Abstract: In an method for generating a data unit for transmission via a communication channel, a data portion of the data unit is generated. Orthogonal frequency division multiplexing (OFDM) symbols of the data portion are generated using one of (i) a normal guard interval, (ii) a short guard interval and (iii) a long guard interval. A preamble of the data unit is generated. The preamble indicates whether at least OFDM symbols of the data portion are generated using the normal guard interval, the short guard interval, or the long guard interval. The data unit is then generated to include the preamble and the data portion.

FIG. 16
EXTENDED GUARD INTERVAL FOR OUTDOOR WLAN

Cross-References to Related Applications

[0001] This disclosure claims the benefit of U.S. Provisional Patent Application No. 61/875,968, entitled "Longer GI for Outdoor" and filed on September 10, 2013, and U.S. Provisional Patent Application No. 61/911,232, entitled "Longer GI for Outdoor" and filed on December 3, 2013, the disclosures of both of which are incorporated herein by reference in their entireties.

Field of the Disclosure

[0002] The present disclosure relates generally to communication networks and, more particularly, to wireless local area networks that utilize orthogonal frequency division multiplexing (OFDM).

Background

[0003] When operating in an infrastructure mode, wireless local area networks (WLANs) typically include an access point (AP) and one or more client stations. WLANs have evolved rapidly over the past decade. Development of WLAN standards such as the Institute for Electrical and Electronics Engineers (IEEE) 802.1 la, 802.1 lb, 802.1 lg, and 802.1 In Standards has improved single-user peak data throughput. For example, the IEEE 802.11b Standard specifies a single-user peak throughput of 11 megabits per second (Mbps), the IEEE 802.11a and 802.11g Standards specify a single-user peak throughput of 54 Mbps, the IEEE 802.1 In Standard specifies a single-user peak throughput of 600 Mbps, and the IEEE 802.1 lac Standard specifies a single-user peak throughput in the gigabits per second (Gbps) range. Future standards promise to provide even greater throughputs, such as throughputs in the tens of Gbps range.
Summary

[0004] In an embodiment, a method for generating a data unit for transmission via a communication channel includes generating a data portion of the data unit, including generating orthogonal frequency division multiplexing (OFDM) symbols of the data portion using one of (i) a normal guard interval, (ii) a short guard interval and (iii) a long guard interval. The method also includes generating a preamble of the data unit, including generating the preamble to indicate whether at least OFDM symbols of the data portion are generated using the normal guard interval, the short guard interval, or the long guard interval. The method additionally includes generating the data unit to include the preamble and the data portion.

[0005] In another embodiment, an apparatus comprises a network interface configured to generate a data portion of the data unit, including generating orthogonal frequency division multiplexing (OFDM) symbols of the data portion using one of (i) a normal guard interval, (ii) a short guard interval and (iii) a long guard interval. The network interface is also configured to generate a preamble of the data unit, including generating the preamble to indicate whether at least OFDM symbols of the data portion are generated using the normal guard interval, the short guard interval, or the long guard interval. The network interface is additionally configured to generate the data unit to include the preamble and the data portion.

Brief Description of the Drawings

[0006] Fig. 1 is a block diagram of an example wireless local area network (WLAN) 10, according to an embodiment;

[0007] Figs. 2A and 2B are diagrams of a prior art data unit format;

[0008] Fig. 3 is a diagram of another prior art data unit format;

[0009] Fig. 4 is a diagram of another prior art data unit format;

[0010] Fig. 5 is a diagram of another prior art data unit format;
[0011] Fig. 6A are diagrams of modulation used to modulate symbols in a prior art data unit;

[0012] Fig. 6B are diagrams of modulation used to modulate symbols in an example data unit, according to an embodiment;

[0013] Fig. 7A is a diagram of an orthogonal frequency division multiplexing (OFDM) data unit, according to an embodiment.

[0014] Fig. 7B are diagrams of modulation used to modulate symbols in the data unit depicted in Fig. 7A, according to an embodiment;

[0015] Fig. 8 is a block diagram of an OFDM symbol, according to an embodiment.

[0016] Fig. 9A is a diagram illustrating an example data unit in which the normal guard interval is used for a preamble of the data unit, according to an embodiment.

[0017] Fig. 9B is a diagram illustrating an example data unit in which the normal guard interval is used for only a portion a preamble of the data unit, according to an embodiment.

[0018] Fig. 10A is a diagram illustrating an example data unit in which OFDM tone spacing is used to effectively increase guard interval duration, according to an embodiment.

[0019] Fig. 10B is a diagram illustrating an example data unit in which OFDM tone spacing is used to effectively increase guard interval duration, according to another embodiment.

[0020] Fig. 11A is a diagram illustrating a regular guard interval mode data unit, according to an embodiment.

[0021] Fig. 11B is a diagram illustrating an extension guard interval mode data unit, according to an embodiment.
[0022] Figs. 12A-12B are diagrams illustrating two possible formats of a long training field, according to two example embodiments.

[0023] Fig 13A is a diagram illustrating a non-legacy signal field of the regular guard interval mode data unit of Fig. 11A, according to an embodiment.

[0024] Fig 13B is a diagram illustrating a non-legacy signal field of the extension guard interval mode data unit of Fig. 11B, according to an embodiment.

[0025] Fig. 14A is a block diagram illustrating an extension guard interval mode data unit, according to an embodiment.

[0026] Fig. 14B is a diagram illustrating a legacy signal field of the extension guard interval data unit of Fig. 14A, according to one embodiment.

[0027] Fig. 14C is a diagram illustrating a Fast Fourier Transform (FFT) window for the legacy signal field of Fig. 14B at the legacy receiving device, according to an embodiment.

[0028] Fig. 15 is a block diagram illustrating format of a non-legacy signal field, according to an embodiment.

[0029] Fig. 16 is a flow diagram of a method for generating a data unit, according to an embodiment.

**Detailed Description**

[0030] In embodiments described below, a wireless network device such as an access point (AP) of a wireless local area network (WLAN) transmits data streams to one or more client stations. The AP is configured to operate with client stations according to at least a first communication protocol. The first communication protocol is sometimes referred herein as "high efficiency WiFi" or "HEW" communication protocol. In some embodiments, different client stations in the vicinity of the AP are configured to operate according to one or more other communication protocols which define operation in the
same frequency band as the HEW communication protocol but with generally lower data throughputs. The lower data throughput communication protocols (e.g., IEEE 802.1 la, IEEE 802.1 In, and/or IEEE 802.1 lac) are collectively referred herein as "legacy" communication protocols. In at least some embodiments, the legacy communication protocols are generally deployed in indoor communication channels, and the HEW communication protocol is at least sometimes deployed for outdoor communications.

[0031] According to an embodiment, symbols transmitted by the AP include guard intervals to prevent or minimize intersymbol interference at the receiver caused by multipath propagation in the communication channel. The length of the guard interval needed to mitigate interference generally depends on the delay spread of the particular channel being utilized. For example, an outdoor communication channel is typically characterized by a greater channel delay spread compared to an indoor communication channel, in at least some embodiments and/or scenarios. In an embodiment, the HEW communication protocol defines a regular guard interval mode and an extension guard interval mode. The regular guard interval mode is generally used with communication channels characterized by shorter channel delay spreads (e.g., indoor communication channels), while the extension guard interval mode is generally used with communication channels characterized by relatively longer channel delay spreads (e.g., outdoor communication channels), in an embodiment. In an embodiment, a normal guard interval (NGI) or a short guard interval (SGI) is used in the regular guard interval mode, and a long guard interval (LGI) is used in the extension guard interval mode.

[0032] In an embodiment, a data unit transmitted by the AP includes a preamble and a data portion, wherein the preamble is used, at least in part, to signal, to a receiving device, various parameters used for transmission of the data portion. In various embodiments, the preamble of a data unit is used to signal, to a receiving device, the particular guard interval being utilized in at least the data portion of the data unit. In some embodiments, a same preamble format is used in the regular guard interval mode an
in the extension guard interval mode. In one such embodiment, the preamble includes an indication set to indicate whether the NGI, the SGI or the LGI is used for at least the data portion of the data unit. In some embodiments, the indicated NGI, SGI or LGI is used for at least a portion of the preamble of the data unit, in addition to the data portion of the data unit. In an embodiment, the receiving device determines the particular guard interval being utilized based on the indication in the preamble of the data unit, and then decodes the appropriate remaining portion of the data unit (e.g., the data portion, or a portion of the preamble and the data portion) using the particular guard interval.

[0033] In another embodiment, a preamble used in the extension guard interval mode is formatted differently from a preamble used in the regular guard interval mode. For example, the preamble used in the extension guard interval mode is formatted such that the receiving device can automatically (e.g., prior to decoding) detect that the data unit corresponds to the extended guard interval mode. In an embodiment, when the receiving device detects that the data unit corresponds to the extended guard interval mode, the receiving device decodes the data portion of the data unit, and in at least some embodiments, at least a portion of the preamble as well as the data portion of the data unit, using the LGI. On the other hand, when the receiving device detects that the data unit does not correspond to the extended guard interval mode, the receiving device assumes that the data unit corresponds to the regular guard interval mode, in an embodiment. The receiving device then determines, for example based on an indication in the preamble, whether the NGI or the SGI is used in the data unit, and decodes at least the data portion of the data unit using the NGI or the SGI according to the determination, in an embodiment.

