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(54) **HIGH-EFFICIENCY WLAN (HEW) MASTER STATION AND METHODS TO INCREASE INFORMATION BITS FOR HEW COMMUNICATION**

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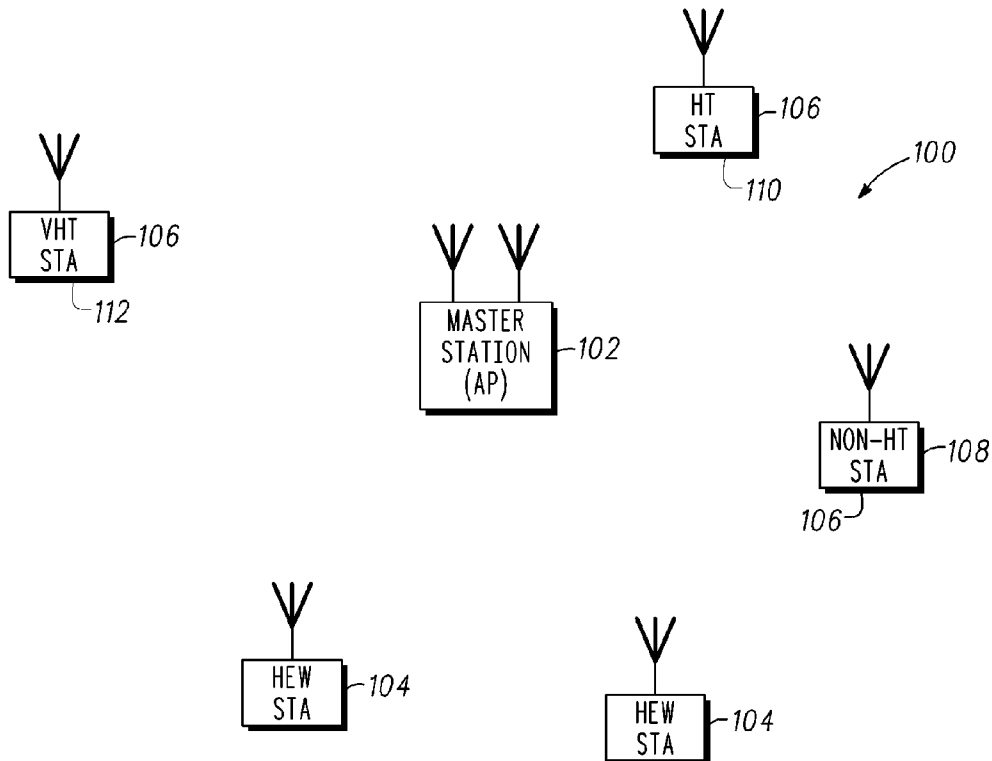
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(57) **ABSTRACT**

Embodiments of an access point and method for high-efficiency WLAN (HEW) communication are generally described herein. In some embodiments, the access point may be configured to operate as a master station and may configure an HEW frame to include a legacy signal field (L-SIG), an HEW signal field (HEW SIG-A) following the L-SIG, and one or more HEW fields following the HEW SIG-A. The L-SIG may be configured for transmission using a legacy number of data subcarriers, a legacy number of pilot subcarriers and a number of additional reference subcarriers modulated with a known reference sequence. At least one symbol of the HEW SIG-A and the one or more HEW fields following the HEW SIG-A of the HEW frame may be configured for transmission using additional data subcarriers. The additional data subcarriers may correspond to the additional reference subcarriers of the L-SIG.



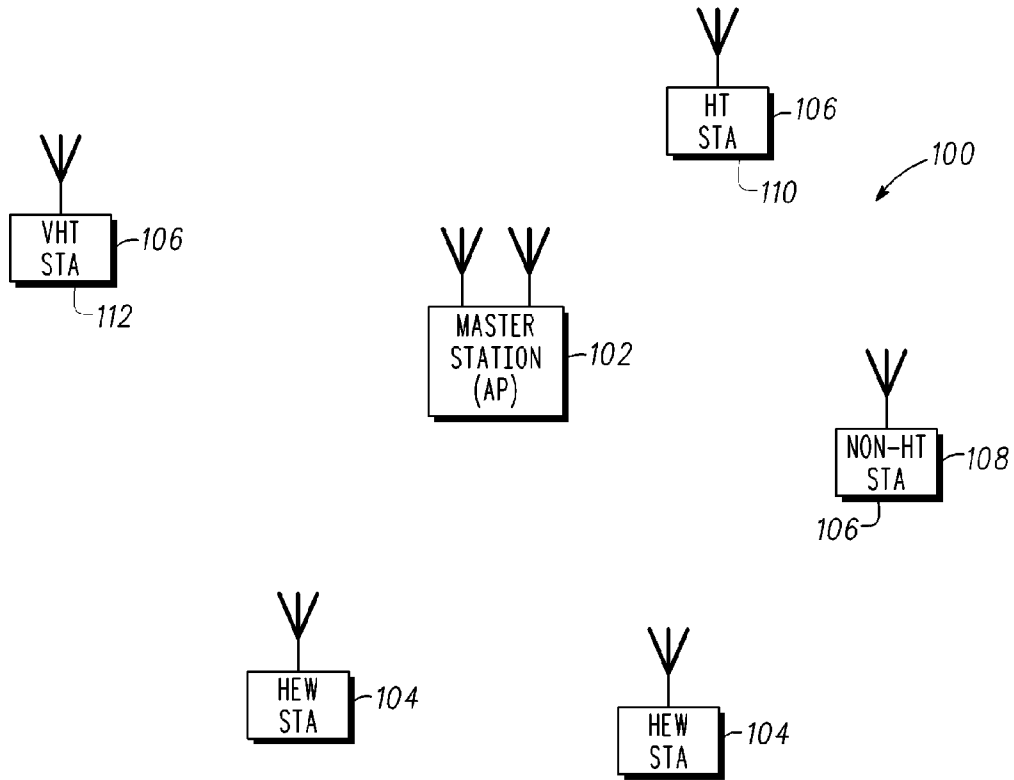


FIG. 1

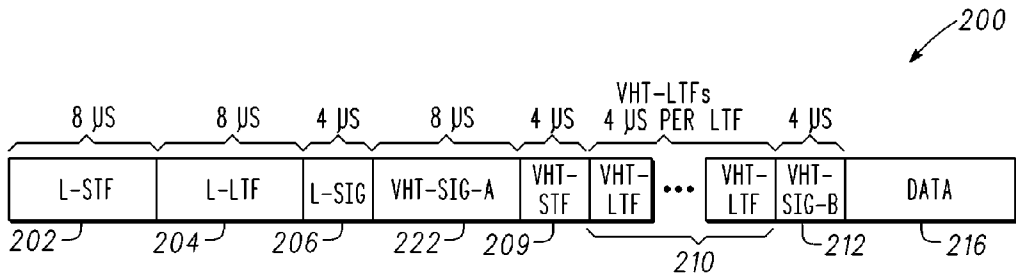


FIG. 2

FIELD	N _{FIELD} AS A FUNCTION OF BANDWIDTH PER FREQUENCY SEGMENT				GUARD INTERVAL DURATION
	20 MHz	40 MHz	80 MHz	160 MHz	
202 L-STF	12	24	48	96	-
204 L-LTF	52	104	208	416	T _{GI2}
206 L-SIG	52	104	208	416	T _{GI}
208 VHT-SIG-A	52	104	208	416	T _{GI}
209 VHT-STF	12	24	48	96	-
210 VHT-LTF	56	114	242	484	T _{GI}
212 VHT-SIG-B	56	114	242	484	T _{GI}
216 VHT-DATA	56	114	242	484	T _{GI} OR T _{GI2}
NON HT DUP OFDM DATA	-	104	208	416	T _{GI}

