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Kenney et al.

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(54) **ACCESS POINT AND METHODS FOR DISTINGUISHING HEW PHYSICAL LAYER PACKETS WITH BACKWARDS COMPATIBILITY**

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CPC *H04W 52/241* (2013.01); *H04B 7/0452* (2013.01); *H04W 16/14* (2013.01); *H04W 28/06* (2013.01); *H04W 52/267* (2013.01); *H04W 52/42* (2013.01); *H04W 74/006* (2013.01); *H04W 52/346* (2013.01); *H04W 56/00* (2013.01); *H04W 84/12* (2013.01)

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(58) **Field of Classification Search**
None
See application file for complete search history.

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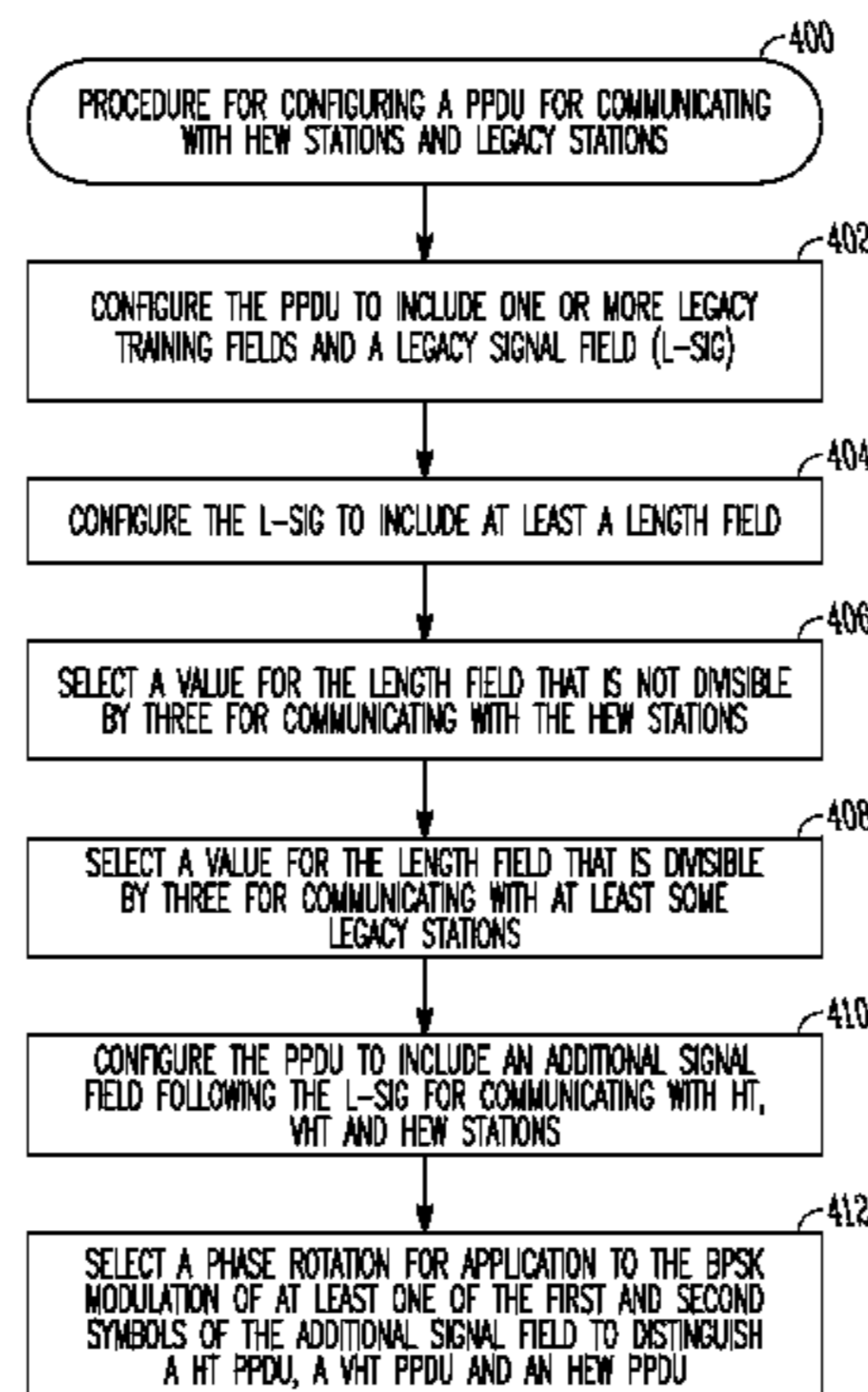
(60) Provisional application No. 61/906,059, filed on Nov. 19, 2013, provisional application No. 61/976,951, filed on Apr. 8, 2014, provisional application No. 61/973,376, filed on Apr. 1, 2014, provisional application No. 61/986,256, filed on Apr. 30, 2014, provisional application No. 61/986,250, filed on Apr. 30, 2014, provisional application No. 61/991,730, filed on May 12, 2014.

(57) **ABSTRACT**

Embodiments of a system and methods for distinguishing high-efficiency Wi-Fi (HEW) packets from legacy packets are generally described herein. In some embodiments, an access point may select a value for the length field of a legacy signal field (L-SIG) that is non-divisible by three for communicating with HEW stations and may select a value for the length field that is divisible by three for communicating with legacy stations. In some embodiments, the access point may select a phase rotation for application to the BPSK modulation of at least one of the first and second symbols of a subsequent signal field to distinguish a high-throughput (HT) PPDU, a very-high throughput (VHT) PPDU and an HEW PPDU.

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20 Claims, 7 Drawing Sheets



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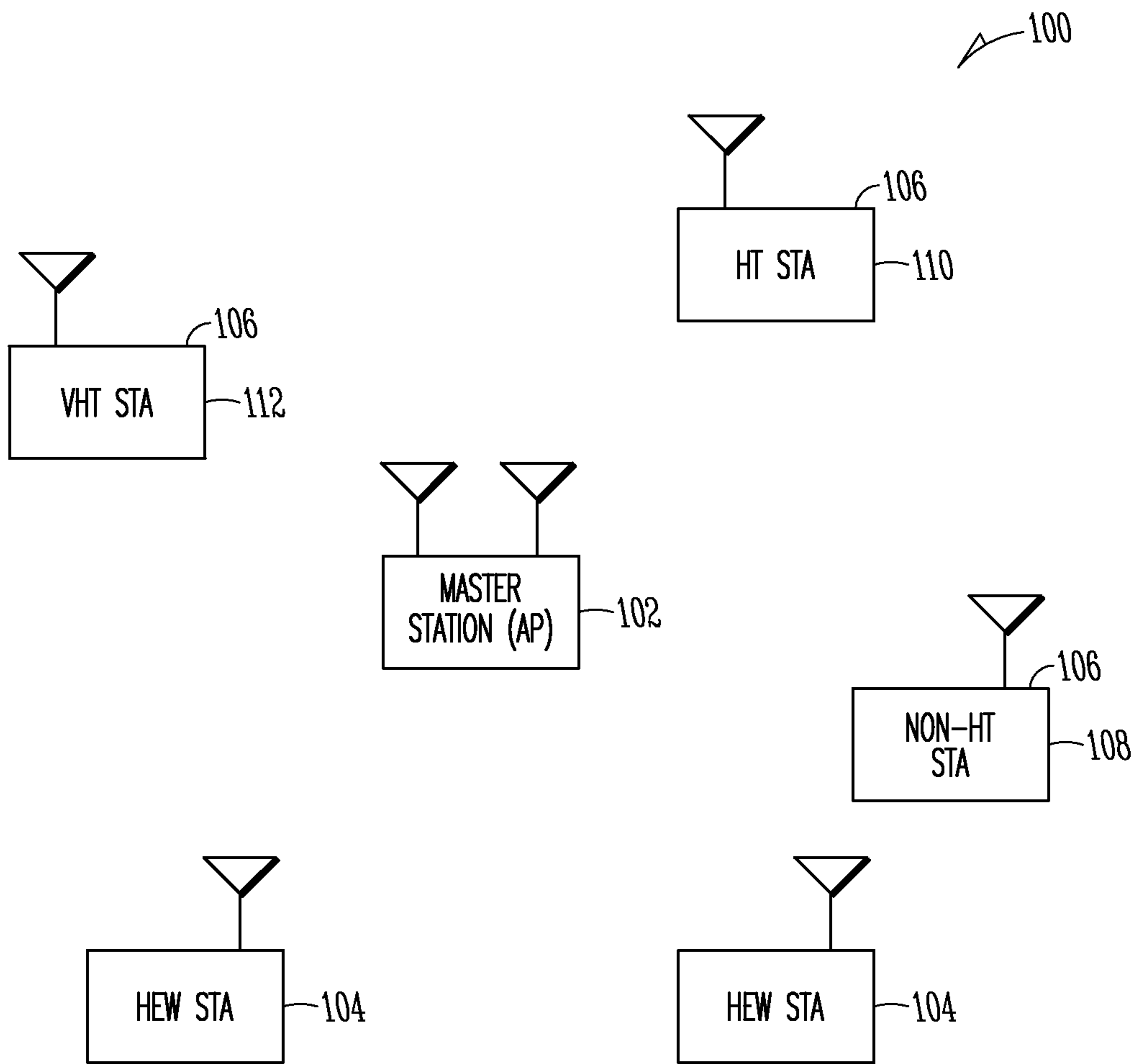