[0034] Additionally, in at least some embodiment, a preamble of a data unit in the regular guard interval mode and/or in the extension guard interval mode is formatted such that a client station that operates according to a legacy protocol, and not the HEW communication protocol, is able to determine certain information regarding the data unit,
such as a duration of the data unit, and/or that the data unit does not conform to the legacy protocol. Additionally, a preamble of the data unit is formatted such that a client station that operates according to the HEW protocol is able to determine the data unit conforms to the HEW communication protocol, in an embodiment. Similarly, a client station configured to operate according to the HEW communication protocol also transmits data units such as described above, in an embodiment.

[0035] In at least some embodiments, data units formatted such as described above are useful, for example, with an AP that is configured to operate with client stations according to a plurality of different communication protocols and/or with WLANs in which a plurality of client stations operate according to a plurality of different communication protocols. Continuing with the example above, a communication device configured to operate according to both the HEW communication protocol and a legacy communication protocol is able to determine that the data unit is formatted according to the HEW communication protocol and not the legacy communication protocol. Similarly, a communication device configured to operate according to a legacy communication protocol but not the HEW communication protocol is able to determine that the data unit is not formatted according to the legacy communication protocol and/or determine a duration of the data unit.

[0036] Fig. 1 is a block diagram of an example wireless local area network (WLAN) 10, according to an embodiment. An AP 14 includes a host processor 15 coupled to a network interface 16. The network interface 16 includes a medium access control (MAC) processing unit 18 and a physical layer (PHY) processing unit 20. The PHY processing unit 20 includes a plurality of transceivers 21, and the transceivers 21 are coupled to a plurality of antennas 24. Although three transceivers 21 and three antennas 24 are illustrated in Fig. 1, the AP 14 includes other suitable numbers (e.g., 1, 2, 4, 5, etc.) of transceivers 21 and antennas 24 in other embodiments. In one embodiment, the MAC processing unit 18 and the PHY processing unit 20 are configured to operate according to
a first communication protocol (e.g., HEW communication protocol). In another embodiment, the MAC processing unit 18 and the PHY processing unit 20 are also configured to operate according to a second communication protocol (e.g., IEEE 802.1 lac Standard). In yet another embodiment, the MAC processing unit 18 and the PHY processing unit 20 are additionally configured to operate according to the second communication protocol, a third communication protocol and/or a fourth communication protocol (e.g., the IEEE 802.11a Standard and/or the IEEE 802.11n Standard).

[0037] The WLAN 10 includes a plurality of client stations 25. Although four client stations 25 are illustrated in Fig. 1, the WLAN 10 includes other suitable numbers (e.g., 1, 2, 3, 5, 6, etc.) of client stations 25 in various scenarios and embodiments. At least one of the client stations 25 (e.g., client station 25-1) is configured to operate at least according to the first communication protocol. In some embodiments, at least one of the client stations 25 is not configured to operate according to the first communication protocol but is configured to operate according to at least one of the second communication protocol, the third communication protocol and/or the fourth communication protocol (referred to herein as a "legacy client station").

[0038] The client station 25-1 includes a host processor 26 coupled to a network interface 27. The network interface 27 includes a MAC processing unit 28 and a PHY processing unit 29. The PHY processing unit 29 includes a plurality of transceivers 30, and the transceivers 30 are coupled to a plurality of antennas 34. Although three transceivers 30 and three antennas 34 are illustrated in Fig. 1, the client station 25-1 includes other suitable numbers (e.g., 1, 2, 4, 5, etc.) of transceivers 30 and antennas 34 in other embodiments.

[0039] According to an embodiment, the client station 25-4 is a legacy client station, i.e., the client station 25-4 is not enabled to receive and fully decode a data unit that is transmitted by the AP 14 or another client station 25 according to the first communication protocol. Similarly, according to an embodiment, the legacy client station 25-4 is not
enabled to transmit data units according to the first communication protocol. On the
other hand, the legacy client station 25-4 is enabled to receive and fully decode and
transmit data units according to the second communication protocol, the third
communication protocol and/or the fourth communication protocol.

[0040] In an embodiment, one or both of the client stations 25-2 and 25-3, has a
structure the same as or similar to the client station 25-1. In an embodiment, the client
station 25-4 has a structure similar to the client station 25-1. In these embodiments, the
client stations 25 structured the same as or similar to the client station 25-1 have the same
or a different number of transceivers and antennas. For example, the client station 25-2
has only two transceivers and two antennas, according to an embodiment.

[0041] In various embodiments, the PHY processing unit 20 of the AP 14 is configured
to generate data units conforming to the first communication protocol and having formats
described herein. The transceiver(s) 21 is/are configured to transmit the generated data
units via the antenna(s) 24. Similarly, the transceiver(s) 24 is/are configured to receive
the data units via the antenna(s) 24. The PHY processing unit 20 of the AP 14 is
configured to process received data units conforming to the first communication protocol
and having formats described hereinafter and to determine that such data units conform to
the first communication protocol, according to various embodiments.

[0042] In various embodiments, the PHY processing unit 29 of the client device 25-1 is
configured to generate data units conforming to the first communication protocol and
having formats described herein. The transceiver(s) 30 is/are configured to transmit the
generated data units via the antenna(s) 34. Similarly, the transceiver(s) 30 is/are
configured to receive data units via the antenna(s) 34. The PHY processing unit 29 of the
client device 25-1 is configured to process received data units conforming to the first
communication protocol and having formats described hereinafter and to determine that
such data units conform to the first communication protocol, according to various
embodiments.
Fig. 2A is a diagram of a prior art OFDM data unit 200 that the AP 14 is configured to transmit to the client station 25-4 via orthogonal frequency division multiplexing (OFDM) modulation, according to an embodiment. In an embodiment, the client station 25-4 is also configured to transmit the data unit 200 to the AP 14. The data unit 200 conforms to the IEEE 802.11a Standard and occupies a 20 Megahertz (MHz) band. The data unit 200 includes a preamble having a legacy short training field (L-STF) 202, generally used for packet detection, initial synchronization, and automatic gain control, etc., and a legacy long training field (L-LTF) 204, generally used for channel estimation and fine synchronization. The data unit 200 also includes a legacy signal field (L-SIG) 206, used to carry certain physical layer (PHY) parameters of with the data unit 200, such as modulation type and coding rate used to transmit the data unit, for example. The data unit 200 also includes a data portion 208. Fig. 2B is a diagram of example data portion 208 (not low density parity check encoded), which includes a service field, a scrambled physical layer service data unit (PSDU), tail bits, and padding bits, if needed. The data unit 200 is designed for transmission over one spatial or space-time stream in a single input single output (SISO) channel configuration.

Fig. 3 is a diagram of a prior art OFDM data unit 300 that the AP 14 is configured to transmit to the client station 25-4 via orthogonal frequency domain multiplexing (OFDM) modulation, according to an embodiment. In an embodiment, the client station 25-4 is also configured to transmit the data unit 300 to the AP 14. The data unit 300 conforms to the IEEE 802.11 In Standard, occupies a 20 MHz band, and is designed for mixed mode situations, i.e., when the WLAN includes one or more client stations that conform to the IEEE 802.11a Standard but not the IEEE 802.11 In Standard. The data unit 300 includes a preamble having an L-STF 302, an L-LTF 304, an L-SIG 306, a high throughput signal field (HT-SIG) 308, a high throughput short training field (HT-STF) 310, and M data high throughput long training fields (HT-LTFs) 312, where M is an integer generally determined by the number of spatial streams used to transmit the
data unit 300 in a multiple input multiple output (MIMO) channel configuration. In particular, according to the IEEE 802.11 Standard, the data unit 300 includes two HT-LTFs 312 if the data unit 300 is transmitted using two spatial streams, and four HT-LTFs 312 is the data unit 300 is transmitted using three or four spatial streams. An indication of the particular number of spatial streams being utilized is included in the HT-SIG field 308. The data unit 300 also includes a data portion 314.

[0045] Fig. 4 is a diagram of a prior art OFDM data unit 400 that the AP 14 is configured to transmit to the client station 25-4 via orthogonal frequency domain multiplexing (OFDM) modulation, according to an embodiment. In an embodiment, the client station 25-4 is also configured to transmit the data unit 400 to the AP 14. The data unit 400 conforms to the IEEE 802.11 Standard, occupies a 20 MHz band, and is designed for "Greenfield" situations, i.e., when the WLAN does not include any client stations that conform to the IEEE 802.11a Standard but not the IEEE 802.11 Standard. The data unit 400 includes a preamble having a high throughput Greenfield short training field (HT-GF-STF) 402, a first high throughput long training field (HT-LTF1) 404, a HT-SIG 406, and M data HT-LTFs 408, where M is an integer which generally corresponds to a number of spatial streams used to transmit the data unit 400 in a multiple input multiple output (MIMO) channel configuration. The data unit 400 also includes a data portion 410.