FIG. 3

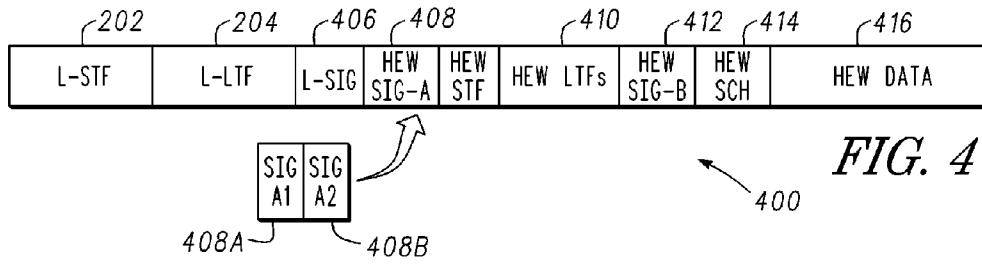


FIG. 4

FIELD	N TONE AS A FUNCTION OF BANDWIDTH PER FREQUENCY SEGMENT				GUARD INTERVAL DURATION
	20 MHz	40 MHz	80 MHz	160 MHz	
202 L-STF	12	24	48	96	-
204 L-LTF	52	104	208	416	T_{GI2}
406 L-SIG	56	114	242	484	T_{GI}
408 HEW-SIG-A	56	114	242	484	T_{GI}
HEW-STF	12	24	48	96	-
410 HEW-LTFs	56	114	242	484	T_{GI}
412 HEW-SIG-B	56	114	242	484	T_{GI}
414 HEW-SCH	56	114	242	484	T_{GI}
416 HEW-DATA	56	114	242	484	T_{GI} OR T_{GI2}

FIG. 5

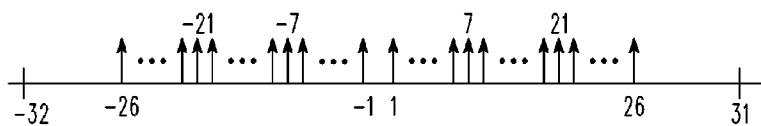


FIG. 6A

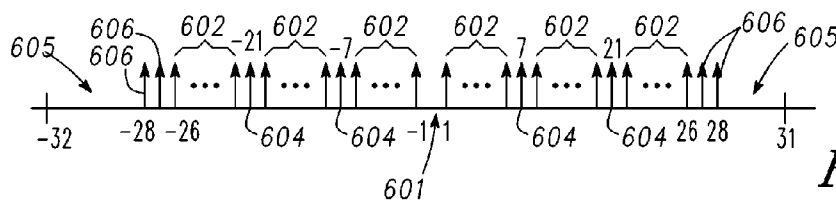


FIG. 6B

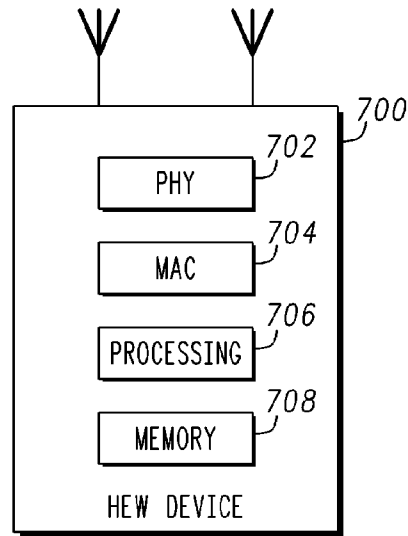


FIG. 7

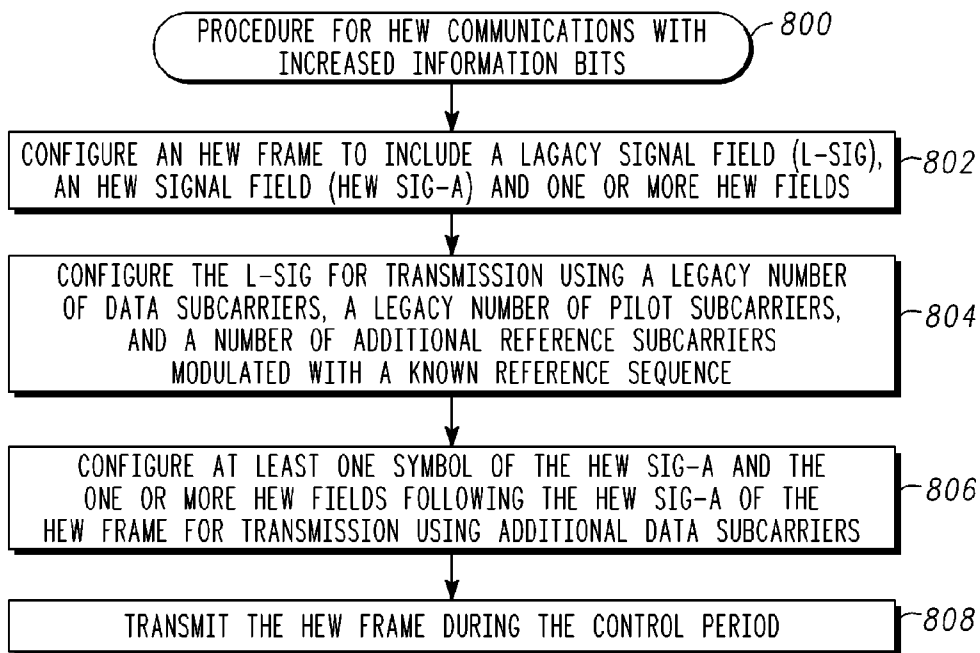


FIG. 8

**HIGH-EFFICIENCY WLAN (HEW) MASTER
STATION AND METHODS TO INCREASE
INFORMATION BITS FOR HEW
COMMUNICATION**

PRIORITY CLAIMS

[0001] This application claims priority under 35 U.S.C. 119 to: United States Provisional Patent Applications: Ser. No. 61/906,059 filed Nov. 19, 2013 [4884.031 PRV (P62429Z)], Ser. No. 61/973,376 filed Apr. 1, 2014 [4884.078 PRV (P65247Z)], Ser. No. 61/976,951 filed Apr. 8, 2014 [4884.087 PRV (P65769Z)], Ser. No. 61/986,256 filed Apr. 30, 2014 [4884.103 PRV (P66983Z)], Ser. No. 61/986,250 filed Apr. 30, 2014 [4884.104 PRV (P66984Z)], Ser. No. 61/991,730 filed May 12, 2014 [4884.108 PRV (P67789Z)], Ser. No. 62/013,869 filed Jun. 18, 2014 [4884.120 PRV (P69557Z)], and Ser. No. 62/024,801 filed Jul. 15, 2014 [4884.128 PRV (P70599Z)], which are all incorporated herein by reference in their entirety.

TECHNICAL FIELD

[0002] Embodiments pertain to wireless networks. Some embodiments relate to Wi-Fi networks and wireless local area networks (WLANs) operating in accordance with one of the IEEE 802.11 standards, such as the IEEE 802.11ac standard or the IEEE 802.11ax SIG (named DensiFi). Some embodiments relate to high-efficiency WLAN (HEW) communications.

BACKGROUND

[0003] Wi-Fi communications has been evolving toward ever increasing data rates (e.g., from IEEE 802.11a/g to IEEE 802.11n to IEEE 802.11ac). The upcoming IEEE 802.11ax standard for High Efficiency WLAN (HEW) is the next evolution of these standards. Thus there are general needs in HEW for achieving an increase in data capacity without additional overhead while maintaining compatibility with legacy systems. There are general needs in HEW for achieving an increase in data capacity while minimizing overhead.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. 1 illustrates an HEW network in accordance with some embodiments;
[0005] FIG. 2 illustrates a legacy frame;
[0006] FIG. 3 is a table illustrating the number of subcarriers for various fields of a legacy frame;
[0007] FIG. 4 illustrates an HEW frame in accordance with some embodiments;
[0008] FIG. 5 is a table illustrating the number of subcarriers for various fields of an HEW frame in accordance with some embodiments;
[0009] FIG. 6A illustrates subcarrier allocations for legacy systems;
[0010] FIG. 6B illustrates subcarrier allocations for HEW in accordance with some embodiments;

[0011] FIG. 7 illustrates an HEW communication device in accordance with some embodiments; and

[0012] FIG. 8 illustrates a procedure for HEW communications with increased information bits in accordance with some embodiments.

DETAILED DESCRIPTION

[0013] 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.

[0014] FIG. 1 illustrates an HEW network in accordance with some embodiments. HEW 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 arranged to communicate with the HEW stations **104** in accordance with an IEEE 802.11ax standard for HEW. 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. Although HEW refers to high-efficiency WLAN, it may also refer to high-efficiency W-Fi.

[0015] In accordance with embodiments, the master station **102** may include 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 scheduled multiple-access 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. In some embodiments, the master-sync transmission may be referred to as an HEW control and schedule transmission.

[0016] In accordance with 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 synchronization and an initial channel estimation.