FIG. 1

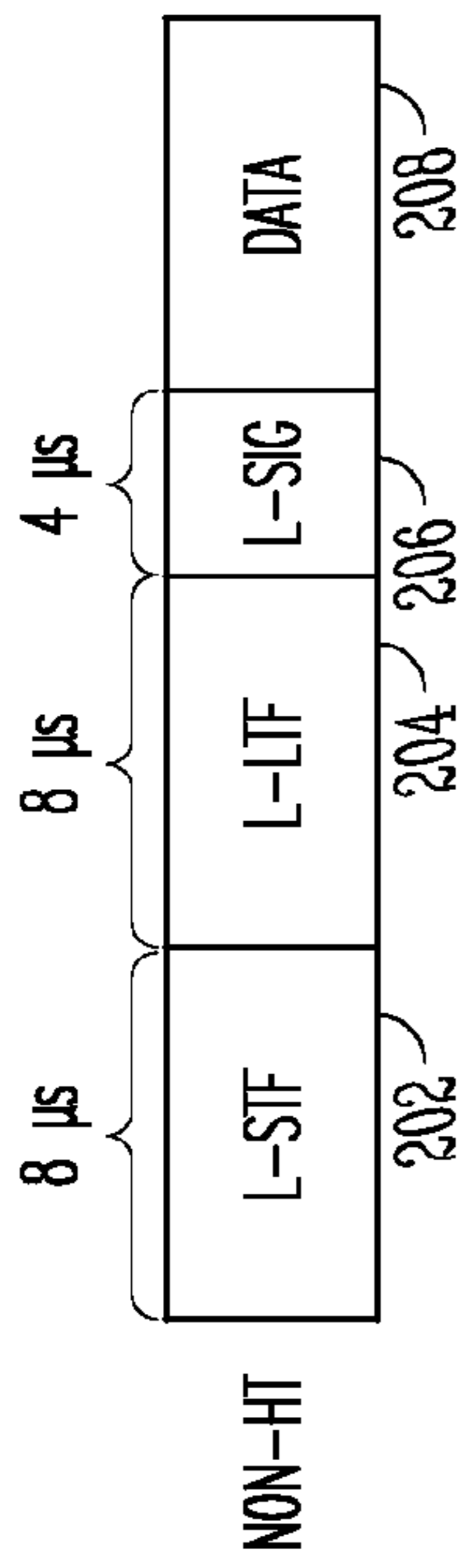


FIG. 2A

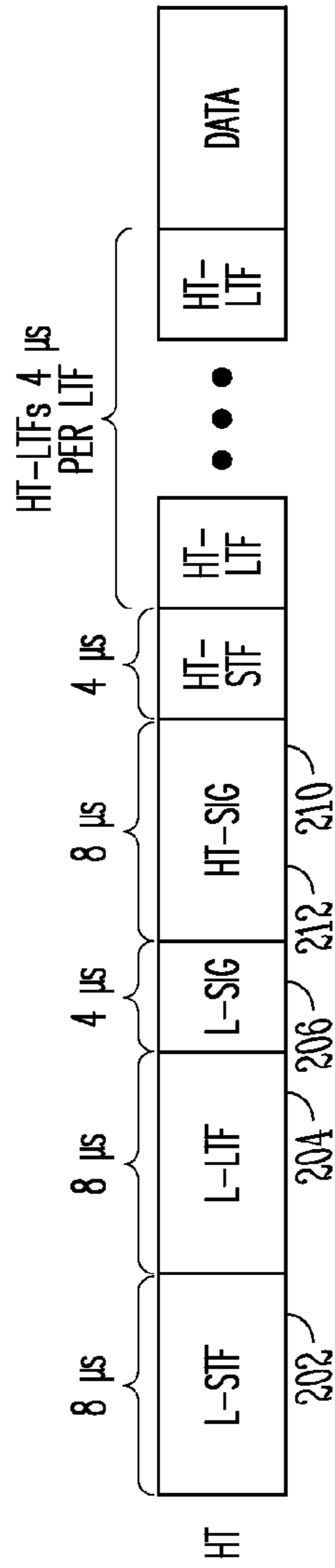


FIG. 2B

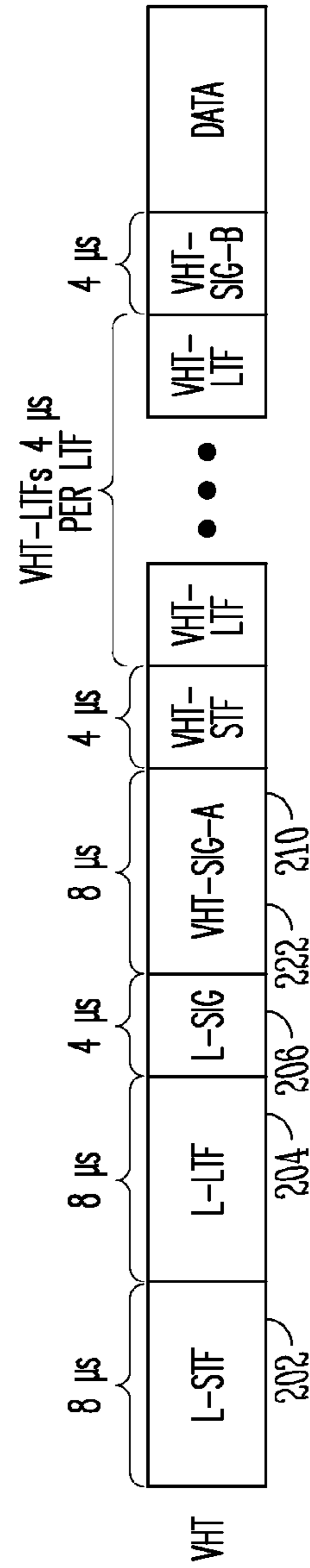


FIG. 2C

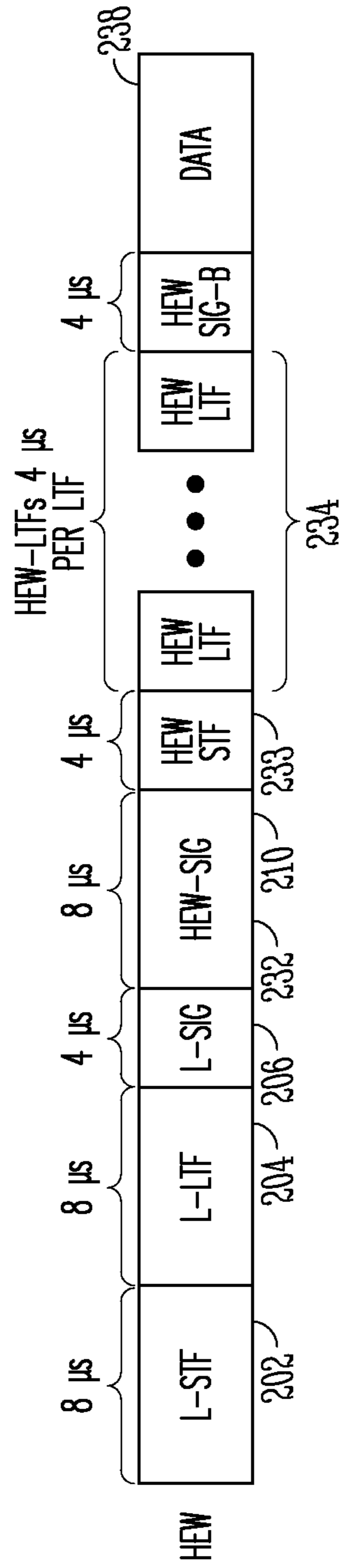


FIG. 2D

