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PACKETS FOR FREQUENCY TRACKING IN WAKE-UP RADIO SYSTEMS

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PRIORITY CLAIM

[0001] This application claims the benefit of priority to U.S. Provisional
Patent Application Serial No. 62/474,868, filed March 22, 2017, which is
10 incorporated herein by reference in its entirety.

TECHNICAL FIELD

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[0002] Embodiments pertain to wireless networks and wireless
communications. Some embodiments relate to wireless local area networks
(WLANs) and Wi-Fi networks including networks operating in accordance with
the IEEE 802.11 family of standards. Some embodiments relate to IEEE
20 802.11ax, IEEE 802.11ba, and/or a low power communications standards, e.g.,
Bluetooth. Some embodiments relate to methods, computer readable media, and
apparatus for packets for frequency tracking in wake-up radio systems. Some
embodiments relate to methods, computer readable media, and apparatus for
packets to enable frequency tracking in non-coherent wake-up radio systems.

25

BACKGROUND

[0003] Efficient use of the resources of a wireless local-area network
30 (WLAN) is important to provide bandwidth and acceptable response times to the
users of the WLAN. However, often there are many devices trying to share the
same resources and some devices may be limited by the communication protocol
they use or by their hardware bandwidth. Moreover, wireless devices may need
to operate with both newer protocols and with legacy device protocols.

BRIEF DESCRIPTION OF THE DRAWINGS

- 5 [0004] The present disclosure is illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like references indicate similar elements and in which:
- [0005] FIG. 1 is a block diagram of a radio architecture in accordance with some embodiments;
- 10 [0006] FIG. 2 illustrates a front-end module circuitry for use in the radio architecture of FIG. 1 in accordance with some embodiments;
- [0007] FIG. 3 illustrates a radio IC circuitry for use in the radio architecture of FIG. 1 in accordance with some embodiments;
- [0008] FIG. 4 illustrates a baseband processing circuitry for use in the radio architecture of FIG. 1 in accordance with some embodiments;
- 15 [0009] FIG. 5 illustrates a wireless network in accordance with some embodiments;
- [0010] FIG. 6 illustrates a block diagram of an example machine upon which any one or more of the operations/techniques (e.g., methodologies) discussed herein may perform;
- 20 [0011] FIG. 7 illustrates a block diagram of an example wireless device upon which any one or more of the techniques (e.g., methodologies or operations) discussed herein may perform;
- [0012] FIG. 8 illustrates transmission of packets for frequency tracking in wake-up radio systems in accordance with some embodiments.
- 25 [0013] FIG. 9 illustrates a method of communicating packets for frequency tracking in wake-up radio systems in accordance with some embodiments;
- [0014] FIG. 10 illustrates a frame with a wake-up preamble in accordance with some embodiments;
- 30 [0015] FIG. 11 illustrates a frame with one or more synchronization fields in accordance with some embodiments;

[0016] FIG. 12 illustrates a frame with one or more synchronization fields in accordance with some embodiments;

[0017] FIG. 13 illustrates carrier offset in accordance with some embodiments;

5 [0018] FIG. 14 illustrates synchronization information in accordance with some embodiments;

[0019] FIG. 15 illustrates a method of packets for frequency tracking in accordance with some embodiments;

[0020] FIG. 16 illustrates a method of packets for frequency tracking in
10 accordance with some embodiments;

[0021] FIG. 17 illustrates a low power (LP) wake-up radio (WUR) (LP-WUR) device in accordance with some embodiments; and

[0022] FIG. 18 illustrates a method of packets for frequency tracking in accordance with some embodiments.

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DESCRIPTION

[0023] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other
20 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.

[0024] FIG. 1 is a block diagram of a radio architecture 100 in
25 accordance with some embodiments. Radio architecture 100 may include radio front-end module (FEM) circuitry 104, radio IC circuitry 106 and baseband processing circuitry 108. Radio architecture 100 as shown includes both Wireless Local Area Network (WLAN) functionality and Bluetooth (BT) functionality although embodiments are not so limited. In this disclosure,
30 “WLAN” and “Wi-Fi” are used interchangeably.

[0025] FEM circuitry 104 may include a WLAN or Wi-Fi FEM circuitry 104A and a Bluetooth (BT) FEM circuitry 104B. The WLAN FEM circuitry 104A may include a receive signal path comprising circuitry configured to

operate on WLAN RF signals received from one or more antennas 101, to amplify the received signals and to provide the amplified versions of the received signals to the WLAN radio IC circuitry 106A for further processing. The BT FEM circuitry 104B may include a receive signal path which may

5 include circuitry configured to operate on BT RF signals received from one or more antennas 101, to amplify the received signals and to provide the amplified versions of the received signals to the BT radio IC circuitry 106B for further processing. FEM circuitry 104A may also include a transmit signal path which may include circuitry configured to amplify WLAN signals provided by the

10 radio IC circuitry 106A for wireless transmission by one or more of the antennas 101. In addition, FEM circuitry 104B may also include a transmit signal path which may include circuitry configured to amplify BT signals provided by the radio IC circuitry 106B for wireless transmission by the one or more antennas. In the embodiment of FIG. 1, although FEM 104A and FEM 104B are shown as

15 being distinct from one another, embodiments are not so limited, and include within their scope the use of an FEM (not shown) that includes a transmit path and/or a receive path for both WLAN and BT signals, or the use of one or more FEM circuitries where at least some of the FEM circuitries share transmit and/or receive signal paths for both WLAN and BT signals.

20 [0026] Radio IC circuitry 106 as shown may include WLAN radio IC circuitry 106A and BT radio IC circuitry 106B. The WLAN radio IC circuitry 106A may include a receive signal path which may include circuitry to down-convert WLAN RF signals received from the FEM circuitry 104A and provide baseband signals to WLAN baseband processing circuitry 108A. BT radio IC

25 circuitry 106B may in turn include a receive signal path which may include circuitry to down-convert BT RF signals received from the FEM circuitry 104B and provide baseband signals to BT baseband processing circuitry 108B. WLAN radio IC circuitry 106A may also include a transmit signal path which may include circuitry to up-convert WLAN baseband signals provided by the

30 WLAN baseband processing circuitry 108A and provide WLAN RF output signals to the FEM circuitry 104A for subsequent wireless transmission by the one or more antennas 101. BT radio IC circuitry 106B may also include a transmit signal path which may include circuitry to up-convert BT baseband

signals provided by the BT baseband processing circuitry 108B and provide BT RF output signals to the FEM circuitry 104B for subsequent wireless transmission by the one or more antennas 101. In the embodiment of FIG. 1, although radio IC circuitries 106A and 106B are shown as being distinct from one another, embodiments are not so limited, and include within their scope the use of a radio IC circuitry (not shown) that includes a transmit signal path and/or a receive signal path for both WLAN and BT signals, or the use of one or more radio IC circuitries where at least some of the radio IC circuitries share transmit and/or receive signal paths for both WLAN and BT signals.

10 [0027] Baseband processing circuitry 108 may include a WLAN baseband processing circuitry 108A and a BT baseband processing circuitry 108B. The WLAN baseband processing circuitry 108A may include a memory, such as, for example, a set of RAM arrays in a Fast Fourier Transform or Inverse Fast Fourier Transform block (not shown) of the WLAN baseband processing circuitry 108A. Each of the WLAN baseband circuitry 108A and the BT baseband circuitry 108B may further include one or more processors and control logic to process the signals received from the corresponding WLAN or BT receive signal path of the radio IC circuitry 106, and to also generate corresponding WLAN or BT baseband signals for the transmit signal path of the radio IC circuitry 106. Each of the baseband processing circuitries 108A and 108B may further include physical layer (PHY) and medium access control layer (MAC) circuitry, and may further interface with application processor 111 for generation and processing of the baseband signals and for controlling operations of the radio IC circuitry 106.

25 [0028] According to the embodiment illustrated in FIG. 1, WLAN-BT coexistence circuitry 113 may include logic providing an interface between the WLAN baseband circuitry 108A and the BT baseband circuitry 108B, which may enable embodiments requiring WLAN and BT coexistence. In addition, a switch 103 may be provided between the WLAN FEM circuitry 104A and the BT FEM circuitry 104B to allow switching between the WLAN and BT radios according to application needs. In addition, although the antennas 101 are depicted as being respectively connected to the WLAN FEM circuitry 104A and the BT FEM circuitry 104B, embodiments include within their scope the sharing

of one or more antennas as between the WLAN and BT FEMs, or the provision of more than one antenna connected to each of FEM 104A or 104B.

[0029] In some embodiments, the front-end module circuitry 104, the radio IC circuitry 106, and baseband processing circuitry 108 may be provided
5 on a single radio card, such as wireless radio card 102. In some other embodiments, the one or more antennas 101, the FEM circuitry 104 and the radio IC circuitry 106 may be provided on a single radio card. In some other embodiments, the radio IC circuitry 106 and the baseband processing circuitry 108 may be provided on a single chip or integrated circuit (IC), such as IC 112.

10 [0030] In some embodiments, the wireless radio card 102 may include a WLAN radio card and may be configured for Wi-Fi communications, although the scope of the embodiments is not limited in this respect. In some of these embodiments, the radio architecture 100 may be configured to receive and transmit orthogonal frequency division multiplexed (OFDM) or orthogonal
15 frequency division multiple access (OFDMA) communication signals over a multicarrier communication channel. The OFDM or OFDMA signals may comprise a plurality of orthogonal subcarriers.