[0017] In accordance with some embodiments, an HEW station **104** may be a Wi-Fi or IEEE 802.11 configured station (STA) that is further configured for HEW operation (e.g., in accordance with IEEE 802.11ax). An HEW station **104** may be configured to communicate with a master station **102** in accordance with a non-contention-based multiple access

technique, such as a scheduled orthogonal frequency division multiple access (OFDMA) technique, during the HEW control period and may be configured to receive and decode the multi-device HEW preamble of an HEW frame. 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.

[0018] In accordance with embodiments, the master station 102 may configure an HEW frame to include a legacy signal field (L-SIG), an HEW signal field (HEW SIG-A) following the L-SIG, and one or more HEW fields following the HEW SIG-A 408. The L-SIG may be configured for transmission using a legacy number of data subcarriers, a legacy number of pilot subcarriers, and a number of additional reference subcarriers modulated with a known reference sequence. At least one symbol of the HEW SIG-A and the one or more HEW fields following the HEW SIG-A of the HEW frame may be configured for transmission using additional data subcarriers. The additional data subcarriers may correspond to the additional reference subcarriers of the L-SIG. In these embodiments, increased data capacity is achieved by increasing the number of signaling bits without an increase in packet overhead. These embodiments are discussed in more detail below.

[0019] FIG. 2 illustrates a legacy frame. Legacy frame 200 may include legacy short training field (L-STF) 202, legacy long training field (L-LTF) 204, legacy signal field (L-SIG) 206, VHT signal field (VHT-SIG-A) 208, a VHT-STF 209, VHT-LTFs 210, a VHT-SIG-B 212 and data 216. For a 20 MHz channel, the L-SIG 206, as well as some of the fields following the L-SIG 206 (e.g., the VHT-SIG-A 208), may use a legacy number of data subcarriers (i.e., 48) and a legacy number of pilot subcarriers (i.e., 4).

[0020] FIG. 3 is a table illustrating the number of subcarriers for various fields of a legacy frame. As shown in FIG. 3, for a 20 MHz channel, the L-SIG 206, as well as some of the fields following the L-SIG 206 (e.g., the VHT-SIG-A 208), may use a legacy number of data subcarriers (i.e., 48) and a legacy number of pilot subcarriers (i.e., 4) for a total of 52 subcarriers. For a 40 MHz channel, the L-SIG 206 and the VHT-SIG-A 208 may utilize a total of 104 subcarriers, for an 80 MHz channel, the L-SIG 206 and the VHT-SIG-A 208 may utilize a total of 208 subcarriers and for a 160 MHz channel, the L-SIG 206 and the VHT-SIG-A 208 may utilize a total of 416 subcarriers.

[0021] FIG. 4 illustrates an HEW frame in accordance with some embodiments. HEW frame 400 may include legacy short training field (L-STF) 202, legacy long training field (L-LTF) 204, legacy signal field (L-SIG) 406, HEW signal field (HEW SIG-A) 408, a HEW-STF 409, HEW-LTFs 210, an HEW-SIG-B 212, an HEW schedule field (HEW-SCH) 414 and data 216. In accordance with embodiments, the access point, when configured to operate as a master station 102 for HEW communications may configure the HEW frame 400 to include the L-SIG 406, the HEW SIG-A 408 following the L-SIG 406 and one or more HEW fields following the HEW SIG-A 408. The L-SIG 406 may be configured for transmission using a legacy number of data subcarriers, a legacy number of pilot subcarriers, and a number of additional reference subcarriers modulated with a known reference sequence. At least one symbol of the HEW SIG-A 408 and the one or more HEW fields following the HEW SIG-A 408 of the HEW frame 400 may be configured for transmission using additional data subcarriers. The additional data subcarriers may correspond to the additional reference sub-

carriers of the L-SIG 406. Increased data capacity is achieved by increasing the number of signaling bits in the HEW SIG-A 408 without an increase in packet overhead.

[0022] FIG. 5 is a table illustrating the number of subcarriers for various fields of an HEW frame in accordance with some embodiments. As shown in FIG. 5, for a 20 MHz channel, the L-SIG 406 may use a legacy number of data subcarriers (i.e., 48), a number of additional reference subcarriers (e.g., four) modulated with a known reference sequence, and a legacy number of pilot subcarriers (i.e., 4) for a total of 56 subcarriers. For a 20 MHz channel, the HEW SIG-A 408 may use a legacy number of data subcarriers (i.e., 48), a number of additional reference subcarriers (e.g., four) modulated with a known reference sequence, and a legacy number of pilot subcarriers (i.e., 4) for a total of 56 subcarriers. For a 40 MHz channel, the L-SIG 406 and the HEW SIG-A 408 may utilize a total of 114 subcarriers, for an 80 MHz channel, the L-SIG 406 and the HEW SIG-A 408 may utilize a total of 242 subcarriers, and for a 160 MHz channel, the L-SIG 406 and the HEW SIG-A 408 may utilize a total of 484 subcarriers, for example.

[0023] FIG. 6A illustrates subcarrier allocations for legacy systems. The subcarrier allocations illustrated in FIG. 6A may be used for the L-SIG 206 (FIG. 2) and the VHT-SIG-A 208 (FIG. 2) and illustrate a total of 52 subcarriers (located between positions -26 and +26).

[0024] FIG. 6B illustrates subcarrier allocations for HEW in accordance with some embodiments. The subcarrier allocations illustrated in FIG. 6B may be used for the L-SIG 406 (FIG. 4) and one or more fields following the L-SIG 406 include the HEW SIG-A 408 (FIG. 4) and illustrate a total of 56 subcarriers (e.g., located between positions -28 and +28). The subcarrier allocations illustrated in FIG. 6B may include a legacy number of data subcarriers 602, a legacy number of pilot subcarriers 604, and a number of additional reference subcarriers 606.

[0025] In accordance with some embodiments, the L-SIG 406 may be configured for transmission using the legacy number of data subcarriers 602, the legacy number of pilot subcarriers 604, and a number of additional reference subcarriers 606 modulated with a known reference sequence. At least one symbol of the HEW SIG-A 408 and the one or more HEW fields following the HEW SIG-A 408 of the HEW frame 400 may also be configured for transmission using additional data subcarriers 606. The additional data subcarriers corresponding to the additional reference subcarriers 606 of the L-SIG 406.

[0026] In accordance with some embodiments, for a 20 MHz channel, the legacy number of data subcarriers 602 may be forty-eight, the legacy number of pilot subcarriers 604 may be four, and the number of additional subcarriers 606 modulated with a known reference sequence may be four, for a total of sixty-four subcarriers including additional null subcarriers (e.g., the DC subcarrier 601 and guard band subcarriers). The number of data subcarriers of the HEW data field 416 following the HEW SIG-A 408 may be fifty-two. In these embodiments, for a 20 MHz channel, the signal including the L-SIG 408 and following the L-SIG 408 is transmitted on a total of fifty-six subcarriers of the L-SIG 408. The number of data subcarriers of the HEW data field 416 may be fifty-two (e.g., the forty-eight legacy data subcarriers and the four additional data subcarriers). As illustrated in FIG. 6, the L-SIG 406 may also include a DC subcarrier 601 and guard tones 605. In these embodiments, the L-SIG 406 may comprise an OFDM sym-

bol that may be generated using a 64-point FFT. In some embodiments, an HEW frame 400 may be transmitted over wider bandwidths that may comprise a plurality of 20 MHz channels. In some embodiments, bandwidth may be one of 20 MHz, 40 MHz, 80 MHz or 160 MHz. In some embodiments, a 320 MHz bandwidth may be used.

[0027] In accordance with some embodiments, when the HEW frame 400 includes a legacy long-training field (L-LTF) 404 preceding the L-SIG 406, the access point may be configured to scale (e.g., increase) a per-subcarrier power allocation the L-SIG 406 by a factor of 56/52. In some alternate embodiments, the hardware processing circuitry may be configured to scale (e.g., decrease) the per-subcarrier power allocation of the L-LTF 404 by a factor of 52/56. In these embodiments, scaling the per-subcarrier power allocation the either the L-LTF 204 or the L-SIG 406 may help maintain the same overall power level of these fields to reduce any effect on the decoding performance of legacy devices.

[0028] In some embodiments, for a 20 MHz channel, the pilot subcarriers 604 are located at positions -21, -7, 7, 21 with respect to a DC subcarrier 601 and the additional reference subcarriers 606 are located at positions -28, -27, 27, 28 with respect to the DC subcarrier 601. In these embodiments, the additional data subcarriers 606 used by the HEW SIG-A 408 and the one or more HEW fields following the HEW SIG-A 408 may also be located at positions -28, -27, 27, 28 with respect to the DC subcarrier 601.