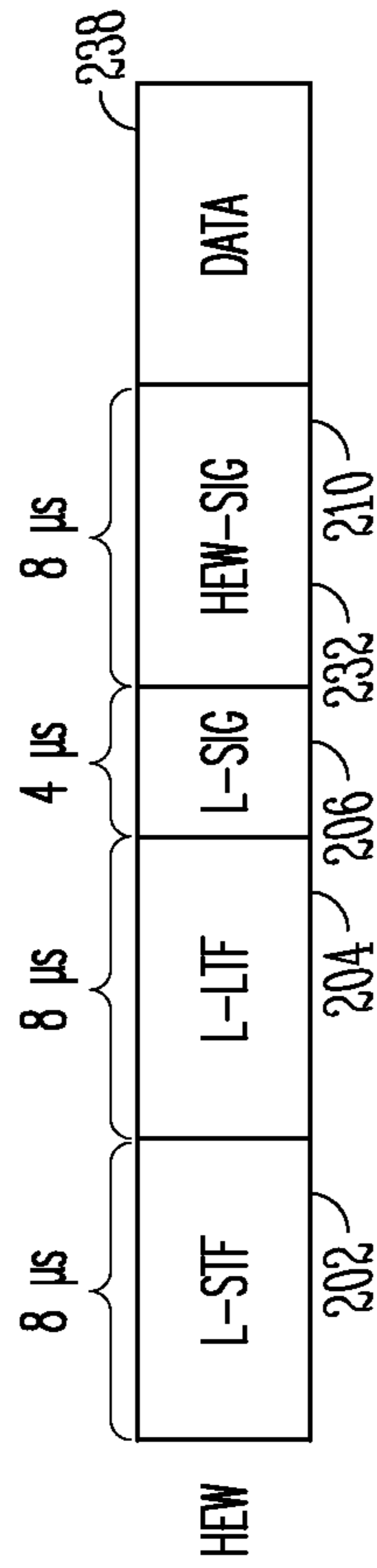


FIG. 2E

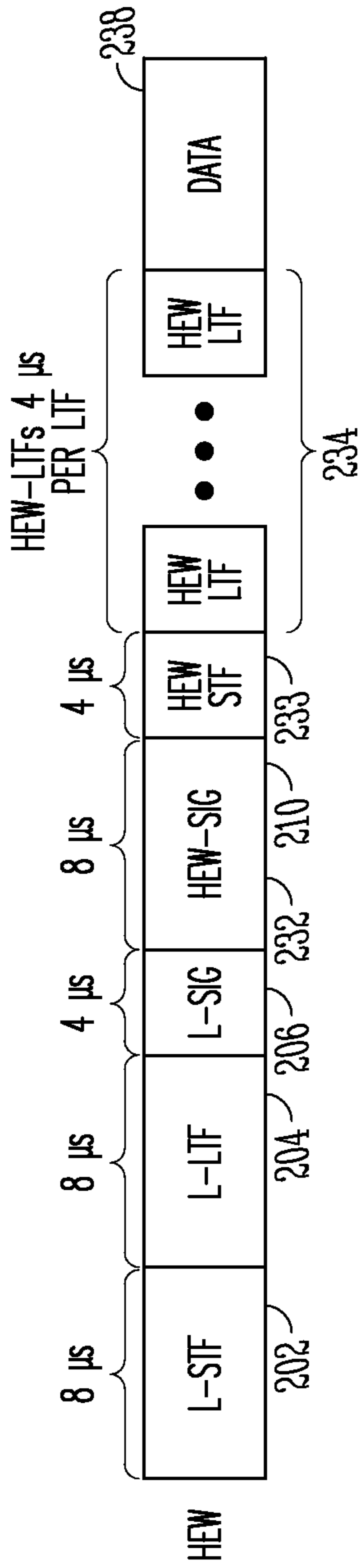


FIG. 2F

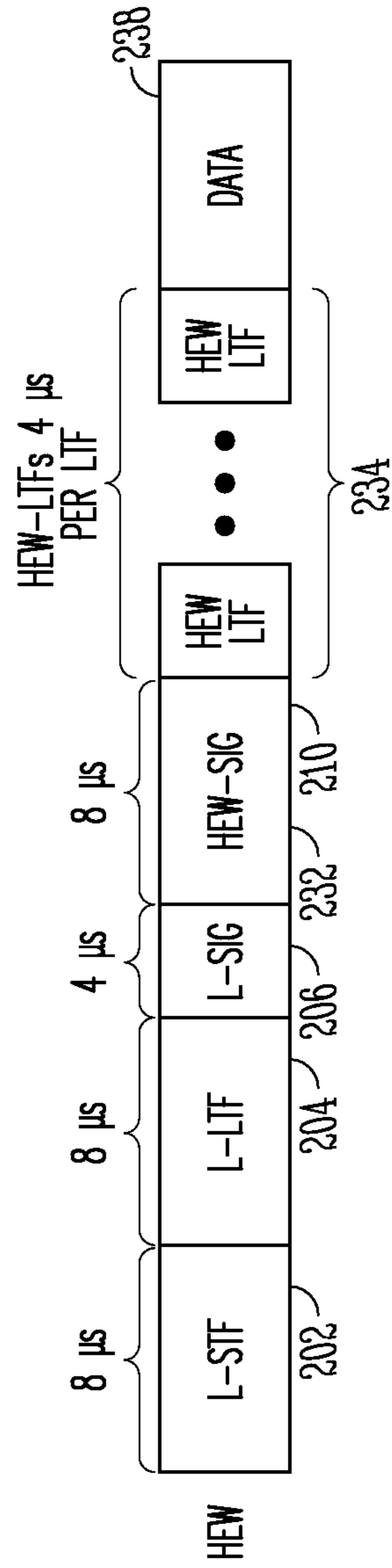


FIG. 2G

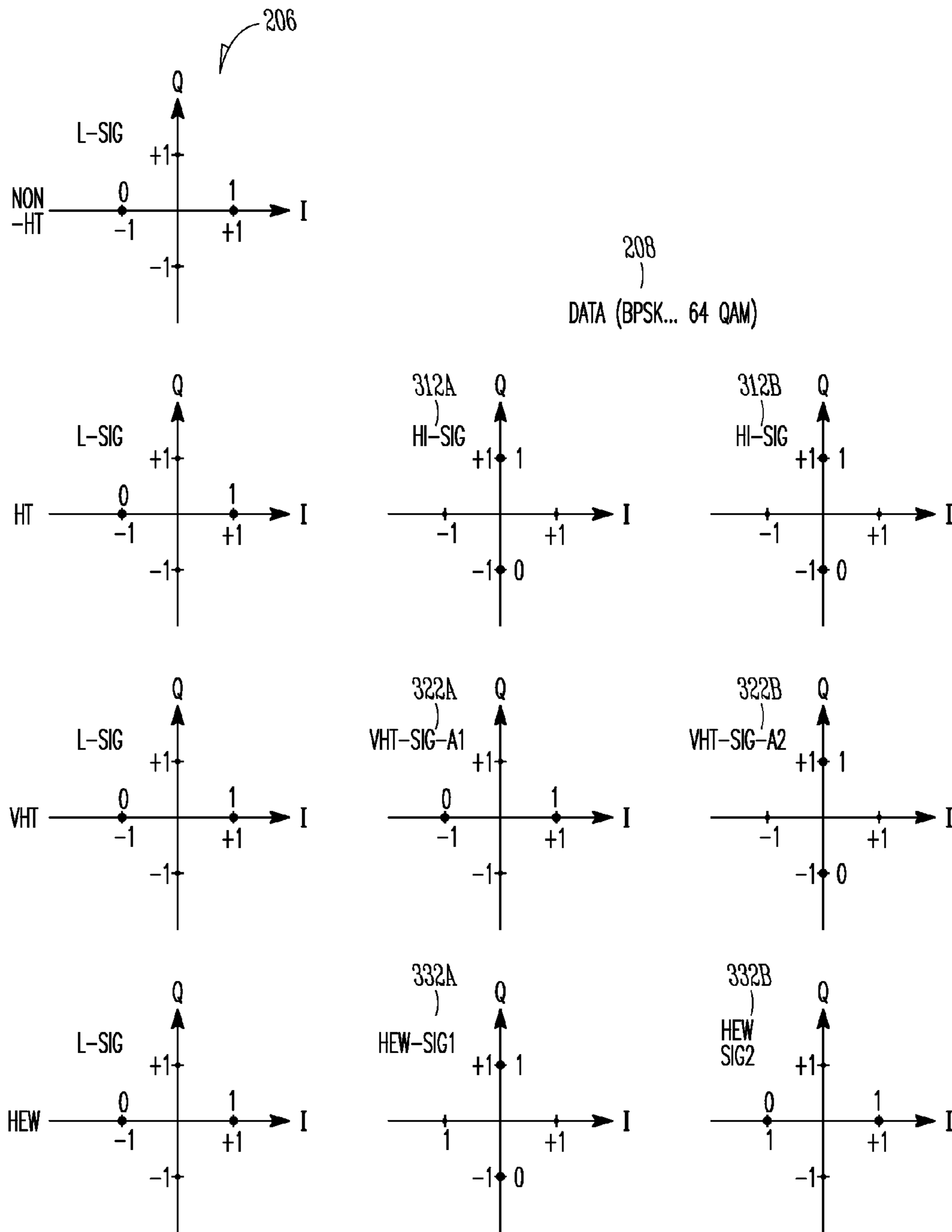
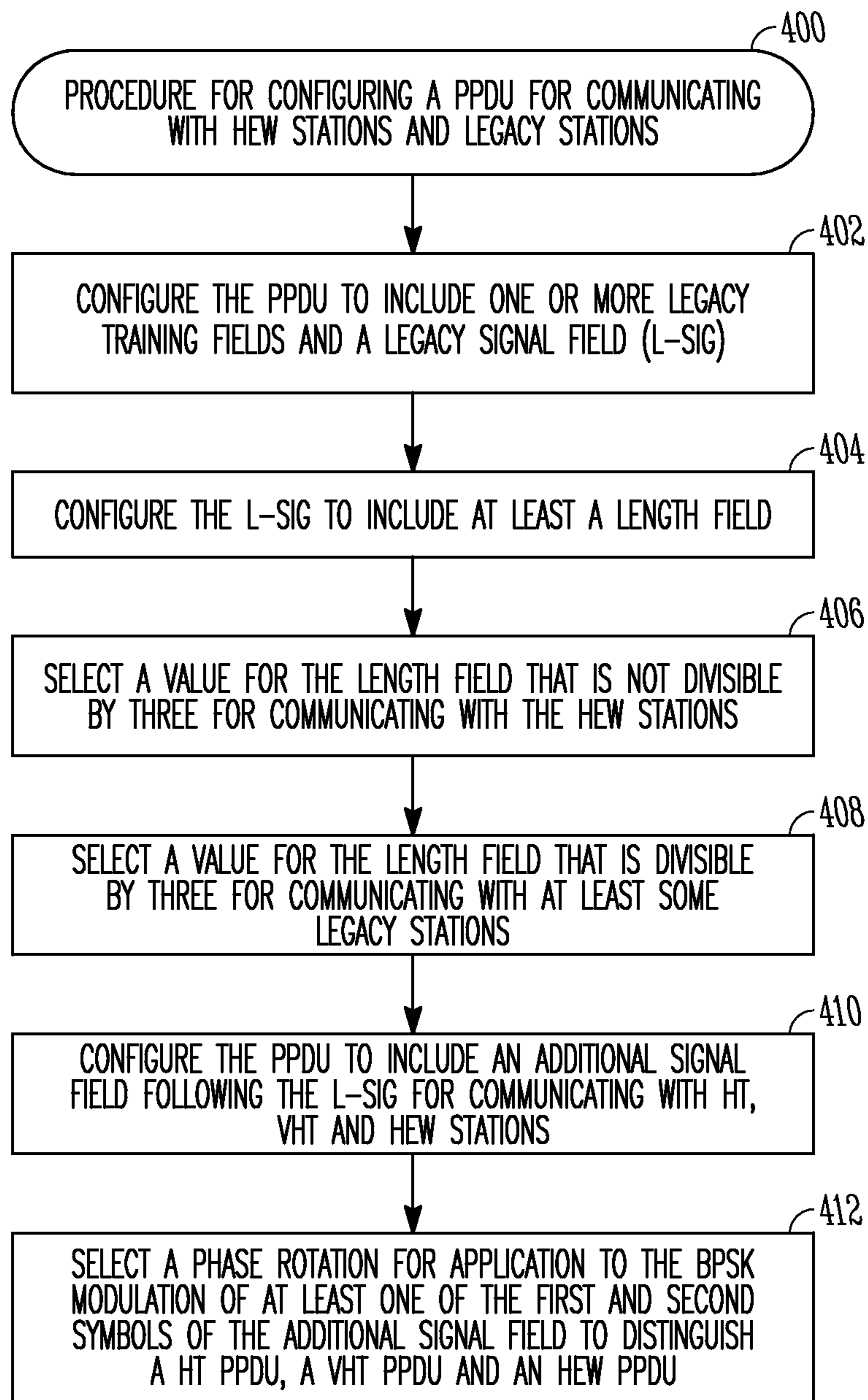