[0031] In some of these multicarrier embodiments, radio architecture 100 may be part of a Wi-Fi communication station (STA) such as a wireless access
20 point (AP), a base station or a mobile device including a Wi-Fi device. In some of these embodiments, radio architecture 100 may be configured to transmit and receive signals in accordance with specific communication standards and/or protocols, such as any of the Institute of Electrical and Electronics Engineers (IEEE) standards including, IEEE 802.11n-2009, IEEE 802.11-2012, IEEE
25 802.11-2016, IEEE 802.11ac, and/or IEEE 802.11ax standards and/or proposed specifications for WLANs, although the scope of embodiments is not limited in this respect. Radio architecture 100 may also be suitable to transmit and/or receive communications in accordance with other techniques and standards.

[0032] In some embodiments, the radio architecture 100 may be
30 configured for high-efficiency (HE) Wi-Fi (HEW) communications in accordance with the IEEE 802.11ax standard. In these embodiments, the radio architecture 100 may be configured to communicate in accordance with an

OFDMA technique, although the scope of the embodiments is not limited in this respect.

[0033] In some other embodiments, the radio architecture 100 may be configured to transmit and receive signals 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.

10 [0034] In some embodiments, as further shown in FIG. 1, the BT baseband circuitry 108B may be compliant with a Bluetooth (BT) connectivity standard such as Bluetooth, Bluetooth 4.0 or Bluetooth 5.0, or any other iteration of the Bluetooth Standard. In embodiments that include BT functionality as shown for example in Fig. 1, the radio architecture 100 may be configured to establish a BT synchronous connection oriented (SCO) link and/or a BT low energy (BT LE) link. In some of the embodiments that include functionality, the radio architecture 100 may be configured to establish an extended SCO (eSCO) link for BT communications, although the scope of the embodiments is not limited in this respect. In some of these embodiments that include a BT functionality, the radio architecture may be configured to engage in a BT Asynchronous Connection-Less (ACL) communications, although the scope of the embodiments is not limited in this respect. In some embodiments, as shown in FIG. 1, the functions of a BT radio card and WLAN radio card may be combined on a single wireless radio card, such as single wireless radio card 102, although embodiments are not so limited, and include within their scope discrete WLAN and BT radio cards

[0035] In some embodiments, the radio-architecture 100 may include other radio cards, such as a cellular radio card configured for cellular (e.g., 3GPP such as LTE, LTE-Advanced or 5G communications).

30 [0036] In some IEEE 802.11 embodiments, the radio architecture 100 may be configured for communication over various channel bandwidths including bandwidths having center frequencies of about 900 MHz, 2.4 GHz, 5 GHz, and bandwidths of about 1 MHz, 2 MHz, 2.5 MHz, 4 MHz, 5MHz, 8

MHz, 10 MHz, 16 MHz, 20 MHz, 40MHz, 80MHz (with contiguous bandwidths) or 80+80MHz (160MHz) (with non-contiguous bandwidths). In some embodiments, a 320 MHz channel bandwidth may be used. The scope of the embodiments is not limited with respect to the above center frequencies

5 however.

[0037] FIG. 2 illustrates FEM circuitry 200 in accordance with some embodiments. The FEM circuitry 200 is one example of circuitry that may be suitable for use as the WLAN and/or BT FEM circuitry 104A/104B (FIG. 1), although other circuitry configurations may also be suitable.

10 [0038] In some embodiments, the FEM circuitry 200 may include a TX/RX switch 202 to switch between transmit mode and receive mode operation. The FEM circuitry 200 may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry 200 may include a low-noise amplifier (LNA) 206 to amplify received RF signals 203 and
15 provide the amplified received RF signals 207 as an output (e.g., to the radio IC circuitry 106 (FIG. 1)). The transmit signal path of the circuitry 200 may include a power amplifier (PA) to amplify input RF signals 209 (e.g., provided by the radio IC circuitry 106), and one or more filters 212, such as band-pass filters (BPFs), low-pass filters (LPFs) or other types of filters, to generate RF signals
20 215 for subsequent transmission (e.g., by one or more of the antennas 101 (FIG. 1)).

[0039] In some dual-mode embodiments for Wi-Fi communication, the FEM circuitry 200 may be configured to operate in either the 2.4 GHz frequency spectrum or the 5 GHz frequency spectrum. In these embodiments, the receive
25 signal path of the FEM circuitry 200 may include a receive signal path duplexer 204 to separate the signals from each spectrum as well as provide a separate LNA 206 for each spectrum as shown. In these embodiments, the transmit signal path of the FEM circuitry 200 may also include a power amplifier 210 and a filter 212, such as a BPF, a LPF or another type of filter for each frequency
30 spectrum and a transmit signal path duplexer 214 to provide the signals of one of the different spectrums onto a single transmit path for subsequent transmission by the one or more of the antennas 101 (FIG. 1). In some embodiments, BT

communications may utilize the 2.4 GHZ signal paths and may utilize the same FEM circuitry 200 as the one used for WLAN communications.

[0040] FIG. 3 illustrates radio IC circuitry 300 in accordance with some embodiments. The radio IC circuitry 300 is one example of circuitry that may be
5 suitable for use as the WLAN or BT radio IC circuitry 106A/106B (FIG. 1), although other circuitry configurations may also be suitable.

[0041] In some embodiments, the radio IC circuitry 300 may include a receive signal path and a transmit signal path. The receive signal path of the radio IC circuitry 300 may include at least mixer circuitry 302, such as, for
10 example, down-conversion mixer circuitry, amplifier circuitry 306 and filter circuitry 308. The transmit signal path of the radio IC circuitry 300 may include at least filter circuitry 312 and mixer circuitry 314, such as, for example, up-conversion mixer circuitry. Radio IC circuitry 300 may also include synthesizer circuitry 304 for synthesizing a frequency 305 for use by the mixer circuitry 302
15 and the mixer circuitry 314. The mixer circuitry 302 and/or 314 may each, according to some embodiments, be configured to provide direct conversion functionality. The latter type of circuitry presents a much simpler architecture as compared with standard super-heterodyne mixer circuitries, and any flicker noise brought about by the same may be alleviated for example through the use of
20 OFDM modulation. Fig. 3 illustrates only a simplified version of a radio IC circuitry, and may include, although not shown, embodiments where each of the depicted circuitries may include more than one component. For instance, mixer circuitry 320 and/or 314 may each include one or more mixers, and filter circuitries 308 and/or 312 may each include one or more filters, such as one or
25 more BPFs and/or LPFs according to application needs. For example, when mixer circuitries are of the direct-conversion type, they may each include two or more mixers.

[0042] In some embodiments, mixer circuitry 302 may be configured to down-convert RF signals 207 received from the FEM circuitry 104 (FIG. 1)
30 based on the synthesized frequency 305 provided by synthesizer circuitry 304. The amplifier circuitry 306 may be configured to amplify the down-converted signals and the filter circuitry 308 may include a LPF configured to remove unwanted signals from the down-converted signals to generate output baseband

signals 307. Output baseband signals 307 may be provided to the baseband processing circuitry 108 (FIG. 1) for further processing. In some embodiments, the output baseband signals 307 may be zero-frequency baseband signals, although this is not a requirement. In some embodiments, mixer circuitry 302
5 may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[0043] In some embodiments, the mixer circuitry 314 may be configured to up-convert input baseband signals 311 based on the synthesized frequency 305 provided by the synthesizer circuitry 304 to generate RF output signals 209
10 for the FEM circuitry 104. The baseband signals 311 may be provided by the baseband processing circuitry 108 and may be filtered by filter circuitry 312. The filter circuitry 312 may include a LPF or a BPF, although the scope of the embodiments is not limited in this respect.

[0044] In some embodiments, the mixer circuitry 302 and the mixer
15 circuitry 314 may each include two or more mixers and may be arranged for quadrature down-conversion and/or up-conversion respectively with the help of synthesizer 304. In some embodiments, the mixer circuitry 302 and the mixer circuitry 314 may each include two or more mixers each configured for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer
20 circuitry 302 and the mixer circuitry 314 may be arranged for direct down-conversion and/or direct up-conversion, respectively. In some embodiments, the mixer circuitry 302 and the mixer circuitry 314 may be configured for super-heterodyne operation, although this is not a requirement.

[0045] Mixer circuitry 302 may comprise, according to one embodiment:
25 quadrature passive mixers (e.g., for the in-phase (I) and quadrature phase (Q) paths). In such an embodiment, RF input signal 207 from Fig. 3 may be down-converted to provide I and Q baseband output signals to be sent to the baseband processor

[0046] Quadrature passive mixers may be driven by zero and ninety-
30 degree time-varying LO switching signals provided by a quadrature circuitry which may be configured to receive a LO frequency (f_{LO}) from a local oscillator or a synthesizer, such as LO frequency 305 of synthesizer 304 (FIG. 3). In some embodiments, the LO frequency may be the carrier frequency, while in other

embodiments, the LO frequency may be a fraction of the carrier frequency (e.g., one-half the carrier frequency, one-third the carrier frequency). In some embodiments, the zero and ninety-degree time-varying switching signals may be generated by the synthesizer, although the scope of the embodiments is not

5 limited in this respect.

[0047] In some embodiments, the LO signals may differ in duty cycle (the percentage of one period in which the LO signal is high) and/or offset (the difference between start points of the period). In some embodiments, the LO signals may have a 25% duty cycle and a 50% offset. In some embodiments, each branch of the mixer circuitry (e.g., the in-phase (I) and quadrature phase (Q) path) may operate at a 25% duty cycle, which may result in a significant reduction in power consumption.

[0048] The RF input signal 207 (FIG. 2) may comprise a balanced signal, although the scope of the embodiments is not limited in this respect. The I and Q baseband output signals may be provided to low-noise amplifier, such as amplifier circuitry 306 (FIG. 3) or to filter circuitry 308 (FIG. 3).