[0029] In some embodiments, the known reference sequence that is modulated on the additional reference subcarriers 606 of the L-SIG 406 may be used for channel estimation by a receiving HEW station 104 (FIG. 1) to allow the receiving HEW station 104 to demodulate and decode the additional data subcarriers of the HEW SIG-A 408 and the additional data subcarriers of the one or more HEW fields following the HEW SIG-A 408. In these embodiments, the HEW frame 400 may also be configured to include a legacy short training field (L-STF) 202 and a legacy long-training field (L-LTF) 204 preceding the L-SIG 406. The L-STF 202 and the L-LTF 204 may be conventional legacy training fields. In accordance with embodiments, channel estimates for the subcarriers in FIG. 6A may be determined from the L-LTF 204 (i.e., all subcarriers of FIG. 6B except for additional reference subcarriers 606), while channel estimates for the additional subcarriers 606 may be determined from the additional reference subcarriers 606 of the L-SIG 406.

[0030] In some embodiments, the access point may be configured to scale (i.e., increase) a per-subcarrier power allocation the L-SIG 406 by a factor of B/A, where A is the legacy number of data subcarriers 602 plus the legacy number of pilot subcarriers 604, and B is the legacy number of data subcarriers 602 plus the legacy number of pilot subcarriers 604 plus the number of additional subcarriers 606.

[0031] In some embodiments, the pilot subcarriers 604 and the additional reference subcarriers 606 of the L-SIG 408 carry information that is known a-priori to the receiver (e.g., a known reference sequence. In some embodiments, the pilot subcarriers 604 and the additional reference subcarriers 606 of the L-SIG 408 may have the same modulation (e.g., BPSK +1 or BPSK -1), while in other embodiments, the pilot subcarriers 604 and the additional reference subcarriers 606 of the L-SIG 408 may have a different modulation (e.g., pilot subcarriers 604 may have BPSK +1 while the additional reference subcarriers 606 may have BPSK -1).

[0032] In some embodiments, one or more HEW fields following the HEW SIG-A 408 of the HEW frame 400 may include an HEW data field 416 and an HEW schedule field (HEW-SCH) 414 preceding the data field 416. The HEW-SCH 414 may include scheduling information for one or more HEW stations 104 that are scheduled to communication with the access point 102 during the data field 416 in accordance with a scheduled orthogonal-frequency divisional multiple-access (OFDMA) technique. In these embodiments, the HEW-SCH 414 and the data field 416 may utilize additional data subcarriers 606 providing for an increase in data capacity. For example, the data subcarriers may be increased from 48 to 52. In some embodiments, the scheduled OFDMA technique may include uplink or downlink communications and may also include the use of uplink or downlink spatial-division multiple access (SDMA), although the scope of the embodiments is not limited in this respect.

[0033] In some embodiments, the HEW SIG-A 408 comprises at least a first symbol (HEW SIG-A1) 408A and a second symbol (HEW SIG-A2) 408B. In these embodiments, information bits carried by HEW SIG-A1 408A may be mapped on the legacy data subcarriers 602, pilot subcarriers of the HEW SIG-A1 408A may be mapped on the legacy pilot subcarriers 604. The additional reference subcarriers 606 of the HEW SIG-A1 408A may be modulated with a known reference sequence. Information bits carried by HEW SIG-A2 408B may be mapped on the data subcarriers 602 and the additional reference subcarriers 606. The pilot subcarriers of the HEW SIG-A2 408B may be mapped on the legacy pilot subcarriers 604. In these embodiments, the HEW SIG-A2 408B may have an extra four subcarriers for data allocation (e.g., up to 52 data subcarriers for a 20 MHz channel). In these embodiments, rather than a conventional joint encoder/decoder, separate encoders/decoders may be used for the HEW SIG-A1 408A and the HEW SIG-A2 408B. In these embodiments, the extra reference subcarriers of the HEW SIG-A1 408A may be utilized the same way the extra four reference subcarriers 606 are utilized in L-SIG 406 (e.g., for channel estimation) to provide a more robust channel estimation in low SNR cases because receiver may be configured to perform averaging over the reference subcarriers of L-SIG 406 and HEW SIG-A1 408.

[0034] In some embodiments, the HEW SIG-A 408 may include additional symbols, such as an HEW SIG-A3, and HEW SIG-A4, etc. In these embodiments, the additional symbols of the HEW SIG-A 408 may be configured similarly to the HEW SIG-A2 408 B utilizing the extra subcarriers for data allocation. In these embodiments, the additional symbols of the HEW SIG-A 408 as well as the number of additional symbols that may be used may depend on the amount of information to be carried.

[0035] In some embodiments, when the access point 102 is operating as a master station, the access point may be configured to contend for a wireless medium during a contention period to receive control of the medium for the HEW control period, and transmit the HEW frame during the HEW control period, wherein during the HEW control period, the master station has exclusive use of the wireless medium for communication with the scheduled HEW stations 104 in accordance with a non-contention based multiple-access technique. In some embodiments, the non-contention based multiple-access technique may be a scheduled OFDMA technique and may include uplink or downlink communications and may also include the use of uplink or downlink SDMA, although

the scope of the embodiments is not limited in this respect. In these embodiments, the access point **102** may either transmit, within the HEW control period, downlink data multiplexed to each of a plurality of scheduled HEW stations, or receive, within the HEW control period, or uplink data multiplexed from the plurality of scheduled HEW stations. The downlink data from each scheduled station **104** may correspond to one link and comprising one or more streams. The uplink data from each scheduled station may correspond to one link and comprising one or more streams. The downlink data and the uplink data may be time-multiplexed, frequency multiplexed and/or spatially multiplexed. In these embodiments, the access point **102** may include the number of LTFs in an LTF portion **410** of an HEW preamble and may include an HEW schedule field (HEW-SCH) **414** to follow the LTF portion. In these embodiments, the access point **102** may configure the HEW frame to include a legacy preamble to precede the HEW preamble. In these embodiments, the HEW-SCH **414** may be configured to identify one or more of modulation parameters for each of the links, an encoding type for each of the links, whether each link is a single user (SU) link or a multi-user (MU) link; and a number of streams for each link. Each data field **416** may be associated with either a single user (SU) link or a multi-user (MU) link, each link configurable to provide multiple streams of data. In some embodiments, the master station may provide an indication of the number of LTFs that are included in the LTF portion of the HEW preamble. In some embodiments, the selection of the number of LTFs to be included in the HEW preamble may be based on a maximum number of streams to be transmitted on a single link, although the scope of the embodiments is not limited in this respect.

[0036] In accordance with embodiments, a communication station **104** that is configured for HEW communication may be configured to receive an HEW frame **400** that includes at least the L-SIG **406**, the HEW SIG-A **408** following the L-SIG **406**, and one or more HEW fields following the HEW SIG-A **408**. In these embodiments, the HEW station **104** may be configured to decode the data subcarriers **602** of the L-SIG **406** to determine length and rate information, calculate channel estimates for the additional reference subcarriers **606** of the L-SIG **406** from the known reference sequence, and utilize the channel estimates to decode the additional data subcarriers of the at least one symbol of HEW SIG-A **408** and the one or more HEW fields following the HEW SIG-A **408**.

[0037] In some embodiments, the HEW station **104** may be further configured to refrain from decoding the additional reference subcarriers **606** of the L-SIG **406**. These additional reference subcarriers **606** of the L-SIG **406** are for use in determining channel estimates and do not carry any data.

[0038] In some embodiments, the HEW station **104** may be configured to utilize channel estimates determined from a legacy training field (e.g., L-LTF **204**) and additional reference subcarriers L-SIG **406** to decode data subcarriers of the HEW SIG-A **408**. The data subcarriers of the HEW SIG-A **408** correspond to the data subcarriers of the L-SIG **406** and the additional data subcarriers correspond to the additional reference subcarriers **606** of the L-SIG **406**. In these embodiments, all (e.g., 52) data subcarriers of the HEW-SIG A **408** (the additional data subcarriers (corresponding to the additional reference subcarriers **606** of the L-SIG **406**) and the legacy data subcarriers (corresponding to data subcarriers **602** of the L-SIG **406**)) may be demodulated and decoded

together. A 64-point FFT, for example, may be used. Conventionally, the legacy signal field did not utilize additional reference subcarriers **606**.