FIG. 3

**FIG. 4**

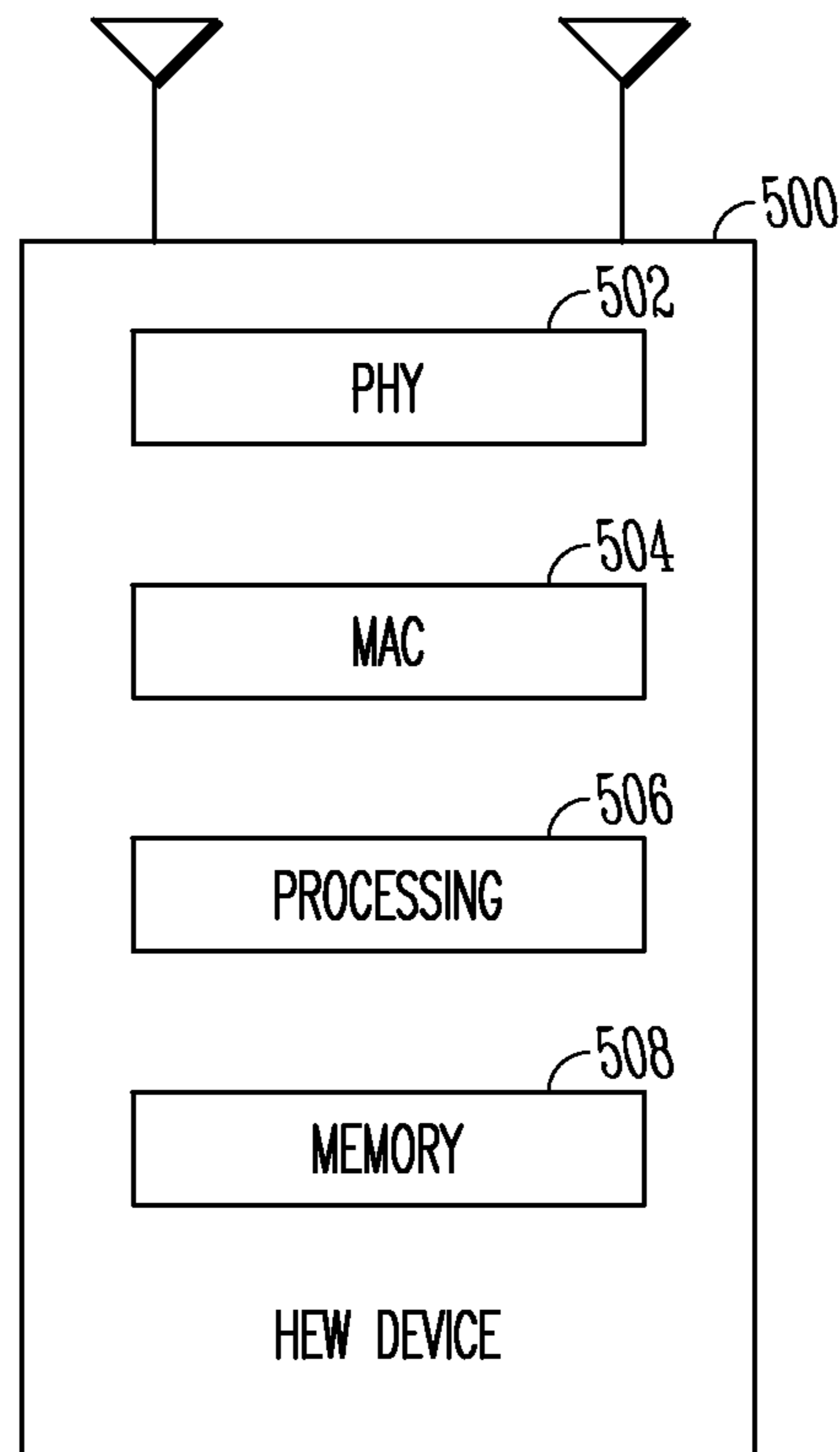


FIG. 5

**ACCESS POINT AND METHODS FOR
DISTINGUISHING HEW PHYSICAL LAYER
PACKETS WITH BACKWARDS
COMPATIBILITY**

PRIORITY CLAIM

This application claims priority under 35 U.S.C. 119(e) to U.S. Provisional Patent Application Ser. No. 61/906,059 filed Nov. 19, 2013 U.S. Provisional Patent Application Ser. No. 61/973,376, filed Apr. 1, 2014, U.S. Provisional Patent Application Ser. No. 61/976,951 filed Apr. 8, 2014, U.S. Provisional Patent Application Ser. No. 61/986,256, filed Apr. 30, 2014, U.S. Provisional Patent Application Ser. No. 61/986,250, filed Apr. 30, 2014, and to U.S. Provisional Patent Application Ser. No. 61/991,730, filed May 12, 2014, each of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

Embodiments pertain to wireless networks. Some embodiments relate to Wi-Fi networks and networks operating in accordance with the IEEE 802.11 standards. Some embodiments relate to high-efficiency wireless or high-efficiency Wi-Fi (HEW) communications in accordance with the IEEE 802.11ax draft standard.

BACKGROUND

IEEE 802.11ax (High Efficiency Wi-Fi (HEW)) is the successor to IEEE 802.11ac standard and is intended to increase the efficiency of wireless local-area networks (WLANs). HEW's goal is to provide up to four-times or more the throughput of IEEE 802.11ac standard. HEW may be particularly suitable in high-density hotspot and cellular offloading scenarios with many devices competing for the wireless medium may have low to moderate data rate requirements. The Wi-Fi standards have evolved from IEEE 802.11b to IEEE 802.11g/a to IEEE 802.11n to IEEE 802.11ac and now to IEEE 802.11ax. In each evolution of these standards, there were mechanisms to afford coexistence with the previous standard. For HEW, the same requirement exists for coexistence with legacy devices and systems.

Thus there are general needs for systems and methods that allow HEW devices to coexist with legacy devices that operate in accordance with prior versions of the standards. There are general needs for systems and methods that allow HEW communications to be distinguished from legacy communications and provide coexistence with legacy devices and systems.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a wireless network in accordance with some embodiments;

FIG. 2A illustrates a non-HT (high-throughput) format packet protocol data unit (PPDU) in accordance with some embodiments;

FIG. 2B illustrates a HT mixed-format PPDU in accordance with some embodiments;

FIG. 2C illustrates a VHT (very-high throughput) format PPDU in accordance with some embodiments;

FIG. 2D illustrates a HEW format PPDU in accordance with some embodiments;

FIG. 2E illustrates a HEW format PPDU for single-stream transmissions in accordance with some embodiments;

FIG. 2F illustrates a HEW format PPDU for multi-stream transmissions with transmit beamforming in accordance with some alternate embodiments;

FIG. 2G illustrates a HEW format PPDU for multi-stream transmissions without transmit beamforming in accordance with some embodiments;

FIG. 3 illustrates signal field constellations in accordance with some embodiments;

FIG. 4 is a procedure for configuring a PPDU for communicating with HEW stations and legacy stations in accordance with some embodiments; and

FIG. 5 is a block diagram of an HEW device in accordance with some embodiments.

DETAILED DESCRIPTION

The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.

Embodiments disclosed herein provide for coexistence of High Efficiency Wi-Fi (HEW) devices with existing legacy Wi-Fi devices. Legacy devices may refer to devices operating in accordance with previous Wi-Fi standards and/or amendments such as IEEE 802.11g/a, IEEE 802.11n or IEEE 802.11ac. HEW is a recent activity in IEEE to evolve the Wi-Fi standard. It has several target use cases, with a large focus on improving system efficiency in dense deployed networks. Since it is an evolution of the previous standards and needs to coexist with the legacy systems, a technique to identify each transmission as either a HEW packet or a legacy packet is needed. Additionally, it would be advantageous if the technique to identify the HEW transmissions could at the same time defer legacy devices. Finally, since one focus on HEW is efficiency, another aspect is to have a mechanism which accomplishes these things without adding any additional overhead to each transmission and possibly reducing the overhead.

Embodiments disclosed herein provide techniques to notify HEW devices that an HEW compliant transmission is occurring while also deferring legacy devices and doing so with little or no additional overhead from what is done in legacy transmissions and in some embodiments, less overhead. Since HEW is an evolution of the existing Wi-Fi standards, there have not been any previous solutions to address this need.

In some embodiments, the preamble portion of the packet has been increased and new fields added with various modulation formats so that the new releases could be identified. Some embodiments described herein are configured to defer legacy devices using the legacy signal field (L-SIG) and build upon the coexistence approach adopted in IEEE 802.11n and IEEE 802.11ac. In those systems, the rate field of the L-SIG was fixed to a set known value and the length was set to a length that would defer those devices beyond the transmission of an IEEE 802.11n or an IEEE 802.11ac transmission.