[0049] In some embodiments, the output baseband signals 307 and the input baseband signals 311 may be analog baseband signals, although the scope of the embodiments is not limited in this respect. In some alternate embodiments, the output baseband signals 307 and the input baseband signals 311 may be digital baseband signals. In these alternate embodiments, the radio IC circuitry may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry.

[0050] In some dual-mode embodiments, a separate radio IC circuitry may be provided for processing signals for each spectrum, or for other spectrums not mentioned here, although the scope of the embodiments is not limited in this respect.

[0051] In some embodiments, the synthesizer circuitry 304 may be a fractional-N synthesizer or a fractional N/N+1 synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 304 may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider. According to some embodiments,

the synthesizer circuitry 304 may include digital synthesizer circuitry. An advantage of using a digital synthesizer circuitry is that, although it may still include some analog components, its footprint may be scaled down much more than the footprint of an analog synthesizer circuitry. In some embodiments, frequency input into synthesizer circuitry 304 may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. A divider control input may further be provided by either the baseband processing circuitry 108 (FIG. 1) or the application processor 111 (FIG. 1) depending on the desired output frequency 305. In some embodiments, a divider control input (e.g., N) may be determined from a look-up table (e.g., within a Wi-Fi card) based on a channel number and a channel center frequency as determined or indicated by the application processor 111.

[0052] In some embodiments, synthesizer circuitry 304 may be configured to generate a carrier frequency as the output frequency 305, while in other embodiments, the output frequency 305 may be a fraction of the carrier frequency (e.g., one-half the carrier frequency, one-third the carrier frequency). In some embodiments, the output frequency 305 may be a LO frequency (f_{LO}).

[0053] FIG. 4 illustrates a functional block diagram of baseband processing circuitry 400 in accordance with some embodiments. The baseband processing circuitry 400 is one example of circuitry that may be suitable for use as the baseband processing circuitry 108 (FIG. 1), although other circuitry configurations may also be suitable. The baseband processing circuitry 400 may include a receive baseband processor (RX BBP) 402 for processing receive baseband signals 309 provided by the radio IC circuitry 106 (FIG. 1) and a transmit baseband processor (TX BBP) 404 for generating transmit baseband signals 311 for the radio IC circuitry 106. The baseband processing circuitry 400 may also include control logic 406 for coordinating the operations of the baseband processing circuitry 400.

[0054] In some embodiments (e.g., when analog baseband signals are exchanged between the baseband processing circuitry 400 and the radio IC circuitry 106), the baseband processing circuitry 400 may include ADC 410 to convert analog baseband signals received from the radio IC circuitry 106 to digital baseband signals for processing by the RX BBP 402. In these

embodiments, the baseband processing circuitry 400 may also include DAC 412 to convert digital baseband signals from the TX BBP 404 to analog baseband signals.

[0055] In some embodiments that communicate OFDM signals or
5 OFDMA signals, such as through baseband processor 108A, the transmit baseband processor 404 may be configured to generate OFDM or OFDMA signals as appropriate for transmission by performing an inverse fast Fourier transform (IFFT). The receive baseband processor 402 may be configured to process received OFDM signals or OFDMA signals by performing an FFT. In
10 some embodiments, the receive baseband processor 402 may be configured to detect the presence of an OFDM signal or OFDMA signal by performing an autocorrelation, to detect a preamble, such as a short preamble, and by performing a cross-correlation, to detect a long preamble. The preambles may be part of a predetermined frame structure for Wi-Fi communication.

[0056] Referring back to FIG. 1, in some embodiments, the antennas 101
15 (FIG. 1) may each 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)
20 embodiments, the antennas may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result. Antennas 101 may each include a set of phased-array antennas, although embodiments are not so limited.

[0057] Although the radio-architecture 100 is illustrated as having
25 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
30 (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 may refer to one or more processes operating on one or more processing elements.

[0058] FIG. 5 illustrates a WLAN 100 in accordance with some embodiments. The WLAN may comprise a basis service set (BSS) 100 that may include one or more HE AP 502, which may be APs, one or more high efficiency (HE) wireless stations (HE stations) (e.g., IEEE 802.11ax) HE stations 104, a plurality of legacy (e.g., IEEE 802.11n/ac) devices 506, a plurality of IoT devices 508 (e.g., IEEE 802.11ax), LP-WUR devices 514, and one or more sensor hubs 510.

[0059] The HE AP 502 may be an AP using the IEEE 802.11 to transmit and receive. The HE AP 502 may be a base station. The HE AP 502 may use other communications protocols as well as the IEEE 802.11 protocol. The IEEE 802.11 protocol may be IEEE 802.11ax. The IEEE 802.11 protocol may include using orthogonal frequency division multiple-access (OFDMA), time division multiple access (TDMA), and/or code division multiple access (CDMA). The IEEE 802.11 protocol may include a multiple access technique. For example, the IEEE 802.11 protocol may include space-division multiple access (SDMA) and/or multiple-user multiple-input multiple-output (MU-MIMO). The HE AP 502 may be a virtual HE AP 502 shares hardware resources with another wireless device such as another HE AP 502.

[0060] The legacy devices 506 may operate in accordance with one or more of IEEE 802.11 a/b/g/n/ac/ad/af/ah/aj/ab, or another legacy wireless communication standard. The legacy devices 506 may be STAs or IEEE STAs. The HE stations 504 may be wireless transmit and receive devices such as cellular telephone, smart telephone, handheld wireless device, wireless glasses, wireless watch, wireless personal device, tablet, a portable wireless device, or another device that may be transmitting and receiving using the IEEE 802.11 protocol such as IEEE 802.11ax or another wireless protocol. In some embodiments, the HE stations 504 may be termed high efficiency wireless local-area network (HEW) stations.

[0061] The HE AP 502 may communicate with legacy devices 506 in accordance with legacy IEEE 802.11 communication techniques. In example

embodiments, the HE AP 502 may also be configured to communicate with HE stations 504 in accordance with legacy IEEE 802.11 communication techniques.

[0062] The IoT devices 508 may operate in accordance with IEEE 802.11ax, IEEE 802.11ba, or another standard of 802.11. The IoT devices 508 may be, in some embodiments, narrow band devices that operate on a smaller sub-channel than the HE stations 504. For example, the IoT devices 508 may operate on 2.03 MHz or 4.06 MHz sub-channels. In some embodiments, the IoT devices 508 are not able to transmit on a full 20 MHz sub-channel to the HE AP 502 with sufficient power for the HE AP 502 to receive the transmission. In some embodiments, the IoT devices 508 are not able to receive on a 20 MHz sub-channel and must use a small sub-channel such as 2.03 MHz or 4.06 MHz sub-channel. In some embodiments, the IoT devices 508 may operate on a sub-channel with exactly 26 or 52 data sub-carriers. The IoT devices 508, in some embodiments, may be short-range, low-power devices.

[0063] The IoT devices 508 may be battery constrained. The IoT devices 508 may be sensors designed to measure one or more specific parameters of interest such as temperature sensor, pressure sensor, humidity sensor, light sensor, etc. The IoT devices 508 may be location-specific sensors. Some IoT devices 508 may be connected to a sensor hub 510. The IoT devices 508 may upload measured data from sensors to the sensor hub 510. The sensor hubs 510 may upload the data to an access gateway 512 that connects several sensor hubs 510 and can connect to a cloud sever or the Internet (not illustrated). The HE AP 502 may act as the access gateway 512 in accordance with some embodiments. The HE AP 502 may act as the sensor hub 510 in accordance with some embodiments. The IoT device 508 may have identifiers that identify a type of data that is measured from the sensors. In some embodiments, the IoT device 508 may be able to determine a location of the IoT device 508 based on received satellite signals or received terrestrial wireless signals.

[0064] In some embodiments, at least some of the IoT devices 508 need to consume very low average power in order to perform a packet exchange with the sensor hub 510 and/or access gateway 512. The IoT devices 508 may be densely deployed.

[0065] The IoT devices 508 may enter a power save mode and may exit the power save at intervals to gather data from sensors and/or to upload the data to the sensor hub 510 or access gateway 512.

[0066] In some embodiments, the IoT device 508 may include a LP-WUR devices. A LP-WUR may be circuitry that is configured to consume a lower amount of power than other devices or other portions of the same device.

[0067] In some embodiments, the IoT device 508 may have different states, e.g., sleeping and awake. In some embodiments, the IoT device 508 may include a WUR 509. The WUR 509 may be configured to signal a wake-up signal to the IoT 508 upon reception of a wake-up field, e.g., wake-up 918 or wake-up preamble 1008. The WUR 509 may be a LP-WUR. The LP-WUR devices 514 are disclosed in FIG. 17.

[0068] In some embodiments, the HE AP 502 HE stations 504, legacy stations 506, IoT devices 508, LP-WUR devices 514, access gateways 512, Bluetooth™ devices, and/or sensor hubs 510 enter a power save mode and exit the power save mode periodically or at a pre-scheduled times to see if there is a packet for them to be received. In some embodiments, the HE AP 502, HE stations 504, legacy stations 506, IoT devices 508, LP-WUR devices 514, access gateways 512, Bluetooth™ devices, and/or sensor hubs 510 may remain in a power save mode until receiving a wake-up packet.