[0039] In some embodiments, the HEW station **104** may further be configured to determine whether a received frame is an HEW frame **400** or a legacy frame based on whether a value in the length field of the L-SIG is divisible three or based on a phase rotation applied to BPSK modulation of first and second symbols of a subsequent signal field.

[0040] In some embodiments, the HEW station **104** may utilize the additional reference subcarriers **606** of the HEW SIG-A1 **408A** and the additional reference subcarriers **606** of the L-SIG **406** for channel estimation (e.g., using a combining or averaging technique). In these embodiments, the HEW station **104** may decode the HEW SIG-A2 **408B** based on channel estimates obtained from a L-LTF **204**, the L-SIG **406** and the HEW SIG-A1 **408A**, although the scope of the embodiments is not limited in this respect.

[0041] In accordance with some embodiments, the master station **102** may be arranged to select a number of 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 and transmit a plurality of data fields sequentially to 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 referred to as packets. The master station **102** may also be arranged receive packets from HEW stations **104** in the uplink direction during the HEW control period.

[0042] In some embodiments, the master station **102** may be arranged to configure a multi-device HEW preamble to include an HEW control signal field (HEW-SCH) 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.

[0043] In these embodiments, the HEW master-sync transmission that may be transmitted at the beginning of the HEW control period may include the multi-device HEW preamble. The data fields of the HEW frame may be transmitted by the master station **102** after the multi-device HEW preamble within the HEW control period in the downlink direction and/or received by the master station **102** in the uplink direction.

[0044] In some embodiments, the links (e.g., data fields) of an HEW frame may be configurable to have the same bandwidth and the bandwidth may be one of 20 MHz, 40 MHz, or 80 MHz contiguous bandwidths or an 80+80 MHz (160 MHz) non-contiguous bandwidth. In some embodiments, a 320 MHz contiguous bandwidth may be used. In some embodiments, bandwidths of 1 MHz, 1.25 MHz, 2.5 MHz, 5 MHz and/or 10 MHz may also be used. In these embodiments, each link of an HEW frame may be configured for transmitting a number of spatial streams.

[0045] Embodiments disclosed herein increase the number of information bits which can be carried in OFDM symbols transmitted after the legacy (IEEE 802.11a/g) part of Wi-Fi preamble (L-SIG). Since HEW is an evolution of the previous standards and needs to coexist with the legacy systems, HEW specific transmissions may begin with the legacy preamble.

The legacy portion of the preamble may include the L-STF **202**, L-LTF **204**, and L-SIG **206** (see FIG. 2) to allow legacy devices to detect HEW transmissions and to defer appropriately. After decoding the L-SIG **206**, if HEW devices can identify each transmission as either a HEW packet or a legacy packet, the rest of packet can be transmitted with a HEW specific format. Any signal field after the L-SIG may be however limited to channel estimates obtained from L-LTF until a new HEW-LTF is transmitted. This limitation has been the case in previous versions of the standards, namely IEEE 802.11n/ac as well. As depicted in FIG. 2, in IEEE 802.11ac the VHT-SIG-A follows L-SIG, and as identified in the table of FIG. 3, the number of subcarriers matches the L-SIG. The OFDMA symbols transmitted after the VHT-LTF have a larger number of data subcarriers because only after processing the VHT-LTFs does the receiver have channel estimates for larger number of subcarriers.

[0046] As a result of this limitation, the number of information bits carried in VHT-SIG-A **208** is limited to the number of information bits carried in L-SIG because they have same number of data-subcarriers and use the same modulation order and code rate. Embodiments disclosed herein provide for an increase in the number of subcarriers, e.g., in the HEW SIG-A **408** (e.g., to 56, 112, 224 and 448 subcarriers for 20 MHz, 40 MHz, 80 MHz and 160 MHz, respectively). This increase in the number of subcarriers may directly translate to the increased number of information bits. Given that OFDMA is a promising technology for HEW and the fact that OFDMA may require additional information to be signaled and therefore more bits of to be carried in HEW SIG-A **408**, these embodiments enable a more efficient OFDMA bit allocation. It should be noted that carrying more information bits in the HEW SIG-A **408** is very valuable because otherwise an additional complete symbol may be required in the preamble increasing the overall protocol overhead. Since the focus on HEW is efficiency, having a mechanism which increases information bits without adding any additional overhead is key for a successful design, and increases the chance of direct adoption in the standard.

[0047] In accordance with embodiments, additional reference subcarriers are introduced into the L-SIG **406** without impacting the performance of legacy devices **106** in detecting the L-SIG **406**. Legacy devices **106** are not aware of the existence of the additional reference subcarriers and are able to decode the L-SIG **406** as before. However, HEW devices **104** may be configured to be aware of the additional reference subcarriers and use them for obtaining channel estimates for their corresponding subcarriers while decoding the L-SIG similar to legacy devices. These newly obtained channel estimates, attained through the use of the reference subcarriers, are used in a HEW receiver for decoding the subsequent OFDM symbols and in particular for decoding the HEW SIG-A **408** with an increased number of subcarriers.

[0048] One target for HEW is to adopt methods to improve the efficiency of Wi-Fi, and specifically the efficiency in dense deployments. With each new amendment to the Wi-Fi standard, additional signaling is utilized so the subsequent amended systems can identify each transmission and categorize it as either one of the legacy systems transmissions or one from the newer amended standard. In Wi-Fi, to maintain legacy capability, 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. In accordance with embodiments, HEW devices **104** are able to iden-

tify a HEW packet from legacy packets. In these embodiments, an HEW frame **400** may be configured to have the format as shown in FIG. 4. It should be noted that the exact number of fields, their order and duration in time do not change the main concept and these embodiments which can be applied to a more general format, and other bandwidths.

[0049] In accordance with embodiments, the OFDM structure of the L-SIG utilizes a 64-FFT with subcarrier allocation as shown in FIG. 6A where the pilots are located at positions (-21, -7, 7, 21). Pilot tones are assigned after encoder and interleaver. Some embodiments may extend L-SIG to 56 subcarriers similar to the subcarrier allocation as shown in FIG. 6B. The newly assigned reference subcarriers illustrated in FIG. 6B (-28, -27, 27, 28) may be known to the HEW receiver and may be used for channel estimation which will be utilized in the subsequent OFDM symbols HEW SIG-A as depicted in FIG. 4. Similar to pilot tones, these reference subcarriers do not go through encoder and interleaver. The reference sub-carriers are assigned some polarity. Those skilled in art may run computer search programs to find their exact values. In general, the values are selected to provide the best peak-to-average power ratio (PAPR) for a combination of random and deterministic selection of information bits in L-SIG. A simple example of it can make the L-SIG extension similar to the extension of the L-LTF to HT-LTF in Greenfield 11n format. The L-SIG with the additional reference subcarriers may also utilize a 64-bit FFT.

[0050] The addition of these new reference symbols to the L-SIG may have no negative impact to the detection of the L-SIG by legacy devices **106** or HEW devices **104**. Also because it may only be one OFDM symbol out of many in a packet, it will not impact adjacent channel interference. However, attention should be given to the per-tone power scaling. With this extension, per-tone power scaling on L-LTF may be different than on L-SIG, which could affect decoding performance for legacy devices. To make the per-tone power level the same, in some embodiments, the L-LTF symbol power may be lowered (e.g., by **52/56**, for example) depending on the number of subcarriers.

[0051] In accordance with embodiments, an HEW receiver proceeds to decode the L-SIG **406** the same as legacy operation by de-interleaving and decoding **52** legacy subcarriers. Additionally, an HEW station **104** may then calculate channel estimations for subcarriers (e.g., subcarriers at positions -28, -27, 27, 28) using the new reference sub-carriers. If the received packet is identified as an HEW frame, the HEW receiver will utilize channel estimations of the subcarriers at positions -28, -27, 27, 28 in addition to those obtained from the L-LTF in decoding the subsequent OFDM symbols. Having these extended channel estimations available allows the HEW SIG-A to now carry **56** data subcarrier allocations as shown in FIG. 6B. Assuming BPSK modulation and rate $\frac{1}{2}$ coding (or QBPSK) for HEW SIG-A **408**, this translates to an additional two information bits. Subcarriers at positions -28, -27, 27, and 28 are used as an example only as the scope of the embodiments is not limited in this respect.