[0046] Fig. 5 is a diagram of a prior art OFDM data unit 500 that the client station AP 14 is configured to transmit to the client station 25-4 via orthogonal frequency domain multiplexing (OFDM) modulation, according to an embodiment. In an embodiment, the client station 25-4 is also configured to transmit the data unit 500 to the AP 14. The data unit 500 conforms to the IEEE 802.11a Standard and is designed for "Mixed field" situations. The data unit 500 occupies a 20MHz bandwidth. In other embodiments or scenarios, a data unit similar to the data unit 500 occupies a different bandwidth, such as a 40MHz, an 80MHz, or a 160MHz bandwidth. The data unit 500 includes a preamble
having an L-STF 502, an L-LTF 504, an L-SIG 506, two first very high throughput signal fields (VHT-SIGAs) 508 including a first very high throughput signal field (VHT-SIGA1) 508-1 and a second very high throughput signal field (VHT-SIGA2) 508-2, a very high throughput short training field (VHT-STF) 510, M very high throughput long training fields (VHT-LTFs) 512, where M is an integer, and a second very high throughput signal field (VHT-SIG-B) 514. The data unit 500 also includes a data portion 516.

[0047] Fig. 6A is a set of diagrams illustrating modulation of the L-SIG, HT-SIG1, and HT-SIG2 fields of the data unit 300 of Fig. 3, as defined by the IEEE 802.1 In Standard. The L-SIG field is modulated according to binary phase shift keying (BPSK), whereas the HT-SIG1 and HT-SIG2 fields are modulated according to BPSK, but on the quadrature axis (Q-BPSK). In other words, the modulation of the HT-SIG1 and HT-SIG2 fields is rotated by 90 degrees as compared to the modulation of the L-SIG field.

[0048] Fig. 6B is a set of diagrams illustrating modulation of the L-SIG, VHT-SIGA1, and VHT-SIGA2 fields of the data unit 500 of Fig. 5, as defined by the IEEE 802.1 lac Standard. Unlike the HT-SIG1 field in Fig. 6A, the VHT-SIGA1 field is modulated according to BPSK, same as the modulation of the L-SIG field. On the other hand, the VHT-SIGA2 field is rotated by 90 degrees as compared to the modulation of the L-SIG field.

[0049] Fig. 7A is a diagram of an OFDM data unit 700 that the client station AP 14 is configured to transmit to the client station 25-1 via orthogonal frequency domain multiplexing (OFDM) modulation, according to an embodiment. In an embodiment, the client station 25-1 is also configured to transmit the data unit 700 to the AP 14. The data unit 700 conforms to the first communication protocol and occupies a 20MHz bandwidth. Data units similar to the data unit 700 occupy other suitable bandwidth such as 40MHz, 80MHz, 160MHz, 320MHz, 640MHz, for example, or other suitable bandwidths, in other embodiments. The data unit 700 is suitable for "mixed mode" situations, i.e. when the
WLAN 10 includes a client station (e.g., the legacy client station 24-4) that conforms to a legacy communication protocol, but not the first communication protocol. The data unit 700 is utilized in other situations as well, in some embodiments.

[0050] The data unit 700 includes a preamble 701 having an L-STF 702, an L-LTF 704, an L-SIG 706, two first HEW signal fields (HEW-SIGAs) 708 including a first HEW signal field (HEW-SIGA1) 708-1 and a second HEW signal field (HEW-SIGA2) 708-2, an HEW short training field (HEW-STF) 710, M HEW long training fields (HEW-LTFs) 712, where M is an integer, and a third HEW signal field (HEW-SIGB) 714. Each of the L-STF 702, the L-LTF 704, the L-SIG 706, the HEW-SIGAs 708, the HEW-STF 710, the M HEW-LTFs 712, and the HEW-SIGB 714 comprises an integer number of one or more OFDM symbols. For example, in an embodiment, the HEW-SIGAs 708 comprise two OFDM symbols, where the HEW-SIGA1 708-1 field comprises the first OFDM symbol and the HEW-SIGA2 comprises the second OFDM symbol. In at least some examples, the HEW-SIGAs 708 are collectively referred to as a single HEW signal field (HEW-SIGA) 708. In some embodiments, the data unit 700 also includes a data portion 716. In other embodiments, the data unit 700 omits the data portion 716.

[0051] In the embodiment of Fig. 7A, the data unit 700 includes one of each of the L-STF 702, the L-LTF 704, the L-SIG 706, the HEW-SIGAs 708. In other embodiments in which an OFDM data unit similar to the data unit 700 occupies a cumulative bandwidth other than 20MHz, each of the L-STF 702, the L-LTF 704, the L-SIG 706, the HEW-SIGAs 708 is repeated over a corresponding number of 20MHz sub-bands of the whole bandwidth of the data unit, in an embodiment. For example, in an embodiment, the OFDM data unit occupies an 80MHz bandwidth and, accordingly, includes four of each of the L-STF 702, the L-LTF 704, the L-SIG 706, the HEW-SIGAs 708, in an embodiment. In some embodiments, the modulation of different 20 MHz sub-bands signals is rotated by different angles. For example, in one embodiment, a first subband is rotated 0-degrees, a second subband is rotated 90-degrees, a third sub-band is rotated
180-degrees, and a fourth sub-band is rotated 270-degrees. In other embodiments, different suitable rotations are utilized. The different phases of the 20MHz sub-band signals result in reduced peak to average power ratio (PAPR) of OFDM symbols in the data unit 700, in at least some embodiments. In an embodiment, if the data unit that conforms to the first communication protocol is an OFDM data unit that occupies a cumulative bandwidth such as 20MHz, 40MHz, 80MHz, 160MHz, 320MHz, 640MHz, etc., the HEW-STF, the HEW-LTFs, the HEW-SIGB and the HEW data portion occupy the corresponding whole bandwidth of the data unit.

[0052] Fig. 7B is a set of diagrams illustrating modulation of the L-SIG 706, HEW-SIGAl 708-1, and HEW-SIGA2 708-2 of the data unit 700 of Fig. 7A, according to an embodiment. In this embodiment, the L-SIG 706, HEW-SIGAl 708-1, and HEW-SIGA2 708-2 fields have the same modulation as the modulation of the corresponding field as defined in the IEEE 802.1 lac Standard and depicted in Fig. 6B. Accordingly, the HEW-SIGAl field is modulated the same as the L-SIG field. On the other hand, the HEW-SIGA2 field is rotated by 90 degrees as compared to the modulation of the L-SIG field.

[0053] In an embodiment, because the modulations of the L-SIG 706, HEW-SIGAl 708-1, and HEW-SIGA2 708-2 fields of the data unit 700 correspond to the modulations of the corresponding fields in a data unit that conforms to the IEEE 802.1 lac Standard (e.g., the data unit 500 of Fig. 5), legacy client stations configured to operate according to the IEEE 802.11a Standard and/or the IEEE 802.1 In Standard will assume, in at least some circumstances, that the data unit 700 conforms to the IEEE 802.1 lac Standard and will process the data unit 700 accordingly. For example, a client station the conforms to the IEEE 802.11a Standard will recognize the legacy IEEE 802.11a Standard portion of the preamble of the data unit 700 and will set the data unit duration according to a duration indicated in the L-SIG 706. For example, the legacy client station will calculate a duration based on a rate and a length (e.g., in number of bytes) indicated in the L-SIG field 706, according to an embodiment. In an embodiment, the rate and the length in the
L-SIG field 706 are set such that a client station configured to operate according to a legacy communication protocol will calculate, based the rate and the length, a packet duration (T) that corresponds to, or at least approximates, the actual duration of the data unit 700. For example, the rate is set to indicate a lowest rate defined by the IEEE 802.11a Standard (i.e., 6 Mbps), and the length is set to a value computed such that packet duration computed using the lowest rate at least approximates the actual duration of the data unit 700, in one embodiment.

[0054] In an embodiment, a legacy client station that conforms to the IEEE 802.11a Standard, when receiving the data unit 700, will compute a packet duration for the data unit 700, e.g., using a rate and a length fields of L-SIG field 706, and will wait until the end of the computed packet duration before performing clear channel assessment (CCA), in an embodiment. Thus, in this embodiment, communication medium is protected against access by the legacy client station at least for the duration of the data unit 700. In an embodiment, the legacy client station will continue decoding the data unit 700, but will fail an error check (e.g., using a frame check sequence (FCS)) at the end of the data unit 700.

[0055] Similarly, a legacy client station configured to operate according to the IEEE 802.1 In Standard, when receiving the data unit 700, will compute a packet duration (T) of the data unit 700 based on the rate and the length indicated in the L-SIG 706 of the data unit 700, in an embodiment. The legacy client station will detect the modulation of the first HEW signal field (HEW-SIGA1) 708-1 (BPSK) and will assume that the data unit 700 is a legacy data unit that conforms to the IEEE 802.11a Standard. In an embodiment, the legacy client station will continue decoding the data unit 700, but will fail an error check (e.g., using a frame check sequence (FCS)) at the end of the data unit. In any event, according to the IEEE 802.1 In Standard, the legacy client station will wait until the end of a computed packet duration (T) before performing clear channel assessment (CCA), in an embodiment. Thus, communication medium will be protected
from access by the legacy client station for the duration of the data unit 700, in an
embodiment.