[0069] The bandwidth of a channel may be 20MHz, 40MHz, or 80MHz, 160MHz, 320MHz contiguous bandwidths or an 80+80MHz (160MHz) non-contiguous bandwidth. In some embodiments, the bandwidth of a channel may be 1 MHz, 1.25MHz, 2.03MHz, 2.5MHz, 4.06 MHz, 5MHz and 10MHz, or a combination thereof or another bandwidth that is less or equal to the available bandwidth may also be used. In some embodiments the bandwidth of the channels may be based on a number of active data subcarriers. In some embodiments the bandwidth of the channels is based on 26, 52, 106, 242, 484, 996, or 2x996 active data subcarriers or tones that are spaced by 20 MHz. In some embodiments the bandwidth of the channels is 256 tones spaced by 20 MHz. In some embodiments the channels are multiple of 26 tones or a multiple of 20 MHz. In some embodiments a 20 MHz channel may comprise 242 active data subcarriers or tones, which may determine the size of a Fast Fourier

Transform (FFT). An allocation of a bandwidth or a number of tones or sub-carriers may be termed a resource unit (RU) allocation in accordance with some embodiments.

[0070] In some embodiments, the 26-subcarrier RU and 52-subcarrier
 5 RU are used in the 20 MHz, 40 MHz, 80 MHz, 160 MHz and 80+80 MHz OFDMA HE physical (PHY) Layer Convergence Procedure (PLCP) protocol data unit (PPDU).

[0071] In some embodiments, the 106-subcarrier RU is used in the 20
 MHz, 40 MHz, 80 MHz, 160 MHz and 80+80 MHz OFDMA and MU-MIMO
 10 HE PPDU formats. In some embodiments, the 242-subcarrier RU is used in the 40 MHz, 80 MHz, 160 MHz and 80+80 MHz OFDMA and MU-MIMO HE PPDU formats. In some embodiments, the 484-subcarrier RU is used in the 80 MHz, 160 MHz and 80+80 MHz OFDMA and MU-MIMO HE PPDU formats. In some embodiments, the 996-subcarrier RU is used in the 160 MHz and 80+80
 15 MHz OFDMA and MU-MIMO HE PPDU formats.

[0072] A HE frame may be configured for transmitting a number of spatial streams, which may be in accordance with MU-MIMO and may be in accordance with OFDMA. In other embodiments, the HE AP 502, HE STA 504, IoT devices 508, LP-WUR devices 514, and/or legacy device 506 may also
 20 implement different technologies such as code division multiple access (CDMA) 2000, CDMA 2000 1X, CDMA 2000 Evolution-Data Optimized (EV-DO), Interim Standard 2000 (IS-2000), Interim Standard 95 (IS-95), Interim Standard 856 (IS-856), Long Term Evolution (LTE), Global System for Mobile communications (GSM), Enhanced Data rates for GSM Evolution (EDGE),
 25 GSM EDGE (GERAN), IEEE 802.16 (i.e., Worldwide Interoperability for Microwave Access (WiMAX)), BlueTooth®, or other technologies.

[0073] Some embodiments relate to HE communications. In accordance with some IEEE 802.11ax embodiments, a HE AP 502 may operate as a HE AP which may be arranged to contend for a wireless medium (e.g., during a
 30 contention period) to receive exclusive control of the medium for an HE control period. In some embodiments, the HE control period may be termed a transmission opportunity (TXOP). The HE AP 502 may transmit a HE trigger frame, which may be a trigger packet or HE control and schedule transmission,

at the beginning of the HEW control period. The HE AP 502 may transmit a time duration of the TXOP and sub-channel information. During the HE control period, HEW stations 504 may communicate with the HE AP 502 in accordance with a non-contention based multiple access technique such as OFDMA or MU-MIMO.

[0074] This is unlike conventional wireless local-area network (WLAN) communications in which devices communicate in accordance with a contention-based communication technique, rather than a multiple access technique. During the HE control period, legacy stations refrain from communicating.

[0075] In some embodiments, the multiple-access technique used during the HE control period may be a scheduled OFDMA technique, although this is not a requirement. In some embodiments, the multiple access technique may be a time-division multiple access (TDMA) technique or a frequency division multiple access (FDMA) technique. In some embodiments, the multiple access technique may be a space-division multiple access (SDMA) technique.

[0076] In some embodiments, the HE station 504, HE AP 502, IoT devices 508, and/or LP-WUR devices 514, may be configured to operate in accordance with IEEE 802.11mc. In example embodiments, the radio architecture of FIG. 1 is configured to implement the HE station 504 and/or the HE AP 502. In example embodiments, the front-end module circuitry of FIG. 2 is configured to implement the HE station 504 and/or the HE AP 502. In example embodiments, the radio IC circuitry of FIG. 3 is configured to implement the HE station 504 and/or the HE AP 502. In example embodiments, the base-band processing circuitry of FIG. 4 is configured to implement the HE station 504 and/or the HE AP 502. In example embodiments, the radio architecture of FIG. 1, the front-end module circuitry of FIG. 2, the radio IC circuitry of FIG. 3, and/or the base-band processing circuitry of FIG. 4 may be configured to perform the methods and functions herein described in conjunction with FIGS. 1-18.

[0077] In example embodiments, The HE AP 502 may also communicate with legacy stations 506, IoT devices 508, LP-WUR devices 514, sensor hubs 510, access gateway 512, and/or HE stations 504 and may include one or more of the following: the radio architecture of FIG. 1, the front-end module circuitry

of FIG. 2, the radio IC circuitry of FIG. 3, and/or the base-band processing circuitry of FIG. 4.

[0078] The HE AP 502 may also communicate with legacy stations 506, sensor hubs 510, access gateway 512, and/or HE stations 504 in accordance with legacy IEEE 802.11 communication techniques. In example embodiments, a HE AP 502, access gateway 512, HE station 504, legacy station 506, IoT devices 508, LP-WUR device 514, and/or sensor hub 510 may be configured to perform the methods and functions herein described in conjunction with FIGS. 1-18. In example embodiments, an apparatus of a HE AP 502, an apparatus of an access gateway 512, an apparatus of a HE station 504, an apparatus of a legacy station 506, apparatus of an IoT devices 508, LP-WUR device 514, and/or an apparatus of a sensor hub 510 may be configured to perform the methods and functions herein described in conjunction with FIGS. 1-18.

[0079] The term Wi-Fi may refer to one or more of the IEEE 802.11 communication standards. AP and STA may refer to HE access point 502 and/or HE station 504, IoT devices 508, LP-WUR devices 514, as well as legacy devices 506.

[0080] In some embodiments, a HE AP 502 or a HE STA 504 performing at least some functions of an HE AP 502 may be referred to as HE AP STA. In some embodiments, a HE STA 504 may be referred to as a HE non-AP STA. In some embodiments, a HE STA 504 may be referred to as either a HE AP STA and/or HE non-AP.

[0081] FIG. 6 illustrates a block diagram of an example machine 600 upon which any one or more of the operations/techniques (e.g., methodologies) discussed herein may perform. In alternative embodiments, the machine 600 may operate as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine 600 may operate in the capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine 600 may act as a peer machine in peer-to-peer (P2P) (or other distributed) network environment.

[0082] The machine 600 may be a HE STAs 504 (FIG. 5), HE AP 502, IoT device 508, LP-WUR device 514, sensor hub 510, access gateway 512, or wireless device 700. The machine 600 may be personal computer (PC), a tablet

PC, a set-top box (STB), a personal digital assistant (PDA), a portable communications device, a mobile telephone, a smart phone, a web appliance, a network router, switch or bridge, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine. Further, while only a single machine is illustrated, the term “machine” shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein, such as cloud computing, software as a service (SaaS), other computer cluster configurations.

10 **[0083]** Machine (e.g., computer system) 600 may include a hardware processor 602 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 604 and a static memory 606, some or all of which may communicate with each other via an interlink (e.g., bus) 608.

15 **[0084]** Specific examples of main memory 604 include Random Access Memory (RAM), and semiconductor memory devices, which may include, in some embodiments, storage locations in semiconductors such as registers. Specific examples of static memory 606 include non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; RAM; and CD-ROM and DVD-ROM disks.

25 **[0085]** The machine 600 may further include a display device 610, an input device 612 (e.g., a keyboard), and a user interface (UI) navigation device 614 (e.g., a mouse). In an example, the display device 610, input device 612 and UI navigation device 614 may be a touch screen display. The machine 600 may additionally include a mass storage (e.g., drive unit) 616, a signal generation device 618 (e.g., a speaker), a network interface device 620, and one or more sensors 621, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The machine 600 may include an output controller 628, such as a serial (e.g., universal serial bus (USB), parallel, or other wired or wireless (e.g., infrared(IR), near field communication (NFC), etc.)

connection to communicate or control one or more peripheral devices (e.g., a printer, card reader, etc.). In some embodiments, the processor 602 and/or instructions 624 may comprise processing circuitry and/or transceiver circuitry.

[0086] The storage device 616 may include a machine readable medium 622 on which is stored one or more sets of data structures or instructions 624 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 624 may also reside, completely or at least partially, within the main memory 604, within static memory 606, or within the hardware processor 602 during execution thereof by the machine 600. In an example, one or any combination of the hardware processor 602, the main memory 604, the static memory 606, or the storage device 616 may constitute machine readable media.

[0087] Specific examples of machine readable media may include: non-volatile memory, such as semiconductor memory devices (e.g., EPROM or EEPROM) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; RAM; and CD-ROM and DVD-ROM disks.

[0088] While the machine readable medium 622 is illustrated as a single medium, the term "machine readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) configured to store the one or more instructions 624.

[0089] An apparatus of the machine 600 may be one or more of a hardware processor 602 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 604 and a static memory 606, sensors 621, network interface device 620, antennas 660, a display device 610, an input device 612, a user interface (UI) navigation device 614, a mass storage 616, instructions 624, a signal generation device 618, and an output controller 628. The apparatus may be configured to perform one or more of the methods and/or operations disclosed herein. The apparatus may be intended as a component of the machine 600 to perform one or more of the methods and/or operations disclosed herein, and/or to perform a portion of one or more of the methods and/or operations disclosed herein. In some embodiments, the apparatus may include a pin or other means to

receive power. In some embodiments, the apparatus may include power conditioning hardware.

