SYM is replaced with T_N.sub.SYM as a temporary number of OFDM data symbol:

(330) $T\_N_{SYM} + \left\lfloor N_{MA}\frac{T_{MA}}{T_{SYM}} \right\rfloor = \left\lceil \frac{\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA}}{T_{SYM}} \right\rceil - b_{PE\text{-}Disambiguity} \quad Eq.65$

(331) Step E2) from the above:

T_N.sub.SYM=M.Math.N.sub.MA+n.sub.0+1,0≤n.sub.0≤M−1   Eq. 66

(332) Step E3) from Step E1 and Step E2:

(333) $\left\lfloor N_{MA}\frac{T_{MA}}{T_{SYM}} \right\rfloor = \left\lceil \frac{\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA}}{T_{SYM}} \right\rceil - b_{PE\text{-}Disambiguity} - T\_N_{SYM} + \beta, \quad Eq.67 \quad 0 \le \beta < 1$

$\left\lfloor \frac{T\_N_{SYM} - n_0 - 1}{M} \frac{T_{MA}}{T_{SYM}} \right\rfloor = \left\lceil \frac{\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA}}{T_{SYM}} \right\rceil - b_{PE\text{-}Disambiguity} - T\_N_{SYM} + \beta \quad Eq.68$

$T\_N_{SYM} = \frac{M}{T_{MA}/T_{SYM}+M} \left(\frac{T_{MA}/T_{SYM}}{M}(n_0 + 1) + \left\lceil \frac{\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA}}{T_{SYM}} \right\rceil - b_{PE\text{-}Disambiguity} + \beta \right) \quad Eq.69$

(334) Step E4) from Step E2 and Step E3,

(335) $N_{MA} = \frac{T\_N_{SYM} - 1 - n_0}{M} \quad Eq.70 \qquad N_{MA} = \frac{1}{T_{MA}/T_{SYM}+M} \left(\left\lceil \frac{\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA}}{T_{SYM}} \right\rceil - b_{PE\text{-}Disambiguity} + \beta - n_0 - 1 \right) \quad Eq.71$

0≤α<1, 0≤n.sub.0≤M−1

(336) Step E5) find minimum value and maximum value of N.sub.MA to find the boundary:

(337) Assuming α=1, n.sub.0=0,

(338) $MaxN_{MA} = \frac{1}{T_{MA}/T_{SYM}+M} \left(\left\lceil \frac{\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA}}{T_{SYM}} \right\rceil - b_{PE\text{-}Disambiguity} - M \right) \quad Eq.72$

Assuming α=0, n.sub.0=M−1,

(339) $MinN_{MA} = \frac{1}{T_{MA}/T_{SYM}+M} \left(\left\lceil \frac{\frac{L\_LENGTH+m+3}{3}\times 4 - T_{PA}}{T_{SYM}} \right\rceil - b_{PE\text{-}Disambiguity} - M \right) \quad Eq.73$

$$\frac{1}{T_{MA}/T_{SYM}+M}\cdot\left(\frac{\frac{\text{L\_LENGTH}+m+3}{3}\times4\text{-}T_{PA}}{T_{SYM}}\cdot-b_{\text{PE - Disambiguity}}-M\right)<N_{MA}<\frac{1}{T_{MA}/T_{SYM}+M}\cdot\left(\frac{\frac{\text{L\_LENGTH}+m+3}{3}\times4\text{-}T_{PA}}{T_{SYM}}\cdot-b_{\text{PE - Disam}}\right.$$

(340) Step E6) Step D6) check (MaxN.sub.MA−MinN.sub.MA) to see the range of N.sub.MA:

(341) $(\text{Max}N_{MA}-\text{Min}N_{MA})=\frac{M}{T_{MA}/T_{SYM}+M}<1$ Eq. 75

Since N.sub.NA is supposed to be a positive integer within 0<(MaxN.sub.MA−MinN.sub.MA)<1, N.sub.MA should be a positive integer, so floor(MaxN.sub.MA)=ceil(MinN.sub.MA):