[0052] In some other embodiments, currently the L-LTF is a repetition of two long training sequences (LTS), and as such, in a very low SNR scenario, the receiver may perform averaging over the two LTSs to obtain more reliable channel estimation. To allow for this same averaging in this proposal for HEW, then the explained subcarrier extension can also be applied to the OFDM symbol that immediately follows L-SIG. In a format such as the one shown in FIG. 4, that would

be the first OFDM symbol of the HEW SIG-A1 408A. Therefore, in this example, the HEW SIG-A1 408A may have 52 subcarriers similar to VHT-SIG-A1. Both the L-SIG and SIG-A1 may be used to calculate channel estimates using the new reference sub-carriers (-28, -27, 27, 28). Then HEW SIG-A2 408B may have an extra four subcarriers for data allocation. In this case, HEW SIG-A1 and HEW SIG-A2 may have independent encoder/decoders unlike the VHT-SIG-A1 and VHT-SIG-A2 that have a joint encoder/decoder.

[0053] Embodiments disclosed herein provide a method that increases the number of subcarriers in the 20 MHz L-SIG (e.g., to 56). Because the L-SIG is duplicated to support bandwidth of 40 MHz in 802.11n, and similar duplication is done to support 80 MHz and 160 MHz in IEEE 802.11ac, the extension L-SIG to 112, 224 and 448 for 40, 80 and 160 MHz, respectively, can be readily applied. The extended reference subcarriers may be utilized at HEW receivers to obtain channel estimates in addition to those obtained from L-LTF. Having channel estimates for 56 subcarriers allows utilizing 56 subcarriers in subsequent OFDM symbols as contrasted to 52 in IEEE 802.11n/11ac. Therefore four data subcarriers are added to HEW SIG-A with no extra overhead. Since the focus on HEW is efficiency, having a mechanism which increases the number of signaling bits without adding any additional overhead is a key to a successful design and increases the chance of direct adoption in the Standards.

[0054] FIG. 7 illustrates an HEW device in accordance with some embodiments. HEW device 700 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 devices. HEW device 700 may be suitable for operating as master station 102 (FIG. 1) or an HEW station 104 (FIG. 1). In accordance with embodiments, HEW device 700 may include, among other things, hardware processing circuitry that may include physical layer (PHY) circuitry 702 and medium-access control layer circuitry (MAC) 704. PHY 702 and MAC 704 may be HEW compliant layers and may also be compliant with one or more legacy IEEE 802.11 standards. PHY 702 may be arranged to transmit HEW frames, such as HEW frame (FIG. 4). HEW device 700 may also include other processing circuitry 706 and memory 708 configured to perform the various operations described herein.

[0055] In accordance with some embodiments, the MAC 704 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 frame. The PHY 702 may be arranged to transmit the HEW frame as discussed above. The PHY 702 may also be arranged to receive an HEW frame from HEW stations. MAC 704 may also be arranged to perform transmitting and receiving operations through the PHY 702. The PHY 702 may include circuitry for modulation/demodulation, upconversion/downconversion, filtering, amplification, etc. In some embodiments, the processing circuitry 706 may include one or more processors. In some embodiments, two or more antennas may be coupled to the physical layer circuitry arranged for sending and receiving signals including transmission of the HEW frame. The memory 708 may be store information for configuring the processing circuitry 706 to perform operations for configuring and transmitting HEW frames and performing the various operations described herein.

[0056] In some embodiments, the HEW device 700 may be configured to communicate using OFDM communication signals over a multicarrier communication channel. In some embodiments, HEW device 700 may be configured to receive signals in accordance with specific communication standards, such as the Institute of Electrical and Electronics Engineers (IEEE) standards including IEEE 802.11-2012, 802.11n-2009 and/or 802.11ac-2013 standards and/or proposed specifications for WLANs including proposed HEW standards, 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 other embodiments, HEW device 700 may be configured to receive signals that were transmitted using one or more other modulation techniques such as spread spectrum modulation (e.g., direct sequence code division multiple access (DS-CDMA) and/or frequency hopping code division multiple access (FH-CDMA)), time-division multiplexing (TDM) modulation, and/or frequency-division multiplexing (FDM) modulation, although the scope of the embodiments is not limited in this respect.

[0057] In some embodiments, HEW device 700 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, HEW device 700 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.

[0058] The antennas of HEW device 700 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 multiple-input multiple-output (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.

[0059] Although HEW device 700 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 HEW device 700 may refer to one or more processes operating on one or more processing elements.

[0060] 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.

[0061] In some embodiments, when HEW device **700** is configured to operate as an HEW station **104** (FIG. 1), the HEW device's receiver may be arranged to receive, during an initial portion of an HEW control period, a master-sync transmission that includes a single multi-device HEW preamble this is arranged to signal and identify a plurality of data fields for a plurality of HEW stations **104** that are scheduled during the HEW control period. The receiver may also be configured to determine an initial channel estimate based on one or more training fields (e.g., a number of LTFs) received within the multi-device HEW preamble. The receiver may also be configured to receive an identified one of the data fields within the HEW control period and demodulate data from the identified data field using the updated channel estimate.

[0062] In some embodiments, the master station **102** may allocate resources to scheduled HEW stations **104** for use during the HEW control period based on criteria that includes one or more of signal-to-noise ratio (SNR), configuration, throughput, amount of data to send, a fairness criteria and quality-of-service requirements. The master station **102** may determine whether stations are HEW stations **104** or legacy stations **106** at the time of association with the master station **102** through a capability exchange. In some embodiments, the master station **102** may notify HEW stations **104** that the control period is to be used for communications in accordance with a multiple-access technique. In some embodiments, the master station **102** may use the control period when there is congestion and communicate in accordance with conventional Wi-Fi techniques (e.g., CSMA/CA) otherwise. In some embodiments, mapping of a control signal may be performed at the beginning of the transmission to list devices that are to communicate during the control period, although the scope of the embodiments is not limited in this respect.

[0063] FIG. 8 illustrates a procedure for HEW communications with increased information bits in accordance with some embodiments. Procedure **800** may be performed by access point configured to operate as a master station, such as master station **102** (FIG. 1) for HEW communications. In operation **802**, the method may include configuring an HEW frame to include a legacy signal field (L-SIG), an HEW signal field (HEW SIG-A) following the L-SIG, and one or more HEW fields following the HEW SIG-A. In operation **804**, the method may include configuring the L-SIG for transmission using a legacy number of data subcarriers, a legacy number of pilot subcarriers, and a number of additional reference subcarriers modulated with a known reference sequence. In operation **806**, the method may include configuring at least one symbol of the HEW SIG-A and the one or more HEW fields following the HEW SIG-A of the HEW frame for transmission using additional data subcarriers. The additional data subcarriers may correspond to the additional reference subcarriers of the L-SIG. In operation **808**, the method may include transmitting the configured HEW frame. The frame

may be transmitted during the HEW control period during which OFDMA communications may take place.

[0064] In one example, an access point is configured to operate as a master station for high-efficiency WLAN (HEW) communications. The access point comprises hardware processing circuitry to configure an HEW frame to include a legacy signal field (L-SIG), an HEW signal field (HEW SIG-A) following the L-SIG, and one or more HEW fields following the HEW SIG-A. In this example, the L-SIG is configured for transmission using a legacy number of data subcarriers, a legacy number of pilot subcarriers, and a number of additional reference subcarriers modulated with a known reference sequence. In this example, at least one symbol of the HEW SIG-A and the one or more HEW fields following the HEW SIG-A of the HEW frame are configured for transmission using additional data subcarriers, the additional data subcarriers corresponding to the additional reference subcarriers of the L-SIG.

[0065] In another example, for a 20 MHz channel, the legacy number of data subcarriers is forty-eight, the legacy number of pilot subcarriers is four, and the number of additional subcarriers modulated with a known reference sequence is four for a total of sixty-four subcarriers, including null subcarriers. In this example, a number of data subcarriers of an HEW data field following the HEW SIG-A is fifty-two.

[0066] In another example, the HEW frame further includes a legacy long-training field (L-LTF) preceding the L-SIG. In this example, the hardware processing circuitry is configured to scale a per-subcarrier power allocation the L-SIG by a factor of 56/52.

[0067] In another example, for a 20 MHz channel, the pilot subcarriers are located at positions -21, -7, 7, 21 with respect to a DC subcarrier and the additional reference subcarriers are located at positions -28, -27, 27, 28 with respect to the DC subcarrier.

[0068] In another example, the known reference sequence that is modulated on the additional reference subcarriers of the L-SIG is to be used for channel estimation by a receiving HEW station to allow the receiving HEW station to demodulate and decode the additional data subcarriers of the HEW SIG-A and the additional data subcarriers of the one or more HEW fields following the HEW SIG-A.