[0056] A legacy client station configured to operate according to the IEEE 802.1 lac
Standard but not the first communication protocol, when receiving the data unit 700, will
compute a packet duration (T) of the data unit 700 based on the rate and the length
indicated in the L-SIG 706 of the data unit 700, in an embodiment. However, the legacy
client station will not be able to detect, based on the modulation of the data unit 700, that
the data unit 700 does not conform to the IEEE 802.1 lac Standard, in an embodiment. In
some embodiments, one or more HEW signal fields (e.g., the HEW-SIGA1 and/or the
HEW-SIGA2) of the data unit 700 is/are formatted to intentionally cause the legacy client
station to detect an error when decoding the data unit 700, and to therefore stop decoding
(or "drop") the data unit 700. For example, HEW-SIGA 708 of the data unit 700 is
formatted to intentionally cause an error when the SIGA field is decoded by a legacy
device according to the IEEE 802.1 lac Standard, in an embodiment. Further, according
to the IEEE 802.1 lac Standard, when an error is detected in decoding the VHT-SIGA
field, the client station will drop the data unit 700 and will wait until the end of a
computed packet duration (T), calculated, for example, based on a rate and a length
indicated in the L-SIG 706 of the data unit 700, before performing clear channel
assessment (CCA), in an embodiment. Thus, communication medium will be protected
from access by the legacy client station for the duration of the data unit 700, in an
embodiment.

[0057] Fig. 8 is a diagram of an OFDM symbol 800, according to an embodiment. The
data unit 700 of Fig. 7 includes OFDM symbols such as the OFDM symbols 800, in an
embodiment. The OFDM symbol 800 includes a guard interval portion 802 and an
information portion 804. In an embodiment, the guard interval comprises a cyclic prefix
repeating an end portion of the OFDM symbol. In an embodiment, the guard interval
portion 802 is used to ensure orthogonality of OFDM tones at a receiving device (e.g., the
client station 25-1) and to minimize or eliminate inter-symbol interference due to multi-path propagation in the communication channel via which the OFDM symbol 800 is transmitted from a transmitting device (e.g., the AP14) to the receiving device. In an embodiment, the length of the guard interval portion 802 is selected based on expected worst case channel delay spread in the communication channel between the transmitting device and the receiving device. For example, a longer guard interval is selected for outdoor communication channels typically characterized by longer channel delay spreads as compared to a shorter guard interval selected for indoor communication channels typically characterized by shorter channel delay spreads, in an embodiment.

[0058] According to an embodiment, the guard interval portion 802 corresponds to a short guard interval, a normal guard interval, or a long guard interval, depending on mode of transmission being utilized. In an embodiment, the short guard interval or the normal guard interval is used for indoor communication channels or communication channels with relatively short channel delay spreads, and the long guard interval is used for outdoor communication channels or communication channels with relatively long delay spreads. In an embodiment, the normal guard interval or the short guard interval is used for some or all OFDM symbols of an HEW data unit (e.g., the HEW data unit 700) when the HEW data unit is transmitted in regular guard interval mode, and the long guard interval is used for at least some OFDM symbols of the HEW data unit when the HEW data unit is transmitted in extension guard interval mode.

[0059] In an embodiment, the short guard interval (SGI) has a length of 0.4 µs, the normal guard interval is 0.8 µs and the long guard interval (LGI) has a length of 1.2 µs or 1.8 µs. In an embodiment, the information portion 804 has a length of 3.2 µs. In other embodiments, other suitable lengths for the SGI, the NGI, the LGI, and/or the information portion 804 are utilized. In some embodiments, the SGI has a length that is 50% of the length of the NGI, and the NGI has a length that is 50% of the length of the LGI. In other embodiments, the SGI has a length that is 75% or less of the length of the
NGI, and the NGI has a length that is 75% or less of the length of the LGI. In other embodiments, the SGI has a length that is 50% or less of the length of the NGI, and the NGI has a length that is 50% or less of the LGI.

[0060] In some embodiments, the extension guard interval mode uses the normal guard interval duration of the regular guard interval mode, but uses a different OFDM modulation that effectively extends the guard interval duration in the extension guard interval mode. For example, in an embodiment, OFDM modulation with reduced tone spacing is used in the extension guard interval mode. For example, whereas the regular guard interval mode for a 20MHz bandwidth OFDM data unit uses a 64-point discrete Fourier transform (DFT), resulting in 64 OFDM tones, the extension guard interval mode uses a 128-point DFT for a 20MHz OFDM data unit, resulting in 128 OFDM tones in the same bandwidth. In this case, tone spacing in the extension guard interval mode OFDM symbols is reduced by a factor of two (1/2) compared to regular guard interval mode OFDM symbols. As another example, whereas the regular guard interval mode for a 20MHz bandwidth OFDM data unit uses a 64-point discrete Fourier transform (DFT) resulting in 64 OFDM tones, the extension guard interval mode uses a 256-point DFT for a 20MHz OFDM data unit resulting in 256 OFDM tones in the same bandwidth. In this case, tone spacing in the extension guard interval mode OFDM symbols is reduced by a factor of four (1/4) compared to the regular guard interval mode OFDM symbols. In such embodiments, long GI duration of, for example, 1.6 µs is used. However, the duration of the information portion of the extension guard interval mode OFDM symbol is increased (e.g., from 3.2 µs to 6.4 µs), and the percentage of the GI portion duration to the total OFDM symbols duration remains the same, in an embodiment. Thus, in this case, loss of efficiency due to a longer GI symbol is avoided, in at least some embodiments. In various embodiments, the term "long guard interval" as used herein encompasses an increased duration of a guard interval as well as a decreased OFDM tone spacing that effectively increases duration of the guard interval.
[0061] Fig. 9A is a diagram illustrating an example data unit 900 in which the normal guard interval is used for a preamble of the data unit, according to an embodiment. The data unit 900 is generally the same as the data unit 700 of Fig. 7A and includes like-numbered elements with the data unit 700 of Fig 7A. The HEW-SIGA field 708 (e.g., the HEW-SIGA1 708-1 or the HEW-SIGA2 708-2) of the data unit 900 includes a GI indication 902. According to an embodiment, the GI indication 902 is set to indicate one of (i) normal guard interval, (ii) short guard interval or (iii) long guard interval. In an embodiment, the guard interval (GI) indication 902 comprises two bits, wherein a first combination of values of the bits indicates the normal guard interval, a second combination of values of the bits indicates the short guard interval, and a third combination of values of the bits indicates the long guard. As illustrated in Fig. 9A, the normal guard interval is used for all OFDM symbols of the preamble of the data unit 700, and one of the normal guard interval, the short guard interval, and the long guard interval, as indicated by the GI indication 902, is used for OFDM symbols of the data portion 716, in the illustrated embodiment.

[0062] Fig. 9B is a diagram illustrating an example data unit 950 in which the normal guard interval is used for a portion of a preamble of the data unit, according to an embodiment. The data unit 950 is generally the same as the data unit 900 of Fig. 9A, except that in the data unit 750 includes a preamble 751 in which the guard interval indicated by the GI indication 902 is applied to OFDM symbols of a portion of the preamble 751 as well as to the OFDM symbols of the data portion 716. In particular, in the illustrated embodiment, the normal guard interval is used for a first portion 751-1 of the preamble 701, and one of the normal guard interval, the short guard interval, and the long guard interval, as indicated by the GI indication 902, is used for OFDM symbols of a second portion 751-2 of the preamble 751, in addition to OFDM symbols of the data portion 716. Accordingly, the guard interval indicated by the GI indication 902 skips the OFDM symbol that corresponds to the HEW-STF 710 and is applied beginning with the
OFDM symbol that corresponds to the HEW-STF 712-1, in the illustrated embodiment. Skipping the HEW-STF 710 allows the device receiving the data unit 950 sufficient time to decode the GI indication 902 and to properly set up the receiver to begin decoding OFDM symbols using the guard interval indicated by the GI indication 902 prior to receiving such OFMD symbols, in at least some embodiments.

[0063] Fig. 10A is a diagram illustrating an example data unit 1000 in which OFDM tone spacing is used to effectively increase guard interval duration, according to an embodiment. The data unit 1000 is generally the same as the data unit 900 of Fig. 7A, except that in the data unit 1000, when the GI indication 902 indicates that the long GI is being utilized, the OFDM symbols of the data portion 716 are generated using OFDM modulation with smaller tone spacing compared to tone spacing used for normal guard interval OFDM symbols of the data unit 1000.