(342)
$$N_{MA}=\frac{1}{T_{MA}/T_{SYM}+M}\cdot\left(\frac{\frac{\text{L\_LENGTH}+m+3}{3}\times4\text{-}T_{PA}}{T_{SYM}}\cdot-b_{\text{PE - Disambiguity}}\right)$$
$$=\frac{1}{T_{MA}/T_{SYM}+M}\cdot\left(\frac{\frac{\text{L\_LENGTH}+m+3}{3}\times4\text{-}T_{PA}}{T_{SYM}}\cdot-b_{\text{PE - Disambiguity}}-M\right)$$ Eq. 75

(343) Then, from the above equations,

(344) $T\_N_{SYM}=\frac{\frac{\text{L\_LENGTH}+m+3}{3}\times4\text{-}T_{PA}}{T_{SYM}}\cdot-b_{\text{PE - Disambiguity}}-N_{MA}\frac{T_{MA}}{T_{SYM}}$,   Eq. 77 and

$$T\_N_{SYM}=\left(\frac{\text{L\_LENGTH}+m+3}{3}\times4\text{-}T_{PA}\right)/T_{SYM}\cdot-b_{\text{PE - Disambiguity}}-\frac{T_{MA}}{T_{SYM}}\cdot\cdot\frac{\left(\frac{\text{L\_LENGTH}+m+3}{3}\times4\text{-}T_{PA}\right)/T_{SYM}\cdot-b_{\text{PE - Disambiguity}}-M}{T_{MA}/T_{SYM}+M}$$

or

$$T\_N_{SYM}=\left(\frac{\text{L\_LENGTH}+m+3}{3}\times4\text{-}T_{PA}\right)/T_{SYM}\cdot-b_{\text{PE - Disambiguity}}-\frac{T_{MA}}{T_{SYM}}\cdot\cdot\frac{\left(\frac{\text{L\_LENGTH}+m+3}{3}\times4\text{-}T_{PA}\right)/T_{SYM}\cdot-b_{\text{PE - Disambigui}}}{T_{MA}/T_{SYM}+M}$$

(345) In another embodiment of the invention, when an HE PPDU is received wherein the Doppler information is set to indicate that one or more mid-ambles exist, if signal loss occurs during reception prior to completion of reception of the PSDU, the error condition PHYRXEND.indication(CarrierLost) shall be reported to the MAC. After waiting for the end of the PPDU as determined by Equation 80, below, the PHY shall set the PHY-CCA.indication (IDLE) primitive and return to the RX IDLE state.

RXTIME=20+T.sub.PA+N.sub.SYMT.sub.SYM+N.sub.MAT.sub.MA+T.sub.PE+SE

T.sub.MA=N.sub.HE-LTFT.sub.HE-LTF+(T.sub.HE-STF).   Eq. 80

Note that the duration of HE-STF T.sub.HE-STF could be omitted from Equation 20.

(346) FIG. **21** illustrates a process **2100**, according to an embodiment, for receiving a PPDU having a data field that includes mid-ambles. The symbols may be symbols in a data field of the PPDU into which mid-ambles are inserted. The process **2100** may be performed by a wireless device including a receiver, and the wireless device may include a processor configured to perform the process **2100**.

(347) At S**2102**, the process **2100** determines a format of a PPDU being received. Determining the format of the PPDU being received may include receiving a first four symbols starting with L-STF of the PPDU being received, determining a modulation method of the third and fourth symbols of the received symbols, and determining whether the contents of the fourth symbol is the same as the contents of the third symbol. The third symbol may be a symbol of a Legacy Signal (L-Sig) field.

(348) When the third and fourth symbols are modulated using BPSK, the third symbol is an L-SIG field symbol, and the fourth symbol carries a duplicate of the contents of the L-SIG field, the PPDU being received is an HE PPDU, and determining the format may further include receiving fifth and sixth symbols, and determining the format of the PPDU being received according to a value of a Length field of the L-SIG field modulo 3 and the modulation methods of the fifth and sixth symbols, as described with respect to FIG. **12**.

(349) At S**2104**, the process **2100** determines whether the PPDU being received is an HE PPDU. In response to determining that the PPDU being received is an HE PPDU, at S**2104** the process **2100** proceeds to S**2106**; otherwise the process **2100** exits.