[0069] In another example, the hardware processing circuitry is configured to scale a per-subcarrier power allocation the L-SIG by a factor of B/A , where A is the legacy number of data subcarriers plus the legacy number of pilot subcarriers, and B is the legacy number of data subcarriers plus the legacy number of pilot subcarriers plus the number of additional subcarriers.

[0070] In another example, one or more HEW fields following the HEW SIG-A of the HEW frame include: an HEW data field; and an HEW schedule field (HEW-SCH) preceding the data field that includes scheduling information for one or more HEW stations that are scheduled to communication with the access point during the data field in accordance with a scheduled orthogonal-frequency divisional multiple access (OFDMA) technique.

[0071] In another example, the HEW SIG-A comprises at least a first symbol (HEW SIG-A1) and a second symbol (HEW SIG-A2). In this example, information bits carried by HEW SIG-A1 are mapped on the legacy data subcarriers and pilot subcarriers of the HEW SIG-A1 are mapped on the legacy pilot subcarriers. In this example, the additional reference subcarriers of the HEW SIG-A1 are modulated with a

known reference sequence. In this example, information bits carried by HEW SIG-A2 are mapped on the data subcarriers and the additional reference subcarriers. In this example, pilot subcarriers of the HEW SIG-A2 are mapped on the legacy pilot subcarriers.

[0072] In another example, when the access point is operating as a master station, the access point is arranged to: contend for a wireless medium during a contention period to receive control of the medium for the HEW control period; and transmit the HEW frame during the HEW control period, wherein during the HEW control period, the master station has exclusive use of the wireless medium for communication with the scheduled HEW stations in accordance with a non-contention based multiple-access technique.

[0073] In another example, when the access point is operating as a master station, the access point is arranged to either: transmit, within the HEW control period, downlink data multiplexed to each of a plurality of scheduled HEW stations, the downlink data from each scheduled station corresponding to one link and comprising one or more streams; or receive, within the HEW control period, uplink data multiplexed from the plurality of scheduled HEW stations, the uplink data from each scheduled station corresponding to one link and comprising one or more streams, and include the number of LTFs in an LTF portion of an HEW preamble; include an HEW schedule field (HEW-SCH) to follow the LTF portion; and configure the HEW frame to include a legacy preamble to precede the HEW preamble.

[0074] In another example, a communication station is configured for high-efficiency WLAN (HEW) communications, the station comprising hardware processing circuitry configured to receive an HEW frame that includes at least a legacy signal field (L-SIG), an HEW signal field (HEW SIG-A) following the L-SIG, and one or more HEW fields following the HEW SIG-A. In this example, the L-SIG uses a legacy number of data subcarriers, a legacy number of pilot subcarriers, and a number of additional reference subcarriers modulated with a known reference sequence. In this example, at least one symbol of the HEW SIG-A and the one or more HEW fields following the HEW SIG-A of the HEW frame are configured for transmission using additional data subcarriers, the additional data subcarriers corresponding to the additional reference subcarriers of the L-SIG. In this example, the access point may decode the data subcarriers of the L-SIG to determine length and rate information, calculate channel estimates for the additional reference subcarriers of the L-SIG from the known reference sequence, and utilize the channel estimates to decode the additional data subcarriers of the at least one symbol of HEW SIG-A and the one or more HEW fields following the HEW SIG-A.

[0075] In another example, the communication station may further be configured to refrain from decoding the additional reference subcarriers of the L-SIG.

[0076] In another example, the communication station is configured to utilize channel estimates determined from a legacy training field to decode data subcarriers of the HEW SIG-A, the data subcarriers of the HEW SIG-A corresponding to the data subcarriers of the L-SIG.

[0077] In another example, the communication station may further be configured to determine whether a received frame is an HEW frame or a legacy frame based on whether a value in the length field of the L-SIG is divisible three or based on a phase rotation applied to BPSK modulation of first and second symbols of a subsequent signal field.

[0078] In another example, the HEW SIG-A comprises at least a first symbol (HEW SIG-A1) and a second symbol (HEW SIG-A2). In this example, information bits carried by HEW SIG-A1 are mapped on the legacy data subcarriers, pilot subcarriers of the HEW SIG-A1 are mapped on the legacy pilot subcarriers. In this example, the additional reference subcarriers of the HEW SIG-A1 are modulated with a known reference sequence. In this example, information bits carried by HEW SIG-A2 are mapped on the data subcarriers and the additional reference subcarriers. In this example, pilot subcarriers of the HEW SIG-A2 are mapped on the legacy pilot subcarriers. In this example, the communication station is configured to utilize the additional reference subcarriers of the HEW SIG-A1 and the additional reference subcarriers of the L-SIG for channel estimation; and decode the HEW SIG-A2 based on channel estimates obtained from an L-LTF, the L-SIG and the HEW SIG-A1.

[0079] In another example, a method for high-efficiency WLAN (HEW) communications comprises configuring an HEW frame to include a legacy signal field (L-SIG), an HEW signal field (HEW SIG-A) following the L-SIG, and one or more HEW fields following the HEW SIG-A; and

[0080] wherein the L-SIG is configured for transmission using a legacy number of data subcarriers, a legacy number of pilot subcarriers, and a number of additional reference subcarriers modulated with a known reference sequence, and

[0081] wherein at least one symbol of the HEW SIG-A and the one or more HEW fields following the HEW SIG-A of the HEW frame are configured for transmission using additional data subcarriers, the additional data subcarriers corresponding to the additional reference subcarriers of the L-SIG.

[0082] In another example, for a 20 MHz channel, the legacy number of data subcarriers is forty-eight, the legacy number of pilot subcarriers is four, and the number of additional subcarriers modulated with a known reference sequence is four for a total of sixty-four subcarriers including null subcarriers. In this example, a number of data subcarriers of an HEW data field following the HEW SIG-A is fifty-two. In this example, for a 20 MHz channel, the pilot subcarriers are located at positions -21 , -7 , 7 , 21 with respect to a DC subcarrier and the additional reference subcarriers are located at positions -28 , -27 , 27 , 28 with respect to the DC subcarrier.

[0083] In another example, the known reference sequence that is modulated on the additional reference subcarriers of the L-SIG is to be used for channel estimation by a receiving HEW station to allow the receiving HEW station to demodulate and decode the additional data subcarriers of the HEW SIG-A and the additional data subcarriers of the one or more HEW fields following the HEW SIG-A.

[0084] In another example, 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 high-efficiency WLAN (HEW) communications is provided In this example, the operations to configure the access point to: configure an HEW frame to include a legacy signal field (L-SIG), an HEW signal field (HEW SIG-A) following the L-SIG and one or more HEW fields following the HEW SIG-A. In this example, the L-SIG is configured for transmission using a legacy number of data subcarriers, a legacy number of pilot subcarriers, and a number of additional reference subcarriers modulated with a known reference sequence. In this example, at least one symbol of the HEW SIG-A and the one or more HEW fields

following the HEW SIG-A of the HEW frame are configured for transmission using additional data subcarriers, the additional data subcarriers corresponding to the additional reference subcarriers of the L-SIG.

[0085] In another example, the known reference sequence that is modulated on the additional reference subcarriers of the L-SIG is to be used for channel estimation by a receiving HEW station to allow the receiving HEW station to demodulate and decode the additional data subcarriers of the HEW SIG-A and the additional data subcarriers of the one or more HEW fields following the HEW SIG-A.

[0086] 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 configured to operate as a master station for high-efficiency WLAN (HEW) communications, the access point comprising hardware processing circuitry configured to:

configure an HEW frame to include a legacy signal field (L-SIG), an HEW signal field (HEW SIG-A) following the L-SIG, and one or more HEW fields following the HEW SIG-A,

wherein the L-SIG is configured for transmission using a legacy number of data subcarriers, a legacy number of pilot subcarriers, and a number of additional reference subcarriers modulated with a known reference sequence, and

wherein at least one symbol of the HEW SIG-A and the one or more HEW fields following the HEW SIG-A of the HEW frame are configured for transmission using additional data subcarriers, the additional data subcarriers corresponding to the additional reference subcarriers of the L-SIG.

2. The access point of claim 1 wherein for a 20 MHz channel, the legacy number of data subcarriers is forty-eight, the legacy number of pilot subcarriers is four, and the number of additional subcarriers modulated with a known reference sequence is four for a total of sixty-four subcarriers, including null subcarriers, and

wherein a number of data subcarriers of an HEW data field following the HEW SIG-A is fifty-two.