[0064] Fig. 10B is a diagram illustrating an example data unit 1050 in which OFDM tone spacing is used to effectively increase guard interval duration, according to another embodiment. The data unit 1050 is generally the same as the data unit 950 of Fig. 9B, except that in the data unit 1050, when the GI indication 902 indicates that the long GI is being utilized, the OFDM symbols of the second portion 751-2 and OFDM symbols of the data portion 716 are generated using OFDM modulation with smaller tone spacing compared to tone spacing used for normal guard interval OFDM symbols of the data unit 1050.

[0065] In some embodiments, a different preamble format is used for extension guard interval mode data units compared to the preamble used for regular guard interval mode data units. In such embodiments, a device receiving a data unit can automatically detect whether the data unit is a regular guard interval mode data unit or an extension guard interval mode data unit based on the format of the preamble of the data unit. Fig. 11A is a diagram illustrating a regular guard interval mode data unit 1100, according to an embodiment. The regular guard interval mode data unit 1100 includes a regular guard
interval mode preamble 1101. The regular guard interval mode preamble 1101 is
generally the same as the preamble 701 of the data unit 700 of Fig. 7A. In an
embodiment, the preamble 1101 includes a HEW-SIGA field 1108, which includes a first
HEW-SIGA1 field 1108-1 and a second first HEW-SIGA2 field 1108-1. In an
embodiment, the HEW-SIGA field 1108 (e.g., the HEW-SIGA1 1108-1 or the HEW-
SIGA2 1108-2) of the preamble 1101 includes a GI indication 1102. The GI indication
1102 is set to indicate whether the normal guard interval or the short guard interval is
used for OFDM symbols of the data portion 716 of the data unit 1100, in an embodiment.
In an embodiment, the GI indication 1102 comprises one bit, wherein a first value of the
bit indicates the normal guard interval and a second value of the bit indicates a short GI.
As will be explained in more detail below, a device receiving the data unit 1100 is able to
detect, based on the format of the preamble 1101, that the preamble 1101 is a regular
guard interval mode preamble, and not an extension guard interval mode preamble, in an
embodiment. Upon detecting that the preamble 1101 is the regular guard interval mode
preamble, the receiving device determines, based on the GI indication 1101, whether the
normal guard interval or the short guard interval is used for OFDM symbols of the data
portion 716, and decodes the data portion 716 accordingly, in an embodiment.

[0066] Fig. 11B is a diagram illustrating an extension guard interval mode data unit
1150, according to an embodiment. The extension guard interval mode data unit 1150
includes an extension guard interval mode preamble 1151. The data unit 1150 is
generally similar to the data unit 1100 of Fig. 11A, except that the preamble 1151 of the
data unit 1150 is formatted differently from the preamble 1101 of the data unit 1100. In
an embodiment, the preamble 1151 is formatted such that a receiving device that operates
according to the HEW communication protocol is able to determine that the preamble
1151 is an extension guard interval mode preamble rather than a regular guard interval
mode preamble. In an embodiment, the extension guard interval mode preamble 1151
includes an L-STF 702, an L-LTF 704, and an L-SIG 706, and one or more first HEW
signal fields (HEW-SIGAs) 1152. In an embodiment, the preamble 1150 further includes one or more secondary L-SIG(s) 1154 that follow the L-SIG field 706. The secondary L-SIG(s) 1154 are followed by a second L-LTF field (L-LTF2) 1156, in some embodiments. In other embodiments, the preamble 1151 omits the L-SIG(s) 1152 and/or the L-LTF2 1154. In some embodiments, the preamble 1151 also includes an HEW-STF 1158, one or more HEW-LTF fields 1160, and a second HEW signal field (HEW-SIGB) 1162. In other embodiments, the preamble 1151 omits the HEW-STF 1156, the HEW-LTF(s) 1158 and/or the HEW-SIGB. In an embodiment, the data unit 1150 also includes a data portion 716 (not shown in Fig. 11B).

[0067] In one embodiment in which the preamble 1151 includes one or more secondary L-LSIG(s) 1154, the content of each of the L-LSIG(s) 1154 is the same as the content of the L-LSIG 706 of the data unit 1150. In an embodiment, a receiving device receiving the data unit 1150 determines that the preamble 1151 corresponds to an extension guard interval mode preamble by detecting the repetition(s) of the L-SIG fields 706, 1154. Further, in an embodiment, both the rate subfield and the length subfield of the L-SIG 706, and, accordingly, the rate subfield(s) and the length subfield(s) of the secondary L-SIG(s) 1154 are set to fixed (e.g., predetermined) values. In this case, upon detecting the repetition(s) of the L-SIG fields 706, 1154, the receiving device uses the fixed values in the repeating L-SIG fields as additional training information to improve channel estimation, in an embodiment. In some embodiments, however, at least the length subfield of the L-SIG 706, and accordingly at least the length fields of the secondary L-SIG(s) 1154, is not set to a fixed value. For example, the length field is instead set to a value determined based on the actual length of the data unit 1150, in an embodiment. In one such embodiment, the receiving device first decodes the L-SIG 706, and then detects the repetition(s) of the L-SIG fields 706, 1154 using the value of the length subfield in L-SIG 706. In another embodiment, the receiving device first detects the repetition(s) of the L-SIG fields 706, 1154, and then combines the detected multiple L-SIG fields 706,
1154 to improve decoding reliability of the L-SIG fields 706, 1154 and/or uses the redundant information in the multiple L-SIG fields 706, 1154 to improve channel estimation.

[0068] In an embodiment in which the preamble 1151 includes L-LTF 1156, the OFDM symbol(s) of the L-LTF 1156 are generated using the long guard interval (e.g., increased duration guard interval or decreased OFDM tone spacing guard interval). In another embodiment in which the preamble 1151 includes L-LTF 11156, the OFDM symbol(s) of the L-LTF2 1506 are generated using the normal guard interval. For example, if a double guard interval (DGI) used in the L-LTF 704 is sufficiently long for the communication channel in which the data unit 1150 travels from the transmitting device to the receiving device, then OFDM symbols of the L-LTF2 1506 are generated using the normal guard interval or, alternatively, the preamble 1151 omits the L-LTF 1556, in an embodiment.

[0069] In another embodiment, the preamble 1151 omits the secondary L-SIG(s) 1154, but includes the L-LTF2 1156. In this embodiment, a receiving device detects that the preamble 1151 is the extension range preamble by detecting the presence of the L-LTF2 1156. Figs. 12A-12B are diagrams illustrating two possible formats of LTFs suitable for use as the L-LTF2 1156 according to two example embodiments. Turning first to Fig. 12A, in a first example embodiment, an L-LTF2 1200 is formatted in the same manner as the L-LTF 704, i.e., as defined by a legacy communication protocol (e.g., the IEEE 802.11a/n/ac Standards). In particular, in the illustrated embodiment, the L-LTF2 1200 includes a double guard interval (DGI) 1202 followed by two repetitions of a long training sequence 1204, 1206. Turning now to Fig. 12B, in another example embodiment, an L-LTF2 1208 is formatted differently from the L-LTF 704. In particular, in the illustrated embodiment, the L-LTF2 1208 includes a first normal guard interval 1210, a first repetition of a long training sequence 1212, a second normal guard interval 1214, and a second repetition of the long training sequence 1216.
Referring back to Fig. 1IB, in an embodiment, the HEW-SIGA(s) 1152 are generated using the long guard interval (e.g., increased duration guard interval or decreased OFDM tone spacing guard interval). In an embodiment, the number of the HEW-SIGAs 1152 is the same as the number of the HEW-SGA(s) 1108 of the regular guard interval mode preamble 1101. Similarly, in an embodiment, the content of the HEW-SIGAs 1152 is the same as the content of the HEW-SGA(s) 1108 of the regular guard interval mode preamble 1101. In other embodiments, the number and/or the content of the HEW-SIGAs 1152 is different from the number and/or content of the HEW-SGA(s) 1108 of the regular guard interval mode preamble 1101. A device receiving the data unit 1150 decodes the HEW-SIGA(s) 1152 using the long guard interval based on detecting that the preamble 1151 corresponds to the extension guard interval mode preamble and interprets the HEW-SIGA(s) 1152 appropriately as defined for the extension guard interval mode, in an embodiment.

In an embodiment in which the preamble 1151 omits the L-SIG(s) 1154 and/or L-LTF2 1156, a receiving device determines whether a preamble corresponds to the extension guard interval mode preamble 1151 or the to the normal guard interval preamble 1101 by detecting whether the HEW-SIGA field in the preamble is generated using the long guard interval or the normal guard interval based on auto-correlation of the HEW-SIGA field using the long guard interval and the normal guard interval. Figs. 13A-13B are diagrams of the HEW-SIGA 1108 of the regular guard interval mode preamble 1101 and the HEW-SIGA 1152 of the extension guard interval mode preamble 1151, respectively, according to an embodiment. In the illustrated embodiment, the HEW-SIGA 1108 of the regular guard interval mode preamble 1101 includes a first NGI 1302, a first HEW-SIGA field 1304, a second NGI 1306, and a second HEW-SIGA field 1308. In the other hand, the HEW-SIGA 1152 of the extension guard interval mode preamble 1151 includes a first LGI 1310, a first HEW-SIGA field 1312, a second LGI 1314, and a second HEW-SIGA field 1312. In an embodiment, a receiving device performs a first
auto-correlation of the HEW-SIGA field using a normal guard interval structure, such as
the structure illustrated in FIG 13A, performs a second auto-correlation using a long
guard interval structure, such as the structure illustrated in Fig. 13B, and performs a
comparison of the auto-correlation results, in an embodiment. If auto-correlation of the
HEW-SIGA field using the long guard interval produces a greater result compared to the
result of the auto-correlation of the HEW-SIGA field using the normal guard interval,
then the receiving device determines that the preamble corresponds to the extension
guard interval mode preamble 1151, in an embodiment. On the other hand, if auto-
correlation of the HEW-SIGA field using the normal guard interval produces a greater
result compared to the result of auto-correlation of the HEW-SIGA field with the long
guard interval, then the receiving device determines that the preamble corresponds to the
regular guard interval mode preamble 1101, in an embodiment.