(350) At S**2106**, the process **2100** determines whether the PPDU being received is an HE Multi-User (MU) or HE Extended Range Single User (ER SU) PPDU. In response to determining that the PPDU being received is either an HE MU PPDU or an HE ER SU PPDU, at S**2106** the process **2100** proceeds to S**2110**; otherwise the process **2100** proceeds to S**2108**.

(351) At S**2108**, the process S**2100** sets a modifier m to 1 in response to the PPDU being received being neither an HE MU PPDU nor an HE ER SU PPDU, then proceeds to S**2112**.

(352) At S**2110**, the process S**2100** sets a modifier m to 2 in response to the PPDU being received being either an HE MU PPDU or an HE ER SU PPDU, then proceeds to S**2112**.

(353) At S**2112**, the process S**2100** decodes an HE Signal A (HE-SIG-A) field. When the PPDU being received is an HE ER SU PPDU, decoding the HE-SIG-A field includes receiving and decoding the fifth through eighth symbols of the PPDU being received. When the PPDU being received is an HE MU PPDU, an HE TB PPDU, or an HE SU PPDU, decoding the HE-SIG-A field includes receiving and decoding the fifth through sixth symbols of the PPDU being received.

(354) At S**2114**, the process S**2100** determines whether the HE-SIG-A field indicates that the PPDU being received include mid-ambles. In an embodiment, the process S**2100** determines that the PPDU being received includes mid-ambles in response to a Doppler field of the HE-SIG-A field has a value (for example, 1) corresponding to a first state, and determines that the PPDU being received does not include mid-ambles when the Doppler field does not have the value corresponding to the first state (i.e., has a value other than the value corresponding to the first state.)

(355) In response to determining that the PPDU being received includes mid-ambles, at S**2114** the process **2100** proceeds to S**2116**; otherwise the process **2100** exits.

(356) At S**2116**, the process **2100** determines values of an L-SIG Length field L_LENGTH, a Packet Extension (PE) Disambiguity bit b.sub.PE-Disambiguity, an HE-LTF duration T.sub.HE-LTF, a preamble duration T.sub.PA, a mid-amble duration T.sub.MA, a duration of a symbol of a data field of the PPDU being received T.sub.SYM (hereinafter, data symbol duration T.sub.SYM), and a mid-amble periodicity M.

(357) The process **2100** determines the value of the L-SIG Length field L_LENGTH using the received L-SIG field of the PPDU being received. The process **2100** determines the values of the PE Disambiguity bit b.sub.PE-Disambiguity, the mid-amble periodicity M, and the data symbol duration T.sub.SYM using information in the HE-SIG-A field in accordance with an applicable standard. In an embodiment, the applicable standard is the IEEE Std 802.11ax or a successor thereto.

(358) The process **2100** determines the HE-LTF duration T.sub.HE-LTF corresponding to the duration of HE-LTFs included in the PPDU being received using information in the HE-SIG-A field in accordance with the applicable standard. As used herein, the HE-LTF duration THE-LTF includes a duration of a guard interval included in each HE-LTF.

(359) The process **2100** determines the value of the preamble duration T.sub.PA as being equal to a sum of a duration of the RL-SIG field (4 μs), a duration of the HE-SIG-A field (16 μs for an HE ER SU PPDU, 8 μs otherwise), a duration of an HE-SIG-B field if present (variable), a duration of an HE-STF (8 μs for an HE TB PPDU, 4 μs otherwise), and the combined durations of one or more HE-LTFs immediately following the HE-STF (hereinafter, the number of which is referred to as a number of HE-LTFs N.sub.HE-LTF). The process **2100** determines the number of HE-LTFs N.sub.HE-LTF using information in the HE-SIG-A field in accordance with the applicable standard.

(360) The process **2100** determines the value of the mid-amble duration T.sub.MA according to the product of the number of HE-LTFs

N.sub.HE_LTF and the HE-LTF duration T.sub.HE-LTF, as prescribed in the applicable standard:

$T.sub.MA = N.sub.HE\text{-}LTF.Math.T.sub.HE\text{-}LTF$ Eq. 81

(361) At S**2118**, the process **2100** determines a value of a number of mid-ambles N.sub.MA using the values determined at S**2116**. In an embodiment, the value of the number of mid-ambles N.sub.MA is determined according to Equation 30B, above, using a value of β prescribed by the applicable standard, wherein β is an integer value greater than or equal to zero indicating a number of data symbols in excess of the mid-amble periodicity M allowed at the end of a data field without requiring the insertion of another mid-amble. In an embodiment, the value of the number of mid-ambles N.sub.MA is determined according to Equation 31B, above, using the value of β prescribed by the applicable standard. In embodiments, the value of β is 0. In other embodiments, the value of β is 1.