3. The access point of claim 2 wherein the HEW frame further includes a legacy long-training field (L-LTF) preceding the L-SIG, and

wherein the hardware processing circuitry is configured to scale a per-subcarrier power allocation the L-SIG by a factor of 56/52.

4. The access point of claim 2 wherein for a 20 MHz channel, the pilot subcarriers are located at positions -21 , -7 , 7 , 21 with respect to a DC subcarrier and the additional reference subcarriers are located at positions -28 , -27 , 27 , 28 with respect to the DC subcarrier.

5. The access point of claim 1 wherein the known reference sequence that is modulated on the additional reference subcarriers of the L-SIG is to be used for channel estimation by a receiving HEW station to allow the receiving HEW station to demodulate and decode the additional data subcarriers of

the HEW SIG-A and the additional data subcarriers of the one or more HEW fields following the HEW SIG-A.

6. The access point of claim 5 wherein the hardware processing circuitry is configured to scale a per-subcarrier power allocation the L-SIG by a factor of B/A ,

where A is the legacy number of data subcarriers plus the legacy number of pilot subcarriers, and B is the legacy number of data subcarriers plus the legacy number of pilot subcarriers plus the number of additional subcarriers.

7. The access point of claim 5 wherein one or more HEW fields following the HEW SIG-A of the HEW frame include: an HEW data field; and

an HEW schedule field (HEW-SCH) preceding the data field that includes scheduling information for one or more HEW stations that are scheduled to communication with the access point during the data field in accordance with a scheduled orthogonal-frequency divisional multiple access (OFDMA) technique.

8. The access point of claim 5 wherein the HEW SIG-A comprises at least a first symbol (HEW SIG-A1) and a second symbol (HEW SIG-A2),

wherein information bits carried by HEW SIG-A1 are mapped on the legacy data subcarriers and pilot subcarriers of the HEW SIG-A1 are mapped on the legacy pilot subcarriers,

wherein the additional reference subcarriers of the HEW SIG-A1 are modulated with a known reference sequence,

wherein information bits carried by HEW SIG-A2 are mapped on the data subcarriers and the additional reference subcarriers, and

wherein pilot subcarriers of the HEW SIG-A2 are mapped on the legacy pilot subcarriers.

9. The access point of claim 1 wherein when the access point is operating as a master station, the access point is arranged to:

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

transmit the HEW frame during the HEW control period, wherein during the HEW control period, the master station has exclusive use of the wireless medium for communication with the scheduled HEW stations in accordance with a non-contention based multiple-access technique.

10. The access point of claim 9 wherein when the access point is operating as a master station, the access point is arranged to:

either:

transmit, within the HEW control period, downlink data multiplexed to each of a plurality of scheduled HEW stations, the downlink data from each scheduled station corresponding to one link and comprising one or more streams; or

receive, within the HEW control period, uplink data multiplexed from the plurality of scheduled HEW stations, the uplink data from each scheduled station corresponding to one link and comprising one or more streams, and include the number of LTFs in an LTF portion of an HEW preamble;

include an HEW schedule field (HEW-SCH) to follow the LTF portion; and

configure the HEW frame to include a legacy preamble to precede the HEW preamble.

11. A communication station configured for high-efficiency WLAN (HEW) communications, the station comprising hardware processing circuitry configured to:

- receive an HEW frame that includes at least a legacy signal field (L-SIG), an HEW signal field (HEW SIG-A) following the L-SIG, and one or more HEW fields following the HEW SIG-A,
- wherein the L-SIG uses a legacy number of data subcarriers, a legacy number of pilot subcarriers, and a number of additional reference subcarriers modulated with a known reference sequence, and
- wherein at least one symbol of the HEW SIG-A and the one or more HEW fields following the HEW SIG-A of the HEW frame are configured for transmission using additional data subcarriers, the additional data subcarriers corresponding to the additional reference subcarriers of the L-SIG,

decode the data subcarriers of the L-SIG to determine length and rate information;

calculate channel estimates for the additional reference subcarriers of the L-SIG from the known reference sequence; and

utilize the channel estimates to decode the additional data subcarriers of the at least one symbol of HEW SIG-A and the one or more HEW fields following the HEW SIG-A.

12. The communication station of claim **11** further configured to refrain from decoding the additional reference subcarriers of the L-SIG.

13. The communication station of claim **12** wherein the communication station is configured to utilize channel estimates determined from a legacy training field to decode data subcarriers of the HEW SIG-A, the data subcarriers of the HEW SIG-A corresponding to the data subcarriers of the L-SIG.

14. The communication station of claim **13** further configured to determine whether a received frame is an HEW frame or a legacy frame based on whether a value in the length field of the L-SIG is divisible three or based on a phase rotation applied to BPSK modulation of first and second symbols of a subsequent signal field.

15. The communication station of claim **13**, wherein the HEW SIG-A comprises at least a first symbol (HEW SIG-A1) and a second symbol (HEW SIG-A2),

- wherein information bits carried by HEW SIG-A1 are mapped on the legacy data subcarriers, pilot subcarriers of the HEW SIG-A1 are mapped on the legacy pilot subcarriers,
- wherein the additional reference subcarriers of the HEW SIG-A1 are modulated with a known reference sequence,
- wherein information bits carried by HEW SIG-A2 are mapped on the data subcarriers and the additional reference subcarriers,
- wherein pilot subcarriers of the HEW SIG-A2 are mapped on the legacy pilot subcarriers, and
- wherein the communication station is further configured to:

utilize the additional reference subcarriers of the HEW SIG-A1 and the additional reference subcarriers of the L-SIG for channel estimation; and

decode the HEW SIG-A2 based on channel estimates obtained from an L-LTF, the L-SIG and the HEW SIG-A1.

16. A method for high-efficiency WLAN (HEW) communications comprising:

- configuring an HEW frame to include a legacy signal field (L-SIG), an HEW signal field (HEW SIG-A) following the L-SIG, and one or more HEW fields following the HEW SIG-A,
- wherein the L-SIG is configured for transmission using a legacy number of data subcarriers, a legacy number of pilot subcarriers, and a number of additional reference subcarriers modulated with a known reference sequence, and
- wherein at least one symbol of the HEW SIG-A and the one or more HEW fields following the HEW SIG-A of the HEW frame are configured for transmission using additional data subcarriers, the additional data subcarriers corresponding to the additional reference subcarriers of the L-SIG.

17. The method of claim **16** wherein for a 20 MHz channel, the legacy number of data subcarriers is forty-eight, the legacy number of pilot subcarriers is four, and the number of additional subcarriers modulated with a known reference sequence is four for a total of sixty-four subcarriers including null subcarriers,

- wherein a number of data subcarriers of an HEW data field following the HEW SIG-A is fifty-two, and
- wherein for a 20 MHz channel, the pilot subcarriers are located at positions $-21, -7, 7, 21$ with respect to a DC subcarrier and the additional reference subcarriers are located at positions $-28, -27, 27, 28$ with respect to the DC subcarrier.

18. The method of claim **17** wherein the known reference sequence that is modulated on the additional reference subcarriers of the L-SIG is to be used for channel estimation by a receiving HEW station to allow the receiving HEW station to demodulate and decode the additional data subcarriers of the HEW SIG-A and the additional data subcarriers of the one or more HEW fields following the HEW SIG-A.

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 high-efficiency WLAN (HEW) communications, the operations to configure the access point to:

- configure an HEW frame to include a legacy signal field (L-SIG), an HEW signal field (HEW SIG-A) following the L-SIG, and one or more HEW fields following the HEW SIG-A,
- wherein the L-SIG is configured for transmission using a legacy number of data subcarriers, a legacy number of pilot subcarriers, and a number of additional reference subcarriers modulated with a known reference sequence, and
- wherein at least one symbol of the HEW SIG-A and the one or more HEW fields following the HEW SIG-A of the HEW frame are configured for transmission using additional data subcarriers, the additional data subcarriers corresponding to the additional reference subcarriers of the L-SIG.

20. The non-transitory computer-readable storage medium of claim **19** wherein the known reference sequence that is modulated on the additional reference subcarriers of the L-SIG is to be used for channel estimation by a receiving

HEW station to allow the receiving HEW station to demodulate and decode the additional data subcarriers of the HEW SIG-A and the additional data subcarriers of the one or more HEW fields following the HEW SIG-A.

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