[0072] Referring again to Fig. 1IB, in an embodiment, the preamble 1151 is formatted
such that a legacy client station can determine a duration of the data unit 1150 and/or that
the data unit does not conform to a legacy communication protocol. Additionally, the
preamble 1151 is formatted such that a client station that operates according to the HEW
protocol is able to determine that the data unit conforms to the HEW communication
protocol, in an embodiment. For example, at least two OFDM symbols immediately
following the L-SIG 706 of the preamble 1151, such as the L-LSIG(s) 1154 and/or the L-
LTF2 1156 and/or the HEW-SIGA(s) 1152, are modulated using BPSK modulation. In
this case, a legacy client station will treat the data unit 1150 as a legacy data unit, will
determine a duration of the data unit based on the L-SIG 706, and will refrain from
accessing the medium for the determined duration, in an embodiment. Further, one or
more other OFDM symbols of the preamble 1151, such as one or more of the HEW-
SIG(s) 1152 are modulated using Q-BPSK modulation, allowing a client station operating
according to the HEW communication protocol to detect that the data unit 1150 conforms
to the HEW communication protocol, in an embodiment.
In some embodiments, the HEW communication protocol allows beamforming and/or multi user MIMO (MU-MIMO) transmission in the extension guard interval mode. In other embodiments, the HEW communication protocol allows only single stream and/or only single user transmission in the extension guard interval mode. With continued reference to Fig. 11B, in an embodiment in which the preamble 1151 includes the HEW-STF 1158 and the HEW-LTF(s) 1160, the AP 14 applies beamforming and/or multi-user transmission beginning with the HEW-STF 1158. In other words, the fields of the preamble 1151 precede the HEW-STF 1158 are omni-directional and, in multi-user mode, are intended to be received by all intended recipients of the data unit 1150, while the HEW-STF field 1158, as well as the preamble fields that follow the HEW-STF field 1158 and the data portion that follows the preamble 1151, are beam-formed and/or include different portions intended to be received by different intended recipients of the data unit 1150, in an embodiment. In an embodiment, the HEW-SIGB field 162 includes user-specific information for the intended recipients of the data unit 1150 in MU-MIMO mode. The HEW-SIGB field 162 is generated using the NGI or the LGI, depending on an embodiment. Similarly, the HEW-STF 1158 is generated using the NGI or the LGI, depending on an embodiment. In an embodiment, the training sequence used on the HEW-STF 1158 is the sequence defined in a legacy communication protocol, such as in the IEEE 802.1 lac protocol.

On the other hand, in an embodiment in which the preamble 1151 omits the HEW-STF 1158 and the HEW-LTF(s) 1160, beamforming and MUMIMO are not allowed in the extension guard interval mode. In this embodiment, only single user single stream transmission is allowed in the extension guard interval mode. In an embodiment, a receiving device obtains a single stream channel estimate based on the L-LTF field 704, and demodulates the data portion of the data unit 1150 based on the channel estimate obtained based on the L-LTF field 704.
[0075] Fig. 14A is a block diagram illustrating an extension guard interval mode data unit 1400, according to an embodiment. The data unit 1400 includes an extension guard interval mode preamble 1401. The extension guard interval 1401 is generally similar to the extension guard interval mode 1151 of Fig. 11B, except that the L-SIG 706 and the secondary L-SIG 1154 of the preamble 1151 are combined into a single L-SIG field 1406 in the preamble 1401. Fig. 14B is a diagram illustrating the L-SIG field 1406 according to one embodiment. In the embodiment of Fig. 14B, the L-SIG field 1406 includes a double guard interval 1410, an first L-SIG field 1412, which includes contents of L-SIG field 706 of the preamble 1151, and a second L-SIG field 1414, which includes contents of the secondary L-SIG2 field 1154 of the preamble 1151. In various embodiments, L-SIG field 1406 includes a length subfield set to a fixed value or set to a variable value, as disused above with respect to the L-SIG fields 706, 1154 of Fig. 11B. In various embodiments, redundant (repeated) bits in L-SIG field 1406 are used for improved channel estimation as discussed above with respect to L-SIG fields 706, 1154 of Fig. 11B.

[0076] In an embodiment, a legacy client station receiving the data unit 1400 assumes that the L-SIG field 1406 includes a normal guard interval. As illustrated in Fig. 14C, the FFT window for L-SIG information bits assumed at the legacy client station is shifted compared to the actual L-SIG field 1412, in this embodiment. In an embodiment, to ensure that constellation points within the FFT window correspond to BPSK modulation, as expected by the legacy client station, and to this allow the legacy client station to properly decode the L-SIG field 1412, modulation of the L-SIG field 1412 is phase-shifted relative to regular BPSK modulation. For example, in a 20MHz OFDM symbol, if the normal guard interval is 0.8 \( \mu s \), and the double guard interval is 1.6 \( \mu s \), then modulation of an OFDM tone k of the L-SIG field 1412 is shifted with respect to the corresponding OFDM tone k of the original L-SIG as can be seen from:

\[
S_{LSIG}^{(k)} = S_{LSIG-LSIG}^{(k)} e^{-j \cdot 0.8 \cdot 20/64} = S_{LSIG-LSIG}^{(k)} \cdot (-j)
\]

Equation 1
Accordingly, in an embodiment, L-SIG field 1412 is modulated using reverse Q-BPSK rather than regular BPSK. Thus, for example, a bit of value 1 is modulated onto -j, and a bit of value 0 is modulated onto j, resulting in \{j, -j\} modulation rather than the regular \{1, -1\} BPSK modulation, in an embodiment. In an embodiment, due to the reverse Q-BPSK modulation of the L-SIG field 1412, a legacy client station can properly decode the L-SIG field 1412 and determine the duration of the data unit 1400 based on the L-SIG 1412 field, in an embodiment. A client station that operates according to the HEW protocol, on the other hand, can auto-detect that the preamble 1401 is an extension guard interval mode preamble by detecting the repetition of the L-SIG field 1412 or by detecting the reverse Q-BPSK modulation of the L-SIG field within the FFT window of the legacy client station, in an embodiment. Alternatively, in other embodiments, a client station that operates according to the HEW protocol detects that the preamble 1401 is an extension guard interval mode preamble using other detection methods discussed above, such as based on modulation or format of the HEW-SIGA field(s) 1152.

[0100] Referring Figs 11A-1 IB and 14A, long guard interval is used for initial OFDM symbols of both a regular guard interval mode preamble (e.g., the preamble 1101) and a long guard interval preamble (e.g., the preamble 1151 or the preamble 1401), in some embodiments. For example, referring to Figs, 11A-1 IB, the L-STF field 702, the L-LTF field 704 and the L-SIG field 706, 1154, and HEW-SIGA field 1152 is each generated using the long guard interval, in an embodiment. Similarly, referring to Fig. 14A, the L-STF field 702, the L-LTF field 704, the L-SIG field 1406, and the HEW-SIGA(s) 1152 are generated using the long guard interval, in an embodiment. In an embodiment, a receiving device can determine whether a preamble corresponds to the regular guard interval mode preamble or the extension guard interval mode preamble based on modulation of the HEW-SIGA field 1152 (e.g., Q-BPSK) or based on an indication included in the HEW-SIGA field 1152, in various embodiments. Further, similar to the
preamble 1151 of Fig. 1IB, the preamble 1401 of Fig. 14A includes or omits the second L-LTF2 field 1156, depending on the embodiment and/or scenario.

[0101] Fig. 15 is a block diagram illustrating format of an HEW-SIGA field 1500, according to an embodiment. In some embodiments, the HEW-SIGA field(s) 1152 of the data unit 1150 or the data unit 1400 are formatted as the HEW-SIGA field 1500. In some embodiments, the HEW-SIGA field(s) 1108 are formatted as the HEW-SIGA field 1500. The HEW-SIGA field 1500 includes a double guard interval 1502, a first repetition of a HEW-SIGA field 1504 and a second repetition of HEW-SIGA 1506. In an example embodiment, the DGI is 1.8 µs and each repetition of HEW-SIGA is 3.2 µs. In an embodiment, the repeated bits in the HEW-SIGA field 1500 are used to increase reliability of decoding of the HEW-SIGA field 1500. In an embodiment, the format of the HEW-SIGA field 1500 is used to auto-detect an extension guard interval mode preamble based on a comparison between autocorrelation of the HEW-SIGA field of the preamble using the format of the HEW-SIGA field 1500 and auto-correlation of the HEW-SIGA field of the preamble using the regular HEW-SIGA field format used in the regular guard interval mode, such as the format illustrated in Fig. 13A.