[0090] The term “machine readable medium” may include any medium that is capable of storing, encoding, or carrying instructions for execution by the machine 600 and that cause the machine 600 to perform any one or more of the techniques of the present disclosure, or that is capable of storing, encoding or carrying data structures used by or associated with such instructions. Non-limiting machine readable medium examples may include solid-state memories, and optical and magnetic media. Specific examples of machine readable media may include: non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; Random Access Memory (RAM); and CD-ROM and DVD-ROM disks. In some examples, machine readable media may include non-transitory machine readable media. In some examples, machine readable media may include machine readable media that is not a transitory propagating signal.

[0091] The instructions 624 may further be transmitted or received over a communications network 626 using a transmission medium via the network interface device 620 utilizing any one of a number of transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communication networks may include a local area network (LAN), a wide area network (WAN), a packet data network (e.g., the Internet), mobile telephone networks (e.g., cellular networks), Plain Old Telephone (POTS) networks, and wireless data networks (e.g., Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards known as Wi-Fi®, IEEE 802.16 family of standards known as WiMax®, IEEE 802.15.4 family of standards, a Long Term Evolution (LTE) family of standards, a Universal Mobile Telecommunications System (UMTS) family of standards, peer-to-peer (P2P) networks, among others.

[0092] In an example, the network interface device 620 may include one or more physical jacks (e.g., Ethernet, coaxial, or phone jacks) or one or more

antennas to connect to the communications network 626. In an example, the network interface device 620 may include one or more antennas 660 to wirelessly communicate using at least one of single-input multiple-output (SIMO), multiple-input multiple-output (MIMO), or multiple-input single-output (MISO) techniques. In some examples, the network interface device 620 may wirelessly communicate using Multiple User MIMO techniques. The term “transmission medium” shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution by the machine 600, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

[0093] Examples, as described herein, may include, or may operate on, logic or a number of components, modules, or mechanisms. Modules are tangible entities (e.g., hardware) capable of performing specified operations and may be configured or arranged in a certain manner. In an example, circuits may be arranged (e.g., internally or with respect to external entities such as other circuits) in a specified manner as a module. In an example, the whole or part of one or more computer systems (e.g., a standalone, client or server computer system) or one or more hardware processors may be configured by firmware or software (e.g., instructions, an application portion, or an application) as a module that operates to perform specified operations. In an example, the software may reside on a machine readable medium. In an example, the software, when executed by the underlying hardware of the module, causes the hardware to perform the specified operations.

[0094] Accordingly, the term “module” is understood to encompass a tangible entity, be that an entity that is physically constructed, specifically configured (e.g., hardwired), or temporarily (e.g., transitorily) configured (e.g., programmed) to operate in a specified manner or to perform part or all of any operation described herein. Considering examples in which modules are temporarily configured, each of the modules need not be instantiated at any one moment in time. For example, where the modules comprise a general-purpose hardware processor configured using software, the general-purpose hardware processor may be configured as respective different modules at different times. Software may accordingly configure a hardware processor, for example, to

constitute a particular module at one instance of time and to constitute a different module at a different instance of time.

[0095] Some embodiments may be implemented fully or partially in software and/or firmware. This software and/or firmware may take the form of instructions contained in or on a non-transitory computer-readable storage medium. Those instructions may then be read and executed by one or more processors to enable performance of the operations described herein. The instructions may be in any suitable form, such as but not limited to source code, compiled code, interpreted code, executable code, static code, dynamic code, and the like. Such a computer-readable medium may include any tangible non-transitory medium for storing information in a form readable by one or more computers, such as but not limited to read only memory (ROM); random access memory (RAM); magnetic disk storage media; optical storage media; flash memory, etc.

[0096] FIG. 7 illustrates a block diagram of an example wireless device 700 upon which any one or more of the techniques (e.g., methodologies or operations) discussed herein may perform. The wireless device 700 may be a HE device. The wireless device 800 may be one or more of HE STAs 504 (FIG. 5), HE AP 502, IoT device 508, LP-WUR device 514, sensor hub 510, example machine 600, or access gateway 512.

[0097] HE STAs 504 (FIG. 5), HE AP 502, IoT device 508, LP-WUR device 514, sensor hub 510, machine 600, or access gateway 512 may include some or all of the components shown in FIGS. 1-7 and 17. The wireless device 700 may be an example machine 600 as disclosed in conjunction with FIG. 6.

[0098] The wireless device 700 may include processing circuitry 708. The processing circuitry 708 may include a transceiver 702, physical layer circuitry (PHY circuitry) 704, and MAC layer circuitry (MAC circuitry) 706, one or more of which may enable transmission and reception of signals to and from other wireless devices 700 (e.g., HE STAs 504 (FIG. 5), HE AP 502, legacy device 506, IoT device 508, LP-WUR device 514, sensor hub 510, machine 600, or access gateway 512) using one or more antennas 712. As an example, the PHY circuitry 704 may perform various encoding and decoding functions that may include formation of baseband signals for transmission and

decoding of received signals. As another example, the transceiver 702 may perform various transmission and reception functions such as conversion of signals between a baseband range and a Radio Frequency (RF) range.

[0099] Accordingly, the PHY circuitry 704 and the transceiver 702 may
5 be separate components or may be part of a combined component, e.g., processing circuitry 708. In addition, some of the described functionality related to transmission and reception of signals may be performed by a combination that may include one, any or all of the PHY circuitry 704 the transceiver 702, MAC circuitry 706, memory 710, and other components or layers. The MAC circuitry
10 706 may control access to the wireless medium. The wireless device 700 may also include memory 710 arranged to perform the operations described herein, e.g., some of the operations described herein may be performed by instructions stored in the memory 710.

[00100] The antennas 712 (some embodiments may include only one
15 antenna) 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 712 may be effectively separated to take advantage
20 of spatial diversity and the different channel characteristics that may result.

[00101] One or more of the memory 710, the transceiver 702, the PHY circuitry 704, the MAC circuitry 706, the antennas 712, and/or the processing circuitry 708 may be coupled with one another. Moreover, although memory
25 710, the transceiver 702, the PHY circuitry 704, the MAC circuitry 706, the antennas 712 are illustrated as separate components, one or more of memory 710, the transceiver 702, the PHY circuitry 704, the MAC circuitry 706, the antennas 712 may be integrated in an electronic package or chip.

[00102] In some embodiments, the wireless device 700 may be a mobile device as described in conjunction with FIG. 6. In some embodiments, the
30 wireless device 700 may be configured to operate in accordance with one or more wireless communication standards as described herein (e.g., as described in conjunction with FIGS. 1-6, IEEE 802.11 and/or Bluetooth®). In some embodiments, the wireless device 700 may include one or more of the

components as described in conjunction with FIG. 6 (e.g., display device 610, input device 612, etc.) Although the wireless 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 may refer to one or more processes operating on one or more processing elements.

[00103] In some embodiments, an apparatus of or used by the wireless device 700 may include various components of the wireless device 700 as shown in FIG. 7 and/or components from FIGS. 1-6. Accordingly, techniques and operations described herein that refer to the wireless device 700 may be applicable to an apparatus for a wireless device 700 (e.g., HE STAs 504 (FIG. 5), HE AP 502, legacy device 506, IoT device 508, LP-WUR device 514, sensor hub 510, machine 600, or access gateway 512), in some embodiments. In some embodiments, the wireless device 700 is configured to decode and/or encode signals, packets, and/or frames as described herein, e.g., PPDU.

[00104] In some embodiments, the MAC circuitry 706 may be arranged to contend for a wireless medium during a contention period to receive control of the medium for a HE TXOP and encode or decode an HE PPDU. In some embodiments, the MAC circuitry 706 may be arranged to contend for the wireless medium based on channel contention settings, a transmitting power level, and a clear channel assessment level (e.g., an energy detect level).

[00105] The PHY circuitry 704 may be arranged to transmit signals in accordance with one or more communication standards described herein. For example, the PHY circuitry 704 may be configured to transmit a HE PPDU. The PHY circuitry 704 may include circuitry for modulation/demodulation, upconversion/downconversion, filtering, amplification, etc. In some embodiments, the processing circuitry 708 may include one or more processors.

The processing circuitry 708 may be configured to perform functions based on instructions being stored in a RAM or ROM, or based on special purpose circuitry. The processing circuitry 708 may include a processor such as a general purpose processor or special purpose processor. The processing circuitry
5 708 may implement one or more functions associated with antennas 712, the transceiver 702, the PHY circuitry 704, the MAC circuitry 706, and/or the memory 710. In some embodiments, the processing circuitry 708 may be configured to perform one or more of the functions/operations and/or methods described herein.

10 [00106] In some embodiments, IoT device 508 may have be a low power device. In some embodiments, the IoT device 508 may be a lower power device than other wireless devices such as the wireless device 802 (see FIG. 8). In some embodiments, the WUR 509 may be a very low power radio frequency portion of the IoT device 508 device so that the WUR 509 may remain active
15 while other portions of the IoT device 508 either sleep or become lower active. In some embodiments, the WUR 509 is configured to generate wake-up signal when it receives a wake-up packet 918 or wake-up preamble 1008 (or another signal that indicates the IoT device 508 should wake-up.) In some embodiments, the WUR 509 is a receive only chain.

20 [00107] In some embodiments, the IoT device 508 has a single receive chain instead of a quadrature receiver chain), which may reduce power by 50 percent. In some embodiments, the IoT device 508 includes oscillators that do not operate as well as oscillators of the wireless device 802. In some embodiments, the IoT device 506 has simple oscillators. In some embodiments,
25 the IoT device 506 has oscillators that have large offsets. In quadrature designs large frequency offsets will degrade performance if frequency is not estimated.