(362) At **2120**, the process **2100** determines a value of number of data symbols N.sub.SYM and a value of a PE duration T.sub.PE. In an embodiment, the process **2100** determines the value of the number of data symbols N.sub.SYM according to Equation 5, above, and then determines the value of the PE duration T.sub.PE according to Equation 6, above.

(363) At **2122**, the process **2100** receives a data field of the PPDU being received using the information determined in S**2102** through S**2120**. Receiving the data field may include iteratively receiving a number of data symbols equal to the mid-amble periodicity M and a mid-amble that immediately follows the data symbols until the number of mid-ambles received is equal to the number of mid-ambles N.sub.MA determined at S**2118**. Each mid-amble consists of N.sub.HE-LTE HE-LTFs.

(364) Once the iterations are complete, the remaining data symbols are then received. The process **2100** then exits. The number of remaining data symbols N.sub.remain is

$N.sub.remain = N.sub.SYM - (M.Math.N.sub.MA)$ Eq. 82

(365) FIG. **22** illustrates a process **2222**, according to an embodiment, for receiving a data field of a PPDU including mid-ambles. The process **2222** may be performed in S**2122** of the process **2100** of FIG. **21**.

(366) At S**2202**, the process **2222** initializes a loop counter N to 1. At S**2204**, the process **2222** receives an N.sup.th plurality of consecutive data symbols, wherein the number of data symbols in each plurality of consecutive data symbols equals the mid-amble periodicity M.

(367) At S**2206**, the process **2222** receives an N.sup.th mid-amble. At S**2208**, the process **2222** increments the loop counter N by 1.

(368) At S**2210**, in response to the loop counter N having a value less than or equal to a value of the number of mid-ambles N.sub.MA, the process **2222** proceeds to S**2204**; otherwise at S**2210** the process **2222** proceeds to S**2212**.

(369) At S**2212**, the process **2222** receives the remaining data symbols. The number of remaining data symbols may be determined according to Equation 82, above.

(370) The solutions provided herein have been described with reference to a wireless LAN system; however, it should be understood that these solutions may also be applicable to other network environments, such as cellular telecommunication networks, wired networks, and so on.

(371) The above explanation and figures are applied to an HE station, an HE frame, an HE PPDU, an HE-SIG field and the like of the IEEE 802.11ax amendment, but they can also applied to a receiver, a frame, PPDU, a SIG field, and the like of another future amendment of IEEE 802.11.

(372) Embodiments of the present disclosure include electronic devices configured to perform one or more of the operations described herein. However, embodiments are not limited thereto.

(373) Embodiments of the present disclosure may further include systems configured to operate using the processes described herein. The systems may include basic service sets (BSSs) such as the BSSs **100** of FIG. **1**, but embodiments are not limited thereto.

(374) Embodiments of the present disclosure may be implemented in the form of program instructions executable through various computer means, such as a processor or microcontroller, and recorded in a non-transitory computer-readable medium. The non-transitory computer-readable medium may include one or more of program instructions, data files, data structures, and the like. The program instructions may be adapted to execute the processes and to generate and decode the frames described herein when executed on a device such as the wireless devices shown in FIG. **1**.

(375) In an embodiment, the non-transitory computer-readable medium may include a read only memory (ROM), a random access memory (RAM), or a flash memory. In an embodiment, the non-transitory computer-readable medium may include a magnetic, optical, or magneto-optical disc such as a hard disk drive, a floppy disc, a CD-ROM, and the like.

(376) In some cases, an embodiment of the invention may be an apparatus (e.g., an AP station, a non-AP station, or another network or computing device) that includes one or more hardware and software logic structure for performing one or more of the operations described herein. For example, as described above, the apparatus may include a memory unit, which stores instructions that may be executed by a hardware processor installed in the apparatus. The apparatus may also include one or more other hardware or software elements, including a network interface, a display device, etc.