[0102] Fig. 16 is a flow diagram of an example method 1600 for generating a data unit, according to an embodiment. With reference to Fig. 1, the method 1600 is implemented by the network interface 16, in an embodiment. For example, in one such embodiment, the PHY processing unit 20 is configured to implement the method 1600. According to another embodiment, the MAC processing 18 is also configured to implement at least a part of the method 1600. With continued reference to Fig. 1, in yet another embodiment, the method 1600 is implemented by the network interface 27 (e.g., the PHY processing unit 29 and/or the MAC processing unit 28). In other embodiments, the method 1600 is implemented by other suitable network interfaces.
At block 1602, a data portion of the data unit is generated. Generating the data portion at block 1602 includes generating OFDM symbols of the data portion using one of (i) a normal guard interval, (ii) a short guard interval, or (iii) a long guard interval.

At block 1604, a preamble of the data unit is generated. The preamble generated at block 1604 is generated to indicate whether at least the data portion of the data unit generated at block 1602 is generated using (i) the normal guard interval, (ii) the short guard interval, or (iii) the long guard interval. In various embodiments and/or scenarios, one of the preambles 701 (Figs. 9A, 10A), 751 (Figs. 9B, 10B), 1101 (Fig. 11A), 1151 (Fig. 11B), or 1401 (Fig. 14A) is generated at block 1604. In other embodiments, other suitable preambles are generated at block 1604. In an embodiment, the preamble generated at block 1604 includes an GI indication to set to indicate whether at least the data portion is generated using (i) the normal guard interval, (ii) the short guard interval, or (iii) the long guard interval. In an embodiment, the GI indication comprises two bits. In an embodiment, a portion of the preamble, in addition to the data portion, is generated using the guard interval indicated by the GI indication. In another embodiment, the preamble generated at block 1604 is formatted such that a receiving device can automatically detect (e.g., without decoding) whether the preamble corresponds to a regular guard interval preamble or to an extension guard interval mode preamble. In an embodiment, detection of the extension guard interval preamble signals to the receiving device that at least the data portion is generated using the long guard interval.

At block 1606, the data unit is generated to include the preamble generated at block 1604 and the data portion generated at block 1602.

At least some of the various blocks, operations, and techniques described above may be implemented utilizing hardware, a processor executing firmware instructions, a processor executing software instructions, or any combination thereof. When implemented utilizing a processor executing software or firmware instructions, the software or firmware instructions may be stored in any computer readable memory such
as on a magnetic disk, an optical disk, or other storage medium, in a RAM or ROM or flash memory, processor, hard disk drive, optical disk drive, tape drive, etc. Likewise, the software or firmware instructions may be delivered to a user or a system via any known or desired delivery method including, for example, on a computer readable disk or other transportable computer storage mechanism or via communication media. Communication media typically embodies computer readable instructions, data structures, program modules or other data in a modulated data signal such as a carrier wave or other transport mechanism. The term "modulated data signal" means a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, and not limitation, communication media includes wired media such as a wired network or direct-wired connection, and wireless media such as acoustic, radio frequency, infrared and other wireless media. Thus, the software or firmware instructions may be delivered to a user or a system via a communication channel such as a telephone line, a DSL line, a cable television line, a fiber optics line, a wireless communication channel, the Internet, etc. (which are viewed as being the same as or interchangeable with providing such software via a transportable storage medium). The software or firmware instructions may include machine readable instructions that, when executed by the processor, cause the processor to perform various acts.

[0107] Further aspects of the present disclosure relate to one or more of the following clauses.

[0108] In an embodiment, a method for generating a data unit for transmission via a communication channel includes generating a data portion of the data unit, including generating orthogonal frequency division multiplexing (OFDM) symbols of the data portion using one of (i) a normal guard interval, (ii) a short guard interval and (iii) a long guard interval. The method also includes generating a preamble of the data unit, including generating the preamble to indicate whether at least OFDM symbols of the data
portion are generated using the normal guard interval, the short guard interval, or the long
guard interval. The method additionally includes generating the data unit to include the
preamble and the data portion.

[0109] In other embodiments, the method includes any suitable combination of one or
more of the following features.

[0110] Generating the preamble of the data unit includes generating a signal field of the
preamble, wherein the signal field includes a guard interval indication set to indicate
whether at least the OFDM symbols of the data portion are generated using the normal
guard interval, the short guard interval, or the long guard interval.

[0111] The guard interval indication comprises two bits.

[0112] Generating the preamble includes generating a first portion of the preamble,
wherein the first portion of the preamble is (i) generated using the normal guard interval
and (ii) includes the signal field, and generating a second portion of the preamble using
the guard interval indicated by the guard interval indication in the signal field.

[0113] Generating the preamble of the data unit comprises generating one of (i) a
regular guard interval mode preamble or (ii) an extension guard interval mode preamble.

[0114] Generating the preamble includes formatting the preamble such that a receiving
device can automatically detect whether the preamble corresponds to the regular guard
interval preamble or to the extension guard interval preamble, wherein the extension
guard interval mode preamble serves as the indication that at least the OFDM symbols of
the data portion are generated using the long guard interval when the preamble
corresponds to the extension guard interval preamble.

[0115] Generating the extension guard interval preamble includes including, in the
extension guard interval preamble, two or more repetitions of a legacy signal field, and
wherein the receiving device can automatically detect that the preamble corresponds the
extension guard interval mode preamble based on detecting the two or more repetitions of the legacy signal field.

[0116] Generating the extension guard interval mode preamble includes generating a non-legacy signal field to be included in the preamble, and modulating the non-legacy signal field differently from a corresponding non-legacy signal field in the regular guard interval mode preamble.

[0117] The receiving device can automatically detect that the preamble corresponds to the extension guard interval mode preamble by detecting the modulation of the non-legacy signal field.

[0118] Generating the non-legacy signal field includes generating the non-legacy signal field using the long guard interval.

[0119] Generating the extension guard interval mode preamble includes generating, using the long guard interval, a non-legacy signal field to be included in the preamble, and wherein the receiving device can automatically detect that the preamble corresponds to the extension mode guard interval preamble by comparing results of autocorrelation of the non-legacy signal field performed using the long guard interval and autocorrelation of the non-legacy signal field performed using the normal guard interval.

[0120] The data unit conforms to a first communication protocol, and wherein generating the preamble further comprises generating the preamble such that (i) a legacy receiver configured to operate according to a legacy communication protocol but not according to the first communication protocol can determine a duration of the data unit and (ii) a receiver configured to operate according to the first communication protocol can detect that the data unit conforms to the first communication protocol.

[0121] In another embodiment, an apparatus comprises a network interface configured to generate a data portion of the data unit, including generating orthogonal frequency division multiplexing (OFDM) symbols of the data portion using one of (i) a normal
guard interval, (ii) a short guard interval and (iii) a long guard interval. The network interface is also configured to generate a preamble of the data unit, including generating the preamble to indicate whether at least OFDM symbols of the data portion are generated using the normal guard interval, the short guard interval, or the long guard interval. The network interface is additionally configured to generate the data unit to include the preamble and the data portion.

[0122] In other embodiments, the apparatus includes any suitable combination of one or more of the following features.

[0123] The network interface is further configured to generate a signal field to be included in the preamble, wherein the signal field includes a guard interval indication set to indicate whether at least the OFDM symbols of the data portion are generated using the normal guard interval, the short guard interval, or the long guard interval.

[0124] The guard interval indication comprises two bits.

[0125] The network interface is further configured to generate a first portion of the preamble, wherein the first portion of the preamble is (i) generated using the normal guard interval and (ii) includes the signal field, and generate a second portion of the preamble using the guard interval indicated by the guard interval indication in the signal field.

[0126] Generating the preamble of the data unit comprises generating one of (i) a regular guard interval mode preamble or (ii) an extension guard interval mode preamble, wherein generating the preamble includes formatting the preamble such that a receiving device can automatically detect whether the preamble corresponds to the regular guard interval preamble or to the extension guard interval preamble, wherein the extension guard interval mode preamble serves as the indication that at least the OFDM symbols of the data portion are generated using the long guard interval when the preamble corresponds to the extension guard interval preamble.
[0127] Generating the extension guard interval preamble includes including, in the extension guard interval preamble, two or more repetitions of a legacy signal field, and wherein the receiving device can automatically detect that the preamble corresponds the extension guard interval mode preamble based on detecting the two or more repetitions of the legacy signal field.

[0128] Generating the extension guard interval mode preamble includes generating a non-legacy signal field to be included in the preamble, and modulating the non-legacy signal field differently from a corresponding non-legacy signal field in the regular guard interval mode preamble.