In some embodiments disclosed herein, the same fixed value in the rate field may be used although this is not a requirement. In some embodiments, the length field of the L-SIG may be computed differently from what is done in an IEEE 802.11n/ac system to allow deferral of legacy systems and identification of an HEW transmission. These embodiments are described in more detail below.

Following the L-SIG in an IEEE 802.11n/ac transmission are additional SIG fields. In IEEE 802.11n/ac systems, these SIG fields follow directly after the L-SIG and are phase rotated in order to allow identification. In the embodiments disclosed herein, an HEW signal field may also be used if needed and may use a modified legacy length value allowing for several preamble designs and potentially several payloads to support not only single user (SU) packets to multi-user (MU) packets like multi-user multiple-input multiple-output (MU-MIMO) or orthogonal frequency division multiple access (OFDMA). In these embodiments that use uplink MU-MIMO or uplink OFDMA, an access point (AP) may operate as a master station which would have mechanisms to contend and hold the medium. Uplink transmissions from scheduled HEW stations may immediately follow. In those cases, the AP may signal the specific devices that are targeted for uplink transmission the transmission parameters. Therefore, each device that transmits in the uplink would not need to send any additional configuration parameters and therefore does not need an additional SIG field in the preamble during their transmission.

Embodiments disclosed herein also allow legacy devices that missed the initial AP transmission (e.g., when returning from a power save mode) to detect the signal and properly defer irrespective of them being an IEEE 802.11a, an IEEE 802.11n or an IEEE 802.11ac device. In these embodiments, a new signal field modulation format is disclosed in which the first symbol is set as rotated BPSK (i.e., rotated by 90 degrees) and then the second would be BPSK (i.e., not rotated). These embodiments are described in more detail below.

FIG. 1 illustrates a wireless network in accordance with some embodiments. Wireless network 100 may include a master station (STA) 102, a plurality of HEW stations 104 (i.e., HEW devices), and a plurality of legacy stations 106 (legacy devices). The master station 102 may be arranged to communicate with the HEW stations 104 and the legacy stations 106 in accordance with one or more of the IEEE 802.11 standards. In some embodiments, the master station 102 may be an access point (AP), although the scope of the embodiments is not limited in this respect.

Legacy stations 106 may include, for example, non-HT stations 108 (e.g., IEEE 802.11a/g stations), HT stations 110 (e.g., IEEE 802.11n stations), and VHT stations 112 (e.g., IEEE 802.11ac stations). Embodiments disclosed herein allow HEW stations 104 to distinguish transmissions (e.g., packets such as packet protocol data units (PPDUs)) from transmissions of legacy stations 106 and cause legacy stations 106 to at least defer their transmissions during HEW transmissions providing backwards compatibility. In some embodiments, the length field of the legacy signal field (L-SIG) may be used to cause some legacy stations 106 to defer transmissions. In some embodiments, the length field of the L-SIG may be used to distinguish HEW PPDUs from non-HEW PPDUs. In some embodiments, a phase rotation applied to a subsequent or additional signal field (an HT-SIG, a VHT SIG or an HEW SIG) may be used to distinguish HT PPDUs, VHT PPDUs and HEW PPDUs. In some embodiments, the rate field of the L-SIG may be used to cause some legacy stations 106 to defer transmissions and distinguish non-HT transmissions from HT, VHT and HEW transmissions. These embodiments are discussed in more detail below.

In accordance with embodiments, the master station 102 may include hardware processing circuitry including physical layer (PHY) and medium-access control layer (MAC) circuitry which may be arranged to contend for a wireless medium (e.g., during a contention period) to receive exclusive control of the medium for an HEW control period (i.e., a

transmission opportunity (TXOP)). The master station 102 may transmit an HEW master-sync transmission at the beginning of the HEW control period. During the HEW control period, the HEW stations 104 may communicate with the master station 102 in accordance with a non-contention based multiple-access technique (e.g., an OFDMA technique or MU-MIMO technique). This is unlike conventional Wi-Fi communications in which devices communicate in accordance with a contention-based communication technique, rather than a non-contention multiple-access technique. During the HEW control period, legacy stations 106 refrain from communicating and defer their transmissions. In some embodiments, the HEW master-sync transmission may be referred to as an HEW control and schedule transmission.

In accordance with some embodiments, the master-sync transmission may include a multi-device HEW preamble arranged to signal and identify data fields for a plurality of scheduled HEW stations 104. The master station 102 may further be arranged to transmit (in the downlink direction) and/or receive (in the uplink direction) one or more of the data fields to/from the scheduled HEW stations 104 during the HEW control period. In these embodiments, the master station 102 may include training fields in the multi-device HEW preamble to allow each of the scheduled HEW stations 104 to perform an initial channel estimate.

In accordance with some embodiments, an HEW station 104 may be an IEEE 802.11ax configured station (STA) that is configured for HEW operation. An HEW station 104 may be configured to communicate with a master station 102 in accordance with a scheduled multiple access technique during the HEW control period and may be configured to receive and decode the multi-device HEW preamble of an HEW frame or PPDUs. An HEW station 104 may also be configured to decode an indicated data field received by the master station 102 during the HEW control period. Examples of HEW PPDUs are illustrated in FIGS. 2D through 2G discussed below.

In accordance with some embodiments, the master station 102 may be arranged to select a number of HEW long-training fields (LTFs) to be included in the multi-device HEW preamble of an HEW frame. The HEW frame may comprise a plurality of links for transmission of a plurality of data streams. The master station 102 may also transmit the selected number of LTFs sequentially as part of the multi-device HEW preamble. The master station 102 may also transmit/receive a plurality of data fields sequentially to/from each of a plurality of scheduled HEW stations 104. The data fields may be part of the HEW frame. Each data field may correspond to one of the links and may comprise one or more data streams. In some embodiments, the data fields may be separate packets. The master station 102 may also be arranged receive packets from HEW stations 104 in the uplink direction during the HEW control period.

In some embodiments, the selection of the number of LTFs to be included in the multi-device HEW preamble may be based on a maximum number of streams to be transmitted on a single link. In some embodiments, the selection of the number of LTFs to be included in the multi-device HEW preamble may be based on a scheduled HEW station 104 with a greatest channel estimation need (e.g., the scheduled HEW station 104 receiving the greatest number of streams on a single link). In some embodiments, the selection of the number of LTFs to be included in the multi-device HEW preamble may be based on the sum of greatest number of streams on each single link that scheduled HEW stations 104 would receive. In some embodiments, the number of LTFs to be included in the multi-device HEW preamble may be prede-

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terminated. In these embodiments, the number of LTFs to be included in the multi-device HEW preamble may be based on the maximum number of streams that can be transmitted on a single link.

In some embodiments, the master station **102** may be arranged to configure the multi-device HEW preamble include an HEW control signal field (i.e., HEW SIG-B) to identify and signal each of the data fields of the HEW frame. In these embodiments, a single HEW preamble is included in an HEW frame, which is unlike conventional techniques which include a preamble for each link.

FIG. 2A illustrates a non-HT format PPDU in accordance with some embodiments. The non-HT format PPDU may be used for communicating with non-HT stations **108** (FIG. 1), which may include stations configured to communicate in accordance with an IEEE 802.11a or IEEE 802.11g standard. In IEEE 802.11a/g, the packet structure comprises a Legacy Short Training Field (L-STF) **202**, a Legacy Long Training Field (L-LTF) **204** and the L-SIG **206** which made up the preamble. The preamble is followed by a data field **208**. The L-SIG **206** provides information about the data field **208** including the coding and modulation (rate) and the length.

FIG. 2B illustrates a HT mixed-format PPDU in accordance with some embodiments. The HT mixed-format PPDU may be used for communicating with HT stations **110** (FIG. 1), which may include stations configured to communicate in accordance with an IEEE 802.11n standard. In IEEE 802.11n, the packet structure allows the IEEE 802.11n devices to coexist with IEEE 802.11a/g devices and therefore included the legacy preamble portion of the packet to be used at the beginning of the transmission. The IEEE 802.11n transmission sets the rate field of the L-SIG **206** to a fixed rate and the length field is set to extend for the full duration of the IEEE 802.11n packet. Following the legacy portion of the preamble, the IEEE 802.11n preamble includes a HT-SIG **212** for the IEEE 802.11n and includes additional configuration information for those devices. The HT-SIG **212** uses rotated binary phase-shift keying (BPSK) in both symbols of the HT-SIG **212** so that IEEE 802.11n devices can distinguish it from non-rotated BPSK data **208** of an IEEE 802.11a/g transmission and allows those devices to detect the existence of an IEEE 802.11n packet. Thus, IEEE 802.11a/g devices are able to recognize the legacy portion of the preamble, but not the portion following the legacy portion and may defer based on the configuration parameters in the L-SIG **206** of the HT mixed-format PPDU of FIG. 2B assuring coexistence.

FIG. 2C illustrates a VHT format PPDU in accordance with some embodiments. The VHT format PPDU may be used for communicating with VHT stations **112** (FIG. 1), which may include stations configured to communicate in accordance with an IEEE 802.11ac standard. In 802.11ac, the packet also starts with the legacy portion of the preamble which is then followed by a VHT-SIG **222** to provide additional configuration parameters for the VHT data field. The IEEE 802.11a/g devices recognize the legacy portion of the packet but would decode the rest of the packet correctly and thus defer from transmission for the full length based on the legacy rate/length fields.