(377) While this invention has been described in connection with what is presently considered to be practical embodiments, embodiments are not limited to the disclosed embodiments, but, on the contrary, may include various modifications and equivalent arrangements included within the spirit and scope of the appended claims. The order of operations described in a process is illustrative and some operations may be re-ordered. Further, two or more embodiments may be combined.

Claims

1. A method performed by a wireless device, the method comprising: receiving a first portion of a PHY Protocol Data Unit (PPDU), the first portion including a Legacy Signal (L-SIG) field; decoding the L-SIG field; determining a format of the PPDU using the first portion; and in response to determining that the format of the PPDU is a High Efficiency (HE) format: receiving and decoding an HE Signal A (HE-SIG-A) field, determining, using a Doppler field of the HE-SIG-A field, whether the PPDU includes mid-ambles, and in response to determining that the PPDU includes mid-ambles: determining, according to the format of the PPDU and using first information determined using the HE-SIG-A field and second information determined using the L-SIG field, a number of mid-ambles N.sub.MA indicating the number of mid-ambles included in a data field of the PPDU, wherein the number of mid-ambles N.sub.MA is determined without using a number of data symbols N.sub.SYM included in the data field of the PPDU; determining, using the number of the mid-ambles N.sub.MA, the number of data symbols N.sub.SYM included in the data field of the PPDU; and receiving, using the number of mid-ambles N.sub.MA and the number of data symbols N.sub.SYM, the data field of the PPDU.

2. The method of claim 1, wherein the first information includes a Packet Extension (PE) Disambiguity bit value b.sub.PE-Disambiguity, a number of HE Long Training Fields (HE-LTFs) value N.sub.HE-LTF, an HE-LTF duration including guard interval T.sub.HE-LTF, and a mid-amble periodicity M.

3. The method of claim 2, wherein the first information further includes a preamble duration T.sub.PA according to the format of the PPDU.

4. The method of claim 2, wherein the first information further includes a mid-amble duration T.sub.MA.

5. The method of claim 1, wherein the second information includes a Length field value L_LENGTH.

6. The method of claim 1, wherein determining the number of mid-ambles N.sub.MA includes determining the number of mid-ambles N.sub.MA according to: $N_{MA} = .Math. \dfrac{\left\lceil \frac{L\_LENGTH + m + 3}{3} \right\rceil \times 4 - T_{PA} - T_{SYM}(1 + \ + b_{PE\text{-}Disambiguity})}{T_{MA} + M .Math. T_{SYM}} .Math.$ wherein L_LENGTH is the value of a LENGTH field of the L-SIG field, m is 1 when the format of the PPDU is an HE Multi-User PPDU or HE Extended Range Single User PPDU format and m is 2 otherwise, T.sub.PA is a preamble duration, T.sub.SYM is a data symbol duration, β is an integer number greater than or equal to zero, b.sub.PE-Disambiguity is a Packet Extension (PE) Disambiguity bit value, T.sub.MA is a mid-amble duration, and M is a mid-amble periodicity.

7. The method of claim 1, wherein determining the number of mid-ambles N.sub.MA includes determining the number of mid-ambles N.sub.MA

according to: $N_{MA} = \left\lfloor \dfrac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + \beta + b_{PE\text{-}Disambiguity} + M)}{T_{MA} + M \cdot T_{SYM}} \right\rfloor$ wherein L_LENGTH is the value of a LENGTH field of the L-SIG field, m is 1 when the format of the PPDU is an HE Multi-User PPDU or HE Extended Range Single User PPDU format and m is 2 otherwise, T.sub.PA is a preamble duration, T.sub.SYM is a data symbol duration, β is an integer number greater than or equal to zero, b.sub.PE-Disambiguity is a Packet Extension (PE) Disambiguity bit value, T.sub.MA is a mid-amble duration, and M is a mid-amble periodicity.

8. The method of claim 1, wherein receiving the data field comprises: repeating, a number of times equal to the number of mid-ambles N.sub.MA: receiving a plurality of consecutive data symbols, wherein the number of data symbols in the plurality of data symbols is equal to a mid-amble periodicity M, and receiving a mid-amble immediately following the plurality of consecutive data symbols; and receiving a remaining 0 or more remaining consecutive data symbols, wherein the number of remaining consecutive data symbols Nremain is equal to:
Nremain=N.sub.SYM−(M.Math.N.sub.MA).