[00108] In some embodiments, the IoT device 508 with a lower quality oscillator with have clocks that will drift from the carrier frequency (e.g., 1306.3) quickly. In some embodiments, since the IoT device 508 only has one
30 receive chain, it cannot resolve phase and thus cannot estimate frequency. In some embodiments, with only one receive chain, the IoT device 508 cannot estimate frequency offset, so the IoT device 508 is unable to estimate frequency drift.

- [00109] In some embodiments, the WUR 509 uses on-off keying modulation, which enables a simple energy detector to detect data. In some embodiments, if the IoT device 508 cannot estimate frequency drift or offset, then a significant degradation in acquisition probability (e.g., the WUR 509 misses the wake-up packet) or a degraded performance may be the result.
- [00110] In some embodiments, MAC level signaling to assist in synchronizing the WUR 509 with the carrier frequency 1306.3 may be used. In some embodiments, the MAC level signaling does not enable the IoT device 506 to track the carrier frequency 1306.3, and the MAC level signaling has a high overhead particularly since the data rate may be low for a WUR 509 packet. The WUR 509 may be a non-coherent receiver in accordance with some embodiments. The synchronization fields 804, 1108, 1208, provide a technical solutions to one or more of the technical problems described above.
- [00111] FIG. 8 illustrates transmission of packets for frequency tracking in wake-up radio systems 800 in accordance with some embodiments. Illustrated in FIG. 8 is wireless device 802, transmission 805, and IoT devices 508. The wireless device 802 may transmit the synchronization field 804, and IoT devices 508 may receive the synchronization 804. The IoT devices 508 may be LP-WUR devices 514.
- [00112] The wireless device 802 may be a HE AP 502, HE station 504, sensor hub 510, access gateway 512, a IoT device 508, or another wireless device. The wireless device 802 may transmit the transmission 805. The transmission 805 may be a frame, PPDU, packet, or another transmission. The transmission 805 may be as disclosed in FIGS. 10, 11, and/or 12.
- [00113] The transmission 805 may include one or more synchronization fields 804, e.g., synchronization fields 804.1 through synchronization field 804.N. In some embodiments, the synchronization field 804 may be similar to a short training field or a long training field. Each synchronization field 804 includes or is associated with an identification (ID) 806, which may be a sequence that is used as an ID 806. In accordance with some embodiments, the ID 806 may be a sequence of the synchronization field 804, e.g., as disclosed in conjunction with FIG. 11 (e.g., 1108). In some embodiments, there may be a fixed number of sequences that are used for the ID 806, which may make it

easier for the IoT device 508 (or LP-WUR devices 514) to identify the sequence. In some embodiments, the ID 806 may be a separate field, e.g., as disclosed in conjunction with FIG. 12 (e.g., 1208). In some embodiments, the synchronization fields 804 are between 1 μ s and 12 μ s in duration and
5 transmitted one after another in time.

[00114] In some embodiments, the synchronization fields 804 are part of a broadcast packet so that more than one IoT device 508 (or LP-WUR devices 514) may receive the synchronization fields 804. In some embodiments, the synchronization fields 804 are PHY signals.

10 [00115] In some embodiments, the IoT devices 508 (or LP-WUR devices 514) correlate against received synchronization fields 804 and provide a detection metric. In some embodiments, a quality metric or signal-to-noise ratio (SNR) is determined for each synchronization field 804. In some embodiments, a detection level has to be met for the IoT device 508 (or LP-WUR devices 514)
15 to use the synchronization field 804 for synchronization, e.g., a minimum received energy.

[00116] The wireless device 802 may transmit the synchronize fields 804 with a carrier offset 808. For example, the carrier offset 808 may be a negative offset from a carrier, a positive offset from the carrier, and no offset from the
20 carrier. In some embodiments, the carrier offset 808 may be as described in conjunction with FIG. 13.

[00117] The wireless device 802 may transmit the synchronize fields 804 with a carrier offset 808. For example, the carrier offset 808 may be a relative offset from the wireless device 802 to the IoT devices 508 or LP-WUR devices
25 514 (not illustrated in FIG. 8). In some embodiments, a relative offset is a difference between carrier frequencies between the transmitting device and receiving device. The carrier offset 808 may be a negative offset from the carrier of the IoT device 508 (or LP-WUR device 514), a positive offset from the carrier of the IoT device 508 (or LP-WUR device 514), and no offset from the
30 carrier of the IoT device 508 (or LP-WUR device 514). In some embodiments, the carrier offset 808 may be as described in conjunction with FIG. 13.

[00118] In some embodiments, the larger offset 808 is due to the WUR 509 (or WUR 1702) which may have a poorer quality receiver and thus the clock

(or clock 1704) of the WUR 509 (or WUR 1702) can drift easily and become misaligned from the clock (not illustrated) of the wireless device 802 (or 1704) which is more stable relatively.

[00119] The IoT device 508 (or LP-WUR device 514) may include ID to
5 carrier offset 810. The ID to carrier offset 810 may be data and/or
implementation of logic that indicates for an ID 806 a carrier offset 808.

[00120] In some embodiments, the IoT devices 508 (or LP-WUR device
514) may receive the synchronize fields 804 and determine the carrier offset 808
based on the ID 806. The IoT devices 508 (or LP-WUR device 514) may then
10 be configured to synchronize the reception and/or transmission of transmissions
805 based on the received synchronize fields 804. For example, the IoT device
508 (or LP-WUR device 514) may determine a signal quality of the
synchronization fields 804 (e.g., SNR, or signal strength) and determine how to
adjust the synchronization to the carrier based on the received signal quality of
15 the received synchronization fields 804. In some embodiments, the IoT devices
508 (or LP-WUR devices 514) may synchronize to find a best or better channel
between the IoT devices 508 (or LP-WUR device 514) and the wireless device
802. In some embodiments, the IoT device 508 (or LP-WUR device 514) may
adjust the synchronization to maximize a SNR, e.g., select a carrier offset based
20 on the highest SNR determined for each of the synchronization fields 804.

[00121] In some embodiments, the synchronization fields 804 do not have
IDs 806. The IoT devices 508 (or LP-WUR device 514) determine the carrier
offset 808 used to transmit the synchronization fields 804 based on their order in
the transmission 805. For example, the first synchronization field 804.1 may be
25 a negative offset to the carrier frequency, the second synchronization field 804.2
may have a zero offset to the carrier frequency, and the third synchronization
field 804.3 may have a positive offset to the carrier frequency.

[00122] FIG. 9 illustrates a method 900 of communicating packets for
frequency tracking in wake-up radio systems in accordance with some
30 embodiments. Illustrated in FIG. 9 is time 912 along a horizontal axis along the
bottom, frequency 914 and state 913 along a vertical axis along the right side,
operations 950 along a horizontal axis along the top, wireless device 802, and
IoT device 508. The wireless device 802 may be as disclosed herein (e.g., FIG.

8.) The IoT device 508 may be as described herein (e.g., FIG. 5). The IoT device 508 may be a LP-WUR device 514. The state 913 may indicate a state, mode, or operation of the IoT device 508.

[00123] The method 900 begins with operation 952 with the wireless device 802 transmitting a wake-up packet 918. The IoT device 508 (or LP-WUR device 514) may be in a low-power 904 state or mode before receiving the wake-up packet 918. The wake-up packet 904 may be recognized by the IoT device 508 (or LP-WUR device 514), which may move to a different state or mode such as wake-up 906. In some embodiments, the WUR 509 recognizes the wake-up packet 918 and wakes up the IoT device 508 (or LP-WUR device 514) or signals to the IoT device 508 (or LP-WUR device 514) that a wake-up packet 918 was received.

[00124] The method 900 continues at operation 954 with the wireless device 802 transmitting one or more synchronization fields 804. Only one synchronization field 804 is illustrated in FIG. 9, but more than one synchronization field 804 may be transmitted in time. The wireless device 802 may transmit each of the one or more synchronization fields 804 with a carrier offset 808 (e.g., see FIG. 13, negative offset 1306.1, carrier frequency 1306.3, and positive offset 1306.2).

[00125] The wireless device 802 may transmit the wake-up packet 918 with a first bandwidth (e.g., 20 MHz), and the one or more synchronization fields 804 with a second bandwidth (e.g., approximately 1, 2, 3, 4, 5 MHz).

[00126] The IoT device 508 (or LP-WUR device 514) may determine the ID 806 of each of the one or more synchronization fields 804. The IoT device 508 (or LP-WUR device 514) may use the ID 806 to carrier offset 810 (e.g., see FIG. 14, ID to carrier offset 1402) to determine what carrier offset 808 the wireless device 802 used to transmit each of the one or more synchronization fields 804. The IoT device 508 (or LP-WUR device 514) may receive one or more synchronization fields 804 and based on the synchronization fields 804 synchronize 910 with a carrier (e.g., carrier frequency 1306.3).

[00127] FIG. 10 illustrates a frame 1000 with a wake-up preamble 1008 in accordance with some embodiments. The frame 1000 may include a legacy preamble 1006, wake-up preamble 1008, media access control (MAC) header

1010, payload 1012, and frame check sequence (FCS) 1014. The frame 1000 does not include synchronization fields 804, 1108, 1208 as illustrated. The legacy preamble 1006 may be a preamble to defer other wireless devices (e.g., legacy devices 506, HE APs 502, HE stations 504, etc.) from transmitting or
 5 trying to access the wireless medium. The legacy preamble 1006 may include a length for other wireless devices to set a network allocation vector (NAV) to defer. The legacy preamble 1006 may be transmitted using a first bandwidth 1002 (e.g., 20 MHz).