IEEE 802.11ac devices are also able to discern IEEE 802.11ac packets from other legacy (IEEE 802.11a/g and IEEE 802.11n) packets. In the discussion above regarding IEEE 802.11n, the HT-SIG field **212** (FIG. 2B) following the L-SIG **206** is modulated using BPSK as in the L-SIG **206**, but it is rotated 90 degrees. This modulation format may be used by an IEEE 802.11n device to detect those packets and identify them as IEEE 802.11n packets. For IEEE 802.11ac devices to detect IEEE 802.11ac packets, the VHT-SIG **222**

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(FIG. 2C) is normal BPSK for the first symbol of the VHT-SIG **222** and is rotated 90 degrees for the second symbol. This allows for the identification of IEEE 802.11ac packets by IEEE 802.11ac devices, but demodulation of the VHT-SIG **222** may not be possible by the IEEE 802.11n devices. In those cases the IEEE 802.11n device will defer based on the L-SIG **206**.

FIGS. 2D-2G illustrate HEW format PPDUs in accordance with various embodiments. The HEW formats PPDU of FIGS. 2D-2G may be used for communicating with HEW stations **104** (FIG. 1), which may include stations configured to communicate in accordance with an IEEE 802.11x standard. In accordance with embodiments, the master station **102** (FIG. 1) may configure a PPDU comprising a legacy signal field (L-SIG) **206** following legacy training fields (i.e., L-STF **202** and L-LTF **204**).

In some embodiments, the L-SIG **206** may be configured to include at least a length field and a rate field. The master station **102** may select a value for the length field that is non-divisible by three for communicating with the HEW stations **104** and may select a value for the length field that is divisible by three for communicating with at least some legacy stations **106**. In these embodiments, when the length field is not divisible by three, at least some legacy stations **106** (i.e., HT stations **110** and VHT stations **112**) would determine that the length field value in the L-SIG **206** is invalid and will properly defer their transmissions. When the length field is not divisible by three, HEW stations **104** may be configured to identify the PPDU as an HEW PPDU and decode one or more of the fields that follow the L-SIG **206**.

In some embodiments, the master station **102** is further arranged to configure the L-SIG **206** with a valid parity bit (i.e., the L-SIG parity bit) when the length field is selected to be divisible by three and when the length field is selected to be non-divisible by three. In these embodiments, the L-SIG may always be configured with a valid parity bit. In these embodiments, when a valid L-SIG parity bit is indicated, the physical layer (PHY) of a device may maintain a busy indication for the predicted duration of the PPDU. Thus legacy stations **106** will defer for the value indicated by the length (L_LENGTH) field in the L-SIG **206** even if the value is invalid (i.e., not divisible by three) as long as the parity bit is valid.

In some embodiments, the master station **102** may multiply a ceiling function by three and subtract either two or one to calculate the value for the length field for the HEW PPDUs. By multiplying the ceiling function by three and then subtracting two or one assures that the length field is not divisible by three. The master station **102** may multiply the ceiling function by three and subtract three to calculate the value for the length field for HT and VHT PPDUs. By multiplying the ceiling function by three and then subtracting three assures that the length field is divisible by three. These embodiments are discussed in more detail below.

In some embodiments, the length calculation used to populate the L-SIG for 0.11ac packets is give as (L_LENGTH):

$$\begin{aligned}
 TXTIME(\text{for } SGI) &= T_{LEG_PREMABLE} + T_{L-SIG} + T_{VHT-SIG-A} + \\
 &T_{VHT_PREMABLE} + T_{VHT-SIG-B} + T_{SYM} \times \left\lceil \frac{T_{SYMS} \times N_{SYM}}{T_{SYM}} \right\rceil \\
 L_LENGTH &= \left\lceil \frac{TXTIME - 20}{4} \right\rceil \times 3 - 3
 \end{aligned}$$

In the above equations, the T variable is the time for the respective portions of the packet and variables T_{SYMS} , T_{SYM}

and N_{SYM} represent the short GI symbol interval, symbol interval and number of symbols in a packet respectively. The equation in the L_LENGTH calculation uses a ceiling function multiplied by three and then three is subtracted. For any value of $TXTIME$, the L_LENGTH will be divisible by three. Thus, for HEW packets, embodiments disclosed herein may set the L_LENGTH to a value that is not divisible by three. In some embodiments, the expression for L_LENGTH for HEW packets may be:

$$L_{LENGTH} = \left\lceil \frac{TXTIME - 20}{4} \right\rceil \times 3 - 2$$

This would result in a length that is one larger than before but is not divisible by three. Doing this may be sufficient to identify HEW packets and may allow coexistence with legacy (IEEE 802.11a/g/n/ac) devices. Legacy stations **106** would decode the L-SIG, and defer for a time based on the L_LENGTH value regardless of the value.

In these embodiments, no additional signaling or other metrics need to be added in order to identify HEW packets. That is very appealing in HEW where efficiency is a key design parameter. Additionally, for techniques like uplink MU-MIMO and OFDMA to be efficient a very short preamble is desirable. These embodiments are very efficient with no overhead and provide full coexistence with legacy systems.

In some embodiments, the master station **102** may be arranged to configure the PPDU to include a subsequent/additional signal field **210** (e.g., HT-SIG **212**, VHT-SIG **222**, or HEW-SIG **232**) following the L-SIG **206**. The subsequent signal field **210** may have first and second symbols that are BPSK modulated. In these embodiments, the master station **102** may select a phase rotation for application to the BPSK modulation of at least one of the first and second symbols of the subsequent signal field **210** to distinguish a HT PPDU (FIG. 2B), a VHT PPDU (FIG. 2C) and an HEW PPDU (FIGS. 2D-2G). These embodiments are discussed in more detail below.

In some embodiments, for communicating with HEW stations **104**, the master station **102** may configure the PPDU to include a number of long-training fields (LTFs) **234** to be included in a multi-device HEW preamble the PPDU. The number of LTFs **234** may be based on a maximum number of streams communicated over a link. The master station **102** may contend for a wireless medium during a contention period to receive control of the medium for an HEW control period (i.e., a TXOP) and may transmit the PPDU during the HEW control period. During the HEW control period, the master station **102** may operate as a master station having exclusive use of the wireless medium for communication of data with a plurality of scheduled HEW stations **104** in accordance with a non-contention based scheduled OFDMA technique in accordance with signaling information indicated in an HEW signal field. The scheduled OFDMA technique may, for example, be an uplink (UL) OFDMA technique, a downlink (DL) OFDMA technique or an UL or DL multi-user multiple-input multiple-output (MU-MIMO) technique.

In some embodiments, for an HEW PPDU, each data field may be associated with either a single user (SU) link or a multi-user (MU) link and each link may be configurable to provide multiple streams of data. The links of the HEW PPDU may be configurable to have a bandwidth of one of 20 MHz, 40 MHz, 80 MHz or 160 MHz.

FIG. 2E illustrates a HEW format PPDU for single-stream transmissions in accordance with some embodiments. In these embodiments, all signaling information for transmission of a single stream over a link may be included within the HEW-SIG **232** eliminating the need for one or more HEW LTFs and an HEW SIG B field. The multi-stream HEW format PPDU of FIG. 2D, on the other hand includes a number of LTFs **234** based on a maximum number of streams communicated over a link and an HEW SIG-B field.

FIG. 2F illustrates a HEW format PPDU for multi-stream transmissions with transmit beamforming in accordance with some embodiments. In these embodiments, the signaling information from the HEW-SIG-B field may be included within the HEW-SIG **232** eliminating the need for a second signal field (e.g., an HEW SIG B field). In these embodiments, the number of HEW LTFs **234** may be based on a maximum number of streams communicated over the link and an HEW STF **233** may be included for transmit beamforming.

FIG. 2G illustrates a HEW format PPDU for multi-stream transmissions without transmit beamforming in accordance with some embodiments. In these embodiments, the signaling information from the HEW-SIG-B field may be included within the HEW-SIG **232** eliminating the need for a second signal field (e.g., an HEW SIG B field). In these embodiments, the number of HEW LTFs **234** may be based on a maximum number of streams communicated over the link and an HEW STF may not be needed since transmit beamforming is not performed.

FIG. 3 illustrates signal field constellations in accordance with some embodiments. As illustrated in FIG. 3, the L-SIG **206** for non-HT stations **108**, for HT stations **110**, for VHT stations **112** and for HEW stations **104** is illustrated with conventional BPSK modulation (i.e., no phase rotation is applied). As further illustrated in FIG. 3, a selected phase rotation for application to the BPSK modulation of the first and second symbols of the subsequent signal field **210** is shown.

In accordance with embodiments, for communicating with the HEW stations **104**, the subsequent signal field **210** may be an HEW signal field (HEW-SIG) **232** (FIGS. 2D-2G) and the master station **102** may apply a ninety-degree phase rotation to the BPSK modulation of the first symbol **332A** of the HEW-SIG **232** (i.e., rotated BPSK) and may refrain from applying a ninety-degree phase rotation to the BPSK modulation of the second symbol **332B** of the HEW-SIG **232**. Accordingly, for an HEW-PPDU, the first symbol **332A** of the HEW-SIG **232** is rotated BPSK and the second symbol **332B** is conventional (i.e., non-rotated) BPSK.

For communicating with VHT stations **112**, the subsequent signal field **210** may be a VHT signal field (VHT-SIG) **222** (FIG. 2C) and the master station **102** may refrain from applying a ninety-degree phase rotation to the BPSK modulation of the first symbol **322A** of the VHT-SIG **222** and may apply a ninety-degree phase rotation to the BPSK modulation of the second symbol **322B** of the VHT-SIG **222**. Accordingly, for a VHT-PPDU, the first symbol **322A** of the VHT-SIG **222** is conventional BPSK and the second symbol **322B** is rotated BPSK.