9. A wireless device comprising: a receiver; and a processor, the processor configured to perform: receiving, using the receiver, a first portion of a PHY Protocol Data Unit (PPDU), the first portion including a Legacy Signal (L-SIG) field; decoding the L-SIG field; determining a format of the PPDU using the first portion; and in response to determining that the format of the PPDU is a High Efficiency (HE) format: receiving and decoding an HE Signal A (HE-SIG-A) field, determining, using a Doppler field of the HE-SIG-A field, whether the PPDU includes mid-ambles, and in response to determining that the PPDU includes mid-ambles: determining, according to the format of the PPDU and using first information determined using the HE-SIG-A field and second information determined using the L-SIG field, a number of mid-ambles N.sub.MA indicating the number of mid-ambles included in a data field of the PPDU, wherein the number of mid-ambles N.sub.MA is determined without using a number of data symbols N.sub.SYM included in the data field of the PPDU; determining, using the number of the mid-ambles N.sub.MA, the number of data symbols N.sub.SYM included in the data field of the PPDU; and receiving, using the number of mid-ambles N.sub.MA and the number of data symbols N.sub.SYM, the data field of the PPDU.

10. The wireless device of claim 9, wherein the first information includes a Packet Extension (PE) Disambiguity bit value b.sub.PE-Disambiguity, a number of HE Long Training Fields (HE-LTFs) value N.sub.HE-LTF, an HE-LTF duration including guard interval T.sub.HE-LTF, and a mid-amble periodicity M.

11. The wireless device of claim 10, wherein the first information further includes a preamble duration T.sub.PA according to the format of the PPDU.

12. The wireless device of claim 10, wherein the first information further includes a mid-amble duration T.sub.MA.

13. The wireless device of claim 9, wherein the second information includes a Length field value L_LENGTH.

14. The wireless device of claim 9, wherein determining the number of mid-ambles N.sub.MA includes determining the number of mid-ambles N.sub.MA according to: $N_{MA} = \left\lfloor \dfrac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + \beta + b_{PE\text{-}Disambiguity})}{T_{MA} + M \cdot T_{SYM}} \right\rfloor$ wherein L_LENGTH is the value of a LENGTH field of the L-SIG field, m is 1 when the format of the PPDU is an HE Multi-User PPDU or HE Extended Range Single User PPDU format and m is 2 otherwise, T.sub.PA is a preamble duration, T.sub.SYM is a data symbol duration, β is an integer number greater than or equal to zero, b.sub.PE-Disambiguity is a Packet Extension (PE) Disambiguity bit value, T.sub.MA is a mid-amble duration, and M is a mid-amble periodicity.

15. The wireless device of claim 9, wherein determining the number of mid-ambles N.sub.MA includes determining the number of mid-ambles N.sub.MA according to: $N_{MA} = \left\lfloor \dfrac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + \beta + b_{PE\text{-}Disambiguity} + M)}{T_{MA} + M \cdot T_{SYM}} \right\rfloor$ wherein L_LENGTH is the value of a LENGTH field of the L-SIG field, m is 1 when the format of the PPDU is an HE Multi-User PPDU or HE Extended Range Single User PPDU format and m is 2 otherwise, T.sub.PA is a preamble duration, T.sub.SYM is a data symbol duration, β is an integer number greater than or equal to zero, b.sub.PE-Disambiguity is a Packet Extension (PE) Disambiguity bit value, T.sub.MA is a mid-amble duration, and M is a mid-amble periodicity.

16. The wireless device of any one of claim 9, wherein receiving the data field comprises: repeating, a number of times equal to the number of mid-ambles N.sub.MA: receiving a plurality of consecutive data symbols, wherein the number of data symbols in the plurality of data symbols is equal to a mid-amble periodicity M, and receiving a mid-amble immediately following the plurality of consecutive data symbols; and receiving a remaining 0 or more remaining consecutive data symbols, wherein the number of remaining consecutive data symbols Nremain is equal to:
Nremain=N.sub.SYM−(M.Math.N.sub.MA).