[00128] The MAC header 1010 may be a header for the MAC portion of
 10 the frame 1000 (e.g., MAC header 1010, payload 1012, and FCS 1014). The MAC header 1010 may include one or more of a transmitter address, frame control, etc. In some embodiments, the MAC header 1010 addresses the IoT devices 508 (or WUR 509, LP-WUR device 514, or WUR 1702).

[00129] The payload 1012 may be data. The FCS 1014 may include
 15 information to enable the receiver (e.g., IoT device 508 or LP-WUR device 514) to perform cyclic redundancy check on the frame 1000, e.g., the MAC portion (e.g., MAC header 1010 and payload 1012) of the frame 1000. The frame 1000 may be used to first wake-up an IoT device 508 (or LP-WUR device 514) and to send the payload 1012.

20 [00130] The wake-up preamble 1008, MAC header 1010, payload 1012, and FCS 1014 may be transmitted on a second bandwidth 1004 (e.g., approximately 1 to 5 MHz). In some embodiments, the MAC header 1010 may include a broadcast address so that more than one IoT device 508 (or LP-WUR device 514) may receive the payload 1012.

25 [00131] In some embodiments, one or more portions of the frame 1000 may be repeated 1016. For example, the MAC header 1010, payload 1012, and FCS 1014 may be repeated 1016 one or more times. In some embodiments, the wake-up preamble 1008 is 128 μ s. In some embodiments, the repeat 1016 portion is 384 μ s.

30 [00132] FIG. 11 illustrates a frame 1100 with one or more synchronization fields 1108 in accordance with some embodiments. The frame 1100 may include synchronization fields 1108 and legacy preamble 1106.

[00133] The legacy preamble 1106 may be a preamble to defer other wireless devices (e.g., legacy devices 506, HE APs 502, HE stations 504, etc.) from transmitting. The legacy preamble 1106 may include a length for other wireless device to set a NAV to defer transmitting for a duration determined
5 based on the length. The legacy preamble 1106 may be transmitted using a first bandwidth 1102 (e.g., 20 MHz).

[00134] The one or more synchronization fields 1108 may include a sequence 1110. The sequence 1110 may be encoded as part of the synchronization field 1108. The sequence 1110 may be orthogonal codes
10 encoded on tones, in accordance with some embodiments. The sequence 1110 may be codes encoded on tones in a difference manner. The synchronization fields 1108 may be similar to a long training field or a short training field with the sequences 1110 encoded on tones of the long training field or short training field (e.g., patterns of -1's, 0's, and 1's). The synchronize fields 1108 may be
15 transmitted with a carrier offset 1109. For example, the carrier offset 1109 may be a negative offset 1306.1 from a carrier frequency 1306.3, a positive offset 1306.2 from the carrier frequency 1306.3, and no offset 1306.3 (carrier frequency) from the carrier. The carrier may be a fixed carrier or a carrier of another wireless device (e.g., IoT 508, LP-WUR device 514, HE AP 502, and
20 HE station 504). In some embodiments, the carrier offset 1109 may be as described in conjunction with FIG. 13 (e.g., 1306). In some embodiments, the carrier offset may be 10 kHz to 1 MHz.

[00135] The sequence 1110 may be used by the IoT device 508 (or a LP-WUR device 514) to identify the carrier offset 1109 used to transmit the
25 corresponding synchronization field 1108. The synchronization fields 1108 may be transmitted on a second bandwidth 1104 (e.g., approximately 1 to 5 MHz). In some embodiments, each of the synchronization fields 1108 is distinct from one another. In some embodiments, the sequences 1110 have good cross correlation properties to make it easier to distinguish among the sequences 1110, e.g., the
30 sequences 1110 may be orthogonal (e.g., a P matrix).

[00136] In some embodiments, the IoT devices 508 correlate against received synchronization fields 1108 to differentiate between the three sequences 1110 and determine a detection metric or threshold. Some embodiments that

correlate against the received synchronization fields 1108 (e.g., 3) need additional hardware to store and process the synchronization fields 1108. In some embodiments, one or more synchronization fields 1108 are transmitted. In some embodiments, one or more of the synchronization fields 1108 are
 5 duplicated. For example, each synchronization field 1108 may be transmitted twice (or more than twice.)

[00137] In some embodiments, the synchronization fields 1108 are PHY layer signaling, e.g., the synchronization fields 1108 may be part of training fields such as long-training fields or short training fields.

10 [00138] FIG. 12 illustrates a frame 1200 with one or more synchronization fields 1208 in accordance with some embodiments. The frame 1200 may include synchronization fields 1208, IDs 1210, and legacy preamble 1206.

[00139] The legacy preamble 1206 may be a preamble to defer other
 15 wireless devices (e.g., legacy devices 506, HE APs 502, HE stations 504, etc.). The legacy preamble 1206 may include a length for other wireless device to set a NAV for a duration based on the length to defer transmitting. The legacy preamble 1206 may be transmitted using a first bandwidth 1202 (e.g., 20 MHz).

[00140] The synchronization fields 1208 may be similar to a long training
 20 field or a short training field. The synchronization fields 1208 may be transmitted with a carrier offset 1209. For example, the carrier offset 1209 may be a negative offset from a carrier (e.g., negative offset 1306.1), a positive offset from the carrier (e.g., positive offset 1306.2), and no offset from the carrier (carrier frequency 1306.3). In some embodiments, the carrier offset 1209 may be as
 25 described in conjunction with FIG. 13 (e.g., 1306). As illustrated, in FIG. 12, three synchronization fields 1208.1, 1208.2, and 1208.3 are transmitted with carrier offset 1 1209.1, carrier offset 2 1209.2, and carrier offset 3 1209.3, respectively, where each carrier offset 1209 may be one of a negative offset (e.g., 1306.1) from a carrier, a positive offset from the carrier (e.g., 1306.2), and
 30 no offset from the carrier (e.g., 1306.3). The carrier may be a fixed carrier or the carrier of another wireless device, e.g., IoT 508, LP-WUR 514, HE AP 502, and/or HE station 504.

[00141] Each of the synchronization fields 1208 may have an associated ID field 1210. The ID field 1210 may be encoded in binary or another encoding scheme may be used. The ID field 1210 may be two bits or another number of bits (e.g., 1 or 3-12). For example, the ID field 1210 may be orthogonal codes of tones of a training field. The value of the ID field 1210 may be used to determine the carrier offset 1209 with which the corresponding synchronization field 1208 was transmitted. In some embodiments, the ID field 1210 includes one or more bits for error detection, e.g., a parity bit. In some embodiments, the ID field 1210 is separate from the synchronization field 1208 in time (e.g., the synchronization field 1208 may have a duration of one or more symbols and the ID field 1210 may have a duration of one or more symbols.) In some embodiments, the ID field 1210 may be before the corresponding synchronization field 1208. In some embodiments, carrier offset 1 1209.1, carrier offset 2 1209.2, and carrier offset 3 1209.3 may be from 10 kHz to 1 MHz. In some embodiments, the synchronization fields 1208 and ID fields 1210 are PHY layer signaling, e.g., the synchronization fields 1208 and ID fields 1210 may be part of training fields such as long-training fields or short training fields.

[00142] In some embodiments, one or more synchronization fields 1208 are transmitted. In some embodiments, one or more of the synchronization fields 1208 and corresponding ID field 1210 are duplicated. For example, each synchronization field 1208 and ID field 1210 may be transmitted twice (or more than twice.)

[00143] In some embodiments, the ID 806, sequence 1110, and/or ID 1210 may be encoded on a resource unit. The resource unit may be one or more tones or sub-carriers and a duration, e.g., one symbol or more symbols (e.g., a duration of 2 μ s to 16 μ s or more). In some embodiments, the encoding may include patterns with different value duration the duration of one symbol. The number of tones or sub-carriers may be a number from 2 to 56 or more. The encoding may transmit energy on some tones and not transmit energy on other tones. The encoding may use orthogonal codes, e.g., a P-matrix for generating the encoding. The encoding may use negative voltage, zero voltage, and positive voltage on one or more tones for a duration. The ID 806, sequence 1110, and/or ID 1210 may be part of PHY layer signaling such as a training field (e.g., long

training field or short training field). An example, ID 806, sequence 1110, and/or ID 1210, may be a resource unit of 12 tones for a duration of one symbol. A first identification (e.g., sequence 1110.1 or ID 1210.1) may be to transmit on energy on the first four tone set and the third four tone set for a duration of one symbol. A second identification (e.g., sequence 1110.2 or ID 1210.2) may be to transmit energy on the second four tone set and to transmit energy on the third four tone set. A third identification (e.g., sequence 1110.3 or ID 1210.3) may be to transmit energy on the first four tone set and to transmit energy on the second four tone set. The IoT device 508 or LP-WUR device 514 may be able to distinguish among these three identifications (e.g., by using a threshold value to determine if energy was transmitted on each four tone sets.)

[00144] FIG. 13 illustrates carrier offset 1300 in accordance with some embodiments. Illustrated in FIG. 13 is frequency 1302 along a horizontal axis along the bottom, and amplitude 1304 along a vertical axis along the left side.

[00145] Zero (0) may indicate the carrier frequency 1306.3 or no offset from the carrier frequency 1306.3. Negative offset 1306.1 may be to the left of the carrier frequency 1306.3. For example, some frequency subtracted from the carrier frequency 1306.3. For example, a value of 5K to 100K subtracted from the carrier frequency 1306.3. Positive offset 1306.2 may be to the right of the carrier frequency 1306.3. For example, some frequency added to the carrier frequency 1306.3. For example, a value of 5K to 100K added to the carrier frequency 1306.3. In some embodiments, the negative offset 1306.1 and positive offset 1306.2 may be from 1K to 500K from the carrier frequency 1306.3. In some embodiments, a wireless device (e.g., wireless device 802) may vary the frequency (e.g., vary the starting frequency and ending frequency of the bandwidth of the transmission of the synchronization fields 804, 1108, or 1208) from the negative offset 1306.1 to the positive offset 1306.