For communicating with HT stations **110**, the subsequent signal field **210** may be an HT signal field (HT-SIG) **212** (FIG. 2B) and the master station **102** may apply a ninety-degree phase rotation to the BPSK modulation of both the first symbol **312A** and the second symbol **312B** of the HT-SIG **212**. Accordingly, for a HT PPDU, both symbols of the HT-SIG **212** are rotated BPSK.

For communicating with non-HT stations **108**, the access point may refrain from including the subsequent signal field **210** following the L-SIG **206**. The data field **208** of a non-HT PDU may have conventional (non-phase rotated) modulation (e.g., BPSK to 64QAM) applied for all symbols allowing a non-HT PDU to be identified and distinguished from other HT, VHT and HEW PDUs.

In accordance with some embodiments, the phase rotation of the symbols in the subsequent signal field **210** may be used to distinguish an HEW PDU from a non-HEW PDU, such as a HT PDU or a VHT PDU. In these embodiments, it may not be necessary to use the length field of the L-SIG **206** to distinguish an HEW PDU from a non-HEW PDU and the length field may be set to a value that is divisible by three, although the scope of the embodiments is not limited in this respect. In some embodiments, the length field may also be used to distinguish an HEW PDU from a non-HEW PDU, such as a HT PDU or a VHT PDU.

In some embodiments, for communicating with the HEW stations **104** and some legacy stations **106** including HT stations **110** and VHT stations **112**, the master station **102** may select a value for the rate field to cause the non-HT stations **108** to defer transmissions. In these embodiments, the non-HT stations **108** may correctly decode the L-SIG **206** but may be unable to correctly decode the remainder of the PDU based on the indicated rate (or the cyclic-redundancy check (CRC) may fail) causing these stations to ignore the PDU but defer based on the length indicated in the length field of the L-SIG **206**. In these embodiments, a predetermined value (e.g., 5 or 6) may be selected for the rate field which may cause the non-HT stations **108** to defer their transmissions because of their inability to decode the subsequent fields.

FIG. 4 is a procedure for configuring a PDU for communicating with HEW stations and legacy stations in accordance with some embodiments. Procedure **400** may be performed by an access point, such as master station **102** (FIG. 1), for communicating with HEW stations **104** (FIG. 1) as well as legacy stations **106** (FIG. 1).

In operation **402**, a PDU is configured to include one or more legacy training fields and a legacy signal field (L-SIG) **206** following the legacy training fields.

In operation **404**, the L-SIG **206** is configured to include at least a length field.

In operation **406**, a value for the length field that is not divisible by three is selected for communicating with the HEW stations **104**.

In operation **408**, a value for the length field that is divisible by three is selected for communicating with at least some legacy stations **106**.

In operation **410**, the PDU is configured to include an additional signal field following the L-SIG **206**.

In operation **412**, a phase rotation is selected for application to the BPSK modulation of at least one of the first and second symbols of the additional signal field to distinguish a HT PDU, a VHT PDU and an HEW PDU.

In some embodiments, operation **412** may be optional as the value selected for the length field in operations **406** and **408** may be used to distinguish HEW from non-HEW PDUs. In some alternate embodiments, the value for the length field that is divisible by three is selected for communicating with all stations and the phase rotation of the symbols of the additional signal field may be used to distinguish a HT PDU, a VHT PDU and an HEW PDU.

FIG. 5 illustrates an HEW device in accordance with some embodiments. HEW device **500** may be an HEW compliant device that may be arranged to communicate with one or more other HEW devices, such as HEW stations **104** (FIG. 1)

or master station **102** (FIG. 1) as well as communicate with legacy stations **106** (FIG. 1). HEW device **500** may be suitable for operating as master station **102** (FIG. 1) or an HEW station **104** (FIG. 1). In accordance with embodiments, HEW device **500** may include, among other things, physical layer (PHY) circuitry **502** and medium-access control layer circuitry (MAC) **504**. PHY **502** and MAC **504** may be HEW compliant layers and may also be compliant with one or more legacy IEEE 802.11 standards. MAC **504** may be arranged to configure PDUs in accordance with one or more of FIGS. 2A-2G and PHY **502** may be arranged to transmit and receive PDUs, among other things. HEW device **500** may also include other hardware processing circuitry **506** and memory **508** configured to perform the various operations described herein.

In accordance with some embodiments, when operating as an HEW station **104**, the HEW device **500** may be arranged to distinguish an HEW PDU from a non-HEW PDU based at least in part on a value in a length field in the L-SIG **206** (FIGS. 2A-2G). In these embodiments, the HEW device **500** may be configured to receive L-SIG **206** following legacy training fields (i.e., L-STF **202** and L-LTF **204**). The L-SIG **206** may include the length field and a rate field. The HEW device **500** may determine whether a value for the length field is divisible by three and verify a parity bit of the L-SIG. The HEW device **500** may identify the PDU as an HEW PDU when the value in the length field is not divisible three and the parity bit is verified, and may identify the PDU as a non-HEW PDU (e.g., a VHT PDU or HT PDU) when the value in the length field is divisible three and the parity bit is verified. In some embodiments, the HEW device **500** may also be configured to decode subsequent fields of the PDU when identified as an HEW PDU and refrain from decoding subsequent fields of the PDU when the PDU is identified as a non-HEW PDU.

In some embodiments, when operating as an HEW station **104**, the HEW device **500** may be arranged to distinguish an HEW PDU from a non-HEW PDU based on the phase rotation of symbols of a subsequent signal field. In these embodiments, the HEW device **500** may be configured to receive an L-SIG **206** and receive a subsequent signal field **210** (HT-SIG **212**, VHT-SIG **222**, or HEW-SIG **232**). The subsequent signal field **210** may have first and second symbols that are BPSK modulated. In these embodiments, the HEW device **500** may determine whether the PDU is a HT PDU, a VHT PDU or an HEW PDU based on the phase rotation applied to the BPSK modulation of at least one of the first and second symbols of the subsequent signal field **210**. For an HEW PDU, a ninety-degree phase rotation may have been applied to the BPSK modulation of the first symbol **332A** and no phase rotation would have been applied to the BPSK modulation of the second symbol **332B** of the subsequent signal field **210**.

In accordance with some embodiments, the MAC **504** may be arranged to contend for a wireless medium during a contention period to receive control of the medium for the HEW control period and configure an HEW PDU (e.g., FIG. 2D). The PHY **502** may be arranged to transmit the HEW PDU as discussed above. The PHY **502** may include circuitry for modulation/demodulation, upconversion/downconversion, filtering, amplification, etc. In some embodiments, the hardware processing circuitry **506** may include one or more processors. In some embodiments, two or more antennas may be coupled to the PHY **502** and arranged for sending and receiving signals including transmission of the HEW packets. The memory **508** may be store information for configuring the

other circuitry to perform operations for configuring and transmitting HEW packets and performing the various operations described herein.

In some embodiments, the HEW device **500** may be configured to communicate using OFDM communication signals over a multicarrier communication channel. In some embodiments, HEW device **500** may be configured to communicate in accordance with one or more specific communication standards, such as the Institute of Electrical and Electronics Engineers (IEEE) standards including IEEE 802.11-2012, 802.11n-2009, 802.11ac-2013, 802.11ax standards and/or proposed specifications for WLANs, although the scope of the invention is not limited in this respect as they may also be suitable to transmit and/or receive communications in accordance with other techniques and standards.

In some embodiments, the HEW device **500** may be part of a portable wireless communication device, such as a personal digital assistant (PDA), a laptop or portable computer with wireless communication capability, a web tablet, a wireless telephone or smartphone, a wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, a medical device (e.g., a heart rate monitor, a blood pressure monitor, etc.), or other device that may receive and/or transmit information wirelessly. In some embodiments, the HEW device **500** may include one or more of a keyboard, a display, a non-volatile memory port, multiple antennas, a graphics processor, an application processor, speakers, and other mobile device elements. The display may be an LCD screen including a touch screen.

The antennas of the HEW device **500** may comprise one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, patch antennas, loop antennas, microstrip antennas or other types of antennas suitable for transmission of RF signals. In some MIMO embodiments, the antennas may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result between each of antennas and the antennas of a transmitting station.

Although the HEW device **500** is illustrated as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For example, some elements may comprise one or more microprocessors, DSPs, field-programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), radio-frequency integrated circuits (RFICs) and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements of the HEW device **500** may refer to one or more processes operating on one or more processing elements.

Embodiments may be implemented in one or a combination of hardware, firmware and software. Embodiments may also be implemented as instructions stored on a computer-readable storage device, which may be read and executed by at least one processor to perform the operations described herein. A computer-readable storage device may include any non-transitory mechanism for storing information in a form readable by a machine (e.g., a computer). For example, a computer-readable storage device may include read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and other storage devices and media. Some embodiments may include one or more processors and may be configured with instructions stored on a computer-readable storage device.

The Abstract is provided to comply with 37 C.F.R. Section 1.72(b) requiring an abstract that will allow the reader to ascertain the nature and gist of the technical disclosure. It is submitted with the understanding that it will not be used to limit or interpret the scope or meaning of the claims. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate embodiment.

What is claimed is:

1. An access point (AP) arranged for communicating with a plurality of stations (STAs) including high-efficiency Wi-Fi (HEW) stations and legacy stations, the access point comprising hardware processing circuitry and physical layer (PHY) circuitry to:

configure a packet protocol data unit (PPDU) comprising a legacy signal field (L-SIG) following legacy training fields, the L-SIG including at least a length field and a rate field;

select a value for the length field that is not-divisible by three for communicating with the HEW stations; and
select a value for the length field that is divisible by three for communicating with at least some of the legacy stations.

2. The access point of claim **1** wherein the access point is further arranged to configure the L-SIG with a valid parity bit when the length field is selected to be divisible by three and when the length field is selected to be non-divisible by three.