[0129] The receiving device can automatically detect that the preamble corresponds to the extension guard interval mode preamble by detecting the modulation of the non-legacy signal field.

[0130] Generating the non-legacy signal field includes generating the non-legacy signal field using the long guard interval.

[0131] Generating the extension guard interval mode preamble includes generating, using the long guard interval, a non-legacy signal field to be included in the preamble, and wherein the receiving device can automatically detect that the preamble corresponds to the extension mode guard interval preamble by comparing results of autocorrelation of the non-legacy signal field performed using the long guard interval and autocorrelation of the non-legacy signal field performed using the normal guard interval.

[0132] The data unit conforms to a first communication protocol, and wherein generating the preamble further comprises generating the preamble such that (i) a legacy receiver configured to operate according to a legacy communication protocol but not according to the first communication protocol can determine a duration of the data unit and (ii) a receiver configured to operate according to the first communication protocol can detect that the data unit conforms to the first communication protocol.
When implemented in hardware, the hardware may comprise one or more of discrete components, an integrated circuit, an application-specific integrated circuit (ASIC), etc.

While the present invention has been described with reference to specific examples, which are intended to be illustrative only and not to be limiting of the invention, changes, additions and/or deletions may be made to the disclosed embodiments without departing from the scope of the invention.
What is claimed is:

1. A method for generating a data unit for transmission via a communication channel, the method comprising:

   generating a data portion of the data unit, including generating orthogonal frequency division multiplexing (OFDM) symbols of the data portion using one of (i) a normal guard interval, (ii) a short guard interval and (iii) a long guard interval;

   generating a preamble of the data unit, including generating the preamble to indicate whether at least OFDM symbols of the data portion are generated using the normal guard interval, the short guard interval, or the long guard interval; and

   generating the data unit to include the preamble and the data portion.

2. The method of claim 1, wherein generating the preamble of the data unit includes generating a signal field of the preamble, wherein the signal field includes a guard interval indication set to indicate whether at least the OFDM symbols of the data portion are generated using the normal guard interval, the short guard interval, or the long guard interval.

3. The method of claim 2, wherein the guard interval indication comprises two bits.

4. The method of claim 2, wherein generating the preamble includes:

   generating a first portion of the preamble, wherein the first portion of the preamble is (i) generated using the normal guard interval and (ii) includes the signal field, and
generating a second portion of the preamble using the guard interval indicated by
the guard interval indication in the signal field.

5. The method of claim 1, wherein generating the preamble of the data unit
comprises generating one of (i) a regular guard interval mode preamble or (ii) an
extension guard interval mode preamble, wherein generating the preamble includes
formatting the preamble such that a receiving device can automatically detect whether the
preamble corresponds to the regular guard interval preamble or to the extension guard
interval preamble, wherein the extension guard interval mode preamble serves as the
indication that at least the OFDM symbols of the data portion are generated using the
long guard interval when the preamble corresponds to the extension guard interval
preamble.

6. The method of claim 5, wherein generating the extension guard interval
preamble includes including, in the extension guard interval preamble, two or more
repetitions of a legacy signal field, and wherein the receiving device can automatically
detect that the preamble corresponds the extension guard interval mode preamble based
on detecting the two or more repetitions of the legacy signal field.

7. The method of claim 5, wherein generating the extension guard interval
mode preamble includes:

generating a non-legacy signal field to be included in the preamble, and
modulating the non-legacy signal field differently from a corresponding non-
legacy signal field in the regular guard interval mode preamble, and
wherein the receiving device can automatically detect that the preamble corresponds to the extension guard interval mode preamble by detecting the modulation of the non-legacy signal field.

8. The method of claim 7, wherein generating the non-legacy signal field includes generating the non-legacy signal field using the long guard interval.

9. The method of claim 5, wherein generating the extension guard interval mode preamble includes generating, using the long guard interval, a non-legacy signal field to be included in the preamble, and wherein the receiving device can automatically detect that the preamble corresponds to the extension mode guard interval preamble by comparing results of autocorrelation of the non-legacy signal field performed using the long guard interval and autocorrelation of the non-legacy signal field performed using the normal guard interval.

10. The method of claim 1, wherein the data unit conforms to a first communication protocol, and wherein generating the preamble further comprises generating the preamble such that (i) a legacy receiver configured to operate according to a legacy communication protocol but not according to the first communication protocol can determine a duration of the data unit and (ii) a receiver configured to operate according to the first communication protocol can detect that the data unit conforms to the first communication protocol.

11. An apparatus comprising:

a network interface configured to:
generate a data portion of the data unit, including generating orthogonal frequency division multiplexing (OFDM) symbols of the data portion using one of (i) a normal guard interval, (ii) a short guard interval and (iii) a long guard interval;

generate a preamble of the data unit, including generating the preamble to indicate whether at least OFDM symbols of the data portion are generated using the normal guard interval, the short guard interval, or the long guard interval; and

generate the data unit to include the preamble and the data portion.

12. The apparatus of claim 1, wherein the network interface is further configured to generate a signal field to be included in the preamble, wherein the signal field includes a guard interval indication set to indicate whether at least the OFDM symbols of the data portion are generated using the normal guard interval, the short guard interval, or the long guard interval.

13. The apparatus of claim 12, wherein the guard interval indication comprises two bits.

14. The apparatus of claim 12, wherein the network interface is further configured to:

generate a first portion of the preamble, wherein the first portion of the preamble is (i) generated using the normal guard interval and (ii) includes the signal field, and

generate a second portion of the preamble using the guard interval indicated by the guard interval indication in the signal field.
15. The apparatus of claim 11, wherein generating the preamble of the data unit comprises generating one of (i) a regular guard interval mode preamble or (ii) an extension guard interval mode preamble, wherein generating the preamble includes formatting the preamble such that a receiving device can automatically detect whether the preamble corresponds to the regular guard interval preamble or to the extension guard interval preamble, wherein the extension guard interval mode preamble serves as the indication that at least the OFDM symbols of the data portion are generated using the long guard interval when the preamble corresponds to the extension guard interval preamble.

16. The apparatus of claim 15, wherein generating the extension guard interval preamble includes including, in the extension guard interval preamble, two or more repetitions of a legacy signal field, and wherein the receiving device can automatically detect that the preamble corresponds the extension guard interval mode preamble based on detecting the two or more repetitions of the legacy signal field.

17. The apparatus of claim 15, wherein generating the extension guard interval mode preamble includes:

   generating a non-legacy signal field to be included in the preamble, and
   modulating the non-legacy signal field differently from a corresponding non-legacy signal field in the regular guard interval mode preamble, and

   wherein the receiving device can automatically detect that the preamble corresponds to the extension guard interval mode preamble by detecting the modulation of the non-legacy signal field.
18. The apparatus of claim 17, wherein generating the non-legacy signal field includes generating the non-legacy signal field using the long guard interval.

19. The apparatus of claim 15, wherein generating the extension guard interval mode preamble includes generating, using the long guard interval, a non-legacy signal field to be included in the preamble, and wherein the receiving device can automatically detect that the preamble corresponds to the extension mode guard interval preamble by comparing results of autocorrelation of the non-legacy signal field performed using the long guard interval and autocorrelation of the non-legacy signal field performed using the normal guard interval.

20. The apparatus of claim 11, wherein the data unit conforms to a first communication protocol, and wherein generating the preamble further comprises generating the preamble such that (i) a legacy receiver configured to operate according to a legacy communication protocol but not according to the first communication protocol can determine a duration of the data unit and (ii) a receiver configured to operate according to the first communication protocol can detect that the data unit conforms to the first communication protocol.
FIG. 3

300

L-STF | L-LTF | L-SIG | HT-SIG1 | HT-SIG2 | HT-STF | HT-LTF 1 | ... | HT-LTF N | HT-DATA | ...

302 | 304 | 306 | 308-1 | 308-2 | 310 | 312-1 | 312-M | 314

PREAMBLE

FIG. 4

400

HT-GF-STF | HT-LTF1 | HT-SIG1 | HT-SIG2 | HT-LTF | ... | HT-LTF | HT-DATA | ...

402 | 404 | 406-1 | 406-2 | 408-1 | 408-M | 410

PREAMBLE

FIG. 5

500

L-STF | L-LTF | L-SIG | VHT-SIG1 | VHT-SIG2 | VHT-STF | VHT-LTF | VHT-LTF | VHT-LTF | VHT-LTF | VHT-DATA | ...

502 | 504 | 506 | 508-1 | 508-2 | 510 | 512-1 | 512-M | 514 | 516

PREAMBLE

PRIOR ART

PRIOR ART

PRIOR ART
FIG. 16

1600

1602

Generate a data portion of a data unit, the data portion including one or more OFDM symbols, the one or more OFDM symbols generated using one of (i) a normal guard interval, (ii) a short guard interval, or (iii) a long guard interval.

1604

Generate a preamble of the data unit, the preamble generated to indicate whether at least the at least the data portion of the data unit is generated using (i) the normal guard interval, (ii) the short guard interval, or (iii) the long guard interval.

1606

Generate the data unit to include the preamble and the data portion