17. A non-transient computer-readable media (CRM) storing instructions which, when executed by a wireless device, cause the wireless device to perform steps comprising: receiving a first portion of a PHY Protocol Data Unit (PPDU), the first portion including a Legacy Signal (L-SIG) field; decoding the L-SIG field; determining a format of the PPDU using the first portion; and in response to determining that the format of the PPDU is a High Efficiency (HE) format: receiving and decoding an HE Signal A (HE-SIG-A) field, determining, using a Doppler field of the HE-SIG-A field, whether the PPDU includes mid-ambles, and in response to determining that the PPDU includes mid-ambles: determining, according to the format of the PPDU and using first information determined using the HE-SIG-A field and second information determined using the L-SIG field, a number of mid-ambles N.sub.MA indicating the number of mid-ambles included in a data field of the PPDU, wherein the number of mid-ambles N.sub.MA is determined without using a number of data symbols N.sub.SYM included in the data field of the PPDU; determining, using the number of the mid-ambles N.sub.MA, the number of data symbols N.sub.SYM included in the data field of the PPDU; and receiving, using the number of mid-ambles N.sub.MA and the number of data symbols N.sub.SYM, the data field of the PPDU.

18. The non-transient CRM of claim 17, wherein the first information includes a Packet Extension (PE) Disambiguity bit value b.sub.PE-Disambiguity, a number of HE Long Training Fields (HE-LTFs) value N.sub.HE-LTF, an HE-LTF duration including guard interval T.sub.HE-LTF, and a mid-amble periodicity M.

19. The non-transient CRM of claim 18, wherein the first information further includes a preamble duration T.sub.PA according to the format of the PPDU.

20. The non-transient CRM of claim 18, wherein the first information further includes a mid-amble duration T.sub.MA.

21. The non-transient CRM of claim 17, wherein the second information includes a Length field value L_LENGTH.

22. The non-transient CRM of claim 17, wherein determining the number of mid-ambles N.sub.MA includes determining the number of mid-ambles N.sub.MA according to: $N_{MA} = \left\lfloor \dfrac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + \beta + b_{PE\text{-}Disambiguity})}{T_{MA} + M \cdot T_{SYM}} \right\rfloor$ wherein L_LENGTH is the value of a LENGTH field of the L-SIG field, m is 1 when the format of the PPDU is an HE Multi-User PPDU or HE Extended Range Single User PPDU format and m is 2 otherwise, T.sub.PA is a preamble duration, T.sub.SYM is a data symbol duration, β is an integer number greater than or equal to zero, b.sub.PE-Disambiguity is a Packet Extension (PE) Disambiguity bit value, T.sub.MA is a mid-amble duration, and M is a mid-amble periodicity.

23. The non-transient CRM of claim 17, wherein determining the number of mid-ambles N.sub.MA includes determining the number of mid-ambles N.sub.MA according to: $N_{MA} = \left\lfloor \dfrac{\frac{L\_LENGTH + m + 3}{3} \times 4 - T_{PA} - T_{SYM}(1 + \beta + b_{PE\text{-}Disambiguity} + M)}{T_{MA} + M \cdot T_{SYM}} \right\rfloor$ wherein L_LENGTH is the value of a LENGTH field of the L-SIG field, m is 1 when the format of the PPDU is an HE Multi-User PPDU or HE Extended Range Single User PPDU format and m is 2 otherwise, T.sub.PA is a preamble duration, T.sub.SYM is a data symbol duration, β is an integer number greater than or equal to zero, b.sub.PE-Disambiguity is a Packet Extension (PE) Disambiguity bit value, T.sub.MA is a mid-amble duration, and M is a mid-amble periodicity.

24. The non-transient CRM of claim 17, wherein receiving the data field comprises: repeating, a number of times equal to the number of mid-ambles

N.sub.MA: receiving a plurality of consecutive data symbols, wherein the number of data symbols in the plurality of data symbols is equal to a mid-amble periodicity M, and receiving a mid-amble immediately following the plurality of consecutive data symbols; and receiving a remaining 0 or more remaining consecutive data symbols, wherein the number of remaining consecutive data symbols Nremain is equal to:

Nremain=N.sub.SYM−(M.$Math$.N.sub.MA).