3. The access point of claim **2** wherein, the access point is further arranged to configure the PPDU to include a subsequent signal field following the L-SIG, the subsequent signal field having first and second symbols that have BPSK modulation, and

wherein the access point is further arranged to select a phase rotation for application to the BPSK modulation of at least one of the first and second symbols of the subsequent signal field to distinguish a high-throughput (HT) PPDU, a very-high throughput (VHT) PPDU and an HEW PPDU.

4. The access point of claim **3** wherein for communicating with the HEW stations, the subsequent signal field is an HEW signal field (HEW-SIG) and the access point is arranged to apply a ninety-degree phase rotation to the BPSK modulation of the first symbol of the HEW-SIG and refrain from applying a ninety-degree phase rotation to the BPSK modulation of the second symbol of the HEW-SIG.

5. The access point of claim **4** wherein for communicating with VHT stations, the subsequent signal field is an VHT signal field (VHT-SIG) and the access point is arranged to apply a ninety-degree phase rotation to the BPSK modulation of the second symbol of the VHT-SIG and refrain from applying a ninety-degree phase rotation to the BPSK modulation of the first symbol of the VHT-SIG,

wherein for communicating with HT stations, the subsequent signal field is an HT signal field (HT-SIG) and the access point is arranged to apply a ninety-degree phase rotation to the BPSK modulation of both the first symbol and the second symbol of the HT-SIG, and

wherein for communicating with non-HT stations, the access point is configured to refrain from including the subsequent signal field following the L-SIG.

6. The access point of claim **5** wherein for communicating with the HEW stations and some legacy stations including HT stations and VHT stations, the access point is arranged to select a value for the rate field to cause the non-HT stations to defer transmissions.

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7. The access point of claim 1 wherein the access point is configured to multiply a ceiling function by three and subtract either two or one to calculate the value for the length field for the HEW stations, and

wherein the access point is configured to multiply the ceiling function by three and subtract three to calculate the value for the length field for non-HEW stations.

8. The access point of claim 4 wherein for communicating with HEW stations, the access point is further configured to: configure the PPDU as an HEW PPDU to include a number of long-training fields (LTFs), the number of LTFs being based on a maximum number of streams communicated over a link;

contend for a wireless medium during a contention period to receive control of the medium for an HEW control period; and

transmit the HEW PPDU during the HEW control period, wherein during the HEW control period, the access point operates as a master station having exclusive use of the wireless medium for communication of data with a plurality of scheduled HEW stations in accordance with a non-contention based scheduled orthogonal frequency division multiple access (OFDMA) technique in accordance with signaling information indicated in the HEW-SIG,

wherein the scheduled OFDMA technique is one of an uplink OFDMA technique, a downlink OFDMA technique or a multi-user multiple-input multiple-output (MU-MIMO) technique.

9. The access point of claim 8 wherein for the HEW PPDU, each data field is associated with either a single user (SU) link or a multi-user (MU) link, each link configurable to provide multiple streams of data, and

wherein the links of the HEW PPDU are configurable to have a bandwidth of one of 20 MHz, 40 MHz, 80 MHz or 160 MHz.

10. An access point arranged for communicating with a plurality of stations including high-efficiency Wi-Fi (HEW) stations and legacy stations, the access point comprising hardware processing circuitry and physical layer (PHY) circuitry to configure a packet protocol data unit (PPDU) comprising:

a legacy signal field (L-SIG) following one or more legacy training fields; and

one or more fields following the L-SIG including a subsequent signal field, the subsequent signal field having first and second symbols that have BPSK modulation,

wherein the access point is further arranged to select a phase rotation for application to the BPSK modulation of at least one of the first and second symbols of the subsequent signal field to distinguish a high-throughput (HT) PPDU, a very-high throughput (VHT) PPDU and an HEW PPDU.

11. The access point of claim 10 wherein for communicating with the HEW stations, the subsequent signal field is an HEW signal field (HEW-SIG) and the access point is arranged to apply a ninety-degree phase rotation to the BPSK modulation of the first symbol of the HEW-SIG and refrain from applying a ninety-degree phase rotation to the BPSK modulation of the second symbol of the HEW-SIG.

12. The access point of claim 11 wherein for communicating with VHT stations, the subsequent signal field is an VHT signal field (VHT-SIG) and the access point is arranged to apply a ninety-degree phase rotation to the BPSK modulation of the second symbol of the VHT-SIG and refrain from applying a ninety-degree phase rotation to the BPSK modulation of the first symbol of the VHT-SIG,

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wherein for communicating with HT stations, the subsequent signal field is an HT signal field (HT-SIG) and the access point is arranged to apply a ninety-degree phase rotation to the BPSK modulation of both the first symbol and the second symbol of the HT-SIG, and

wherein for communicating with non-HT stations, the access point is configured to refrain from including the subsequent signal field following the L-SIG.

13. A high-efficiency Wi-Fi (HEW) station arranged to distinguish an HEW packet protocol data unit (PPDU) from a non-HEW PPDU, the HEW station comprising hardware processing circuitry and physical layer (PHY) circuitry configured to:

receive a legacy signal field (L-SIG) following legacy training fields, the L-SIG including at least a length field and a rate field;

determine whether a value for the length field is divisible by three;

verify a parity bit of the L-SIG;

identify the PPDU as an HEW PPDU when the value in the length field is not divisible three and the parity bit is verified; and

identify the PPDU as a non-HEW PPDU when the value in the length field is divisible three and the parity bit is verified.

14. The HEW station of claim 12 wherein the HEW station is further configured to:

decode subsequent fields of the PPDU when the PPDU identified as an HEW PPDU, and

refrain from decoding subsequent fields of the PPDU when the PPDU is identified as a non-HEW PPDU.

15. A high-efficiency Wi-Fi (HEW) station arranged to distinguish an HEW packet protocol data unit (PPDU) from a non-HEW PPDU, the HEW station comprising hardware processing circuitry and physical layer (PHY) circuitry configured to:

receive a legacy signal field (L-SIG) following legacy training fields, the L-SIG including at least a length field and a rate field;

receive a subsequent signal field, the subsequent signal field having first and second symbols that have BPSK modulation,

determine whether the PPDU is a high-throughput (HT) PPDU, a very-high throughput (VHT) PPDU or an HEW PPDU based on the phase rotation applied to the BPSK modulation of at least one of the first and second symbols of the subsequent signal field,

wherein for an HEW PPDU, a ninety-degree phase rotation is applied to the BPSK modulation of the first symbol and no phase rotation is applied to the BPSK modulation of the second symbol of the subsequent signal field.

16. The HEW station of claim 15 wherein when an HEW PPDU is determined, the subsequent signal field is an HEW-SIG, and

wherein the HEW station is further configured to communicate with an HEW master station in accordance with a scheduled OFDMA technique based on information received in the HEW-SIG.

17. A method performed by an access point for communicating with a plurality of stations including high-efficiency Wi-Fi (HEW) stations and legacy stations, the method comprising:

configuring a packet protocol data unit (PPDU) comprising a legacy signal field (L-SIG) following legacy training fields, the L-SIG including at least a length field and a rate field;

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selecting a value for the length field that is not-divisible by three for communicating with the HEW stations; and either
 selecting a value for the length field that is divisible by three for communicating with at least some of the legacy stations; or
 selecting a phase rotation for application to BPSK modulation of at least one of first and second symbols of a subsequent signal field to distinguish a high-throughput (HT) PPDU, a very-high throughput (VHT) PPDU and an HEW PPDU.

18. The method of claim 17 further comprising:
 configuring the PPDU as an HEW PPDU to include a number of long-training fields (LTFs), the number of LTFs being based on a maximum number of streams communicated over a link;
 contending for a wireless medium during a contention period to receive control of the medium for an HEW control period; and
 transmitting the HEW PPDU during the HEW control period, wherein during the HEW control period, the access point operates as a master station having exclusive use of the wireless medium for communication of data with a plurality of scheduled HEW stations in accordance with a non-contention based scheduled orthogonal frequency division multiple access (OFDMA) technique in accordance with signaling information indicated in the HEW-SIG,
 wherein the scheduled OFDMA technique is one of an uplink OFDMA technique, a downlink OFDMA technique or a multi-user multiple-input multiple-output (MU-MIMO) technique.

19. A non-transitory computer-readable storage medium that stores instructions for execution by one or more processors of an access point to perform operations for communicating with a plurality of stations including high-efficiency Wi-Fi (HEW) stations and legacy stations, the operations to configure the access point to:

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configure a packet protocol data unit (PPDU) comprising a legacy signal field (L-SIG) following legacy training fields, the L-SIG including at least a length field and a rate field;
 select a value for the length field that is not-divisible by three for communicating with the HEW stations; and either
 select a value for the length field that is divisible by three for communicating with at least some of the legacy stations; or
 select a phase rotation for application to BPSK modulation of at least one of first and second symbols of a subsequent signal field to distinguish a high-throughput (HT) PPDU, a very-high throughput (VHT) PPDU and an HEW PPDU.

20. The non-transitory computer-readable storage medium of claim 19 wherein the operations further configure the access point to:
 configure the PPDU as an HEW PPDU to include a number of long-training fields (LTFs), the number of LTFs being based on a maximum number of streams communicated over a link;
 contend for a wireless medium during a contention period to receive control of the medium for an HEW control period; and
 transmit the HEW PPDU during the HEW control period, wherein during the HEW control period, the access point operates as a master station having exclusive use of the wireless medium for communication of data with a plurality of scheduled HEW stations in accordance with a non-contention based scheduled orthogonal frequency division multiple access (OFDMA) technique in accordance with signaling information indicated in the HEW-SIG,
 wherein the scheduled OFDMA technique is one of an uplink OFDMA technique, a downlink OFDMA technique or a multi-user multiple-input multiple-output (MU-MIMO) technique.

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