[00146] FIG. 14 illustrates synchronization information 1400 in accordance with some embodiments. The synchronization information 1400 may include ID to carrier offset 1402 information. For example, the ID to carrier offset 1402 information may indicate ID to carrier offset 810 as disclosed in conjunction with FIGS. 8 and 9.

[00147] The ID to carrier offset 1402 information may indicate a carrier offset (1306) for a sequence 1110 or ID 1210, or in some embodiments, a position of the synchronization field 804, 1106, 1206.

[00148] The synchronization information 1400 may be an information element. The synchronization information 1400 may be included in one or more of beacons, association requests, association responses, probe requests, probe responses, etc. The synchronization information 1400 may be included in one or more fields of a packet, e.g., an association response.

[00149] Some embodiments provide a technical solution to a technical problem of how to keep a IoT device 508 (or LP-WUR device 514) synchronized to a carrier signal, e.g., to a wireless device 802. Some embodiments provide a technical solution to a technical problem of how to keep a LP-WUR (e.g., 514) synchronized to a carrier signal, e.g., to a wireless device 802. Some embodiments provide a technical solution to a technical problem of how to keep a LP-WUR device (e.g., 514) with only one receive chain synchronized to a carrier signal, e.g., to a wireless device 802. Some embodiments provide a technical solution to one or more of the technical problems described herein with a very low overhead of the synchronization fields 804, 1108, 1208.

[00150] Some embodiments provide PHY signaling to enable carrier frequency tracking to improve IoT device 508 (or LP-WUR device 514) detection capability. Some embodiments, improve WUR 509 receiver detection and improve system performance by improving SNR that use non-coherent receivers and lower quality oscillators.

[00151] FIG. 15 illustrates a method 1500 of packets for frequency tracking in accordance with some embodiments. The method 1500 begins at operation 1502 with decoding one or more synchronize fields, the one or more synchronize fields each comprising a corresponding identification, the corresponding identification indicating a corresponding carrier offset of the synchronize field.

[00152] For example, IoT devices 508 (or LP-WUR device 514) may decode synchronization fields 804 with IDs 806 (or synchronization fields 1108 with sequences 1110, or synchronization fields 1206 with IDs 1210). The IDs

806 (or sequences 1110 or IDs 1210) may be used by the IoT devices 508 (or LP-WUR device 514) to determine a carrier offset 808 (1109, 1209) used to transmit the synchronization fields 804 (or 1108, 1206).

[00153] The method 1500 continues at operation 1504 with synchronizing
5 the wireless device based on the one or more synchronize fields. For example, IoT devices 508 (or LP-WUR device 514) may synchronize closer to the carrier frequency 1306.3 by determining characteristics of the synchronization fields 804, 1108, 1208, based on the corresponding carrier offsets 808, 1109, 1209, respectively, used to transmit the synchronization fields 804, 1108, 1208. For
10 example, the IoT devices 508 (or LP-WUR device 514) may shift or tune the receiver WUR 509 (or WUR 1702) negative if a synchronization field 804, 1108, 1208 that has a negative offset 1306.1 has the highest SNR from other decoded synchronization fields 804, 1108, 1208. In some embodiments, the IoT devices 508 (or LP-WUR device 514) may adjust a clock (e.g., clock 1704)
15 based on the synchronization field 804, 1108, 1208.

[00154] In some embodiments, the method 1500 may be performed by an IoT device 508, LP-WUR device 514, HE AP 502, wireless device 802, and/or HE station 504. In some embodiments, the method 1500 may be performed by an apparatus of an IoT device 508, an apparatus of a LP-WUR device 514, an
20 apparatus of a HE AP 502, an apparatus of wireless device 802, and/or an apparatus of a HE station 504.

[00155] FIG. 16 illustrates a method 1600 of packets for frequency tracking in accordance with some embodiments. The method 1600 begins at operation 1602 with encoding synchronize fields, the synchronize fields each
25 comprising an identification, the identification indicating a frequency the synchronize field is to be transmitted on, wherein the frequency is indicated by a carrier offset.

[00156] For example, wireless device 802 may encode synchronization fields 804 with IDs 806. Similarly, wireless device 802 may encode
30 synchronization fields 1108 with sequences 1110. Similarly, wireless device 802 may encode synchronization fields 1208 with IDs 1208.

[00157] The method 1600 continues at operation 1604 with configuring the wireless device to transmit each of the synchronize fields on a frequency

indicated by a corresponding identification. For example, wireless device 802 may transmit synchronization fields 804 with IDs 806 in accordance with the carrier offsets 808. Similarly, wireless device 802 transmit synchronization fields 1108 with sequences 1110 in accordance with carrier offsets 808.

- 5 Similarly, wireless device 802 may transmit synchronization fields 1208 with IDs 1208 in accordance with carrier offsets 808.

[00158] In some embodiments, the method 1600 may be performed by an IoT device 508, HE AP 502, wireless device 802, and/or HE station 504. In some embodiments, the method 1500 may be performed by an apparatus of an
10 IoT device 508, an apparatus of a HE AP 502, an apparatus of wireless device 802, and/or an apparatus of a HE station 504.

[00159] FIG. 17 illustrates a low power (LP) wake-up radio (WUR) (LP-WUR) device 514 in accordance with some embodiments. The LP-WUR device 514 may include a WUR 1702, clock 1704, and oscillator 1706.

- 15 [00160] The LP-WUR device 514 may operate in accordance with IEEE 802.11ax, Bluetooth®, IEEE 802.11ba, or another standard of 802.11. The LP-WUR device 514 may be, in some embodiments, a narrow band device that operates on a smaller sub-channel than the HE stations 504 (see FIG. 5). For example, the LP-WUR device 514 may operate on 2.03 MHz or 4.06 MHz sub-
20 channels. In some embodiments, the LP-WUR device 514 are not able to transmit on a full 20 MHz sub-channel to the HE AP 502 with sufficient power for the HE AP 502 to receive the transmission. In some embodiments, the LP-WUR device 514 are not able to receive on a 20 MHz sub-channel and must use a small sub-channel such as 2.03 MHz or 4.06 MHz sub-channel. In some
25 embodiments, the LP-WUR device 514 may operate on a sub-channel with exactly 26 or 52 data sub-carriers. The LP-WUR device 514, in some embodiments, may be short-range, low-power devices. In some embodiments, the LP-WUR device 514 may not be able to transmit.

- [00161] The LP-WUR device 514 may be battery constrained. The LP-
30 WUR device 514 may be sensors designed to measure one or more specific parameters of interest such as temperature sensor, pressure sensor, humidity sensor, light sensor, etc. The LP-WUR device 514 may be location-specific sensors. Some LP-WUR device 514 may be connected to a sensor hub 510. The

LP-WUR device 514 may upload measured data from sensors to the sensor hub 510. The sensor hubs 510 may upload the data to an access gateway 512 that connects several sensor hubs 510 and can connect to a cloud sever or the Internet (not illustrated). The HE AP 502 may act as the access gateway 512 in
5 accordance with some embodiments. The HE AP 502 may act as the sensor hub 510 in accordance with some embodiments. The LP-WUR device 514 may have identifiers that identify a type of data that is measured from the sensors. In some embodiments, the LP-WUR device 514 may be able to determine a location of the LP-WUR device 514 based on received satellite signals or received terrestrial
10 wireless signals.

[00162] In some embodiments, the LP-WUR device 514 may need to consume very low average power in order to perform a packet exchange with the sensor hub 510 and/or access gateway 512 (or another device). The LP-WUR device 514 may enter a power save mode and may exit the power save at
15 intervals to gather data from sensors and/or to upload the data to the sensor hub 510 or access gateway 512. A WUR 1702 may be circuitry that is configured to consume a lower amount of power than other devices or other portions of the same device. In some embodiments, the LP-WUR device 514 may have different states, e.g., sleeping and awake. The WUR 1702 may be configured to
20 signal a wake-up signal to the LP-WUR device 514 upon reception of a wake-up field, e.g., wake-up 918 or wake-up preamble 1008. The WUR 1702 may be a LP-WUR.

[00163] In some embodiments, the WUR 1702 may be a very low power radio frequency portion of the LP-WUR device 514 device so that the WUR
25 1702 may remain active while other portions of the LP-WUR device 514 either sleep or become lower active. In some embodiments, the WUR 1702 is configured to generate wake-up signal when it receives a wake-up packet 918 or wake-up preamble 1008 (or another signal that indicates the LP-WUR device 514 should wake-up.) In some embodiments, the WUR 1702 is a receive only
30 chain.

[00164] In some embodiments, the LP-WUR device 514 has a single receive chain, e.g., no quadrature receiver chain, which may reduce power by 50 percent. In some embodiments, the oscillator 1706 may be one or more

oscillators that do not operate as well as oscillators of the wireless device 802.

In some embodiments, the LP-WUR device 514 has simple oscillators. In some embodiments, the LP-WUR device 514 has oscillators that have large offsets. In quadrature designs large frequency offsets will degrade performance if

5 frequency is not estimated.

[00165] In some embodiments, the LP-WUR device 514 with a lower quality oscillator has clock 1704 (e.g., one or more clocks) that will drift from the carrier frequency (e.g., 1306.3) quickly. In some embodiments, since the LP-WUR device 514 only has one receive chain, it cannot resolve phase and
10 thus cannot estimate frequency. In some embodiments, with only one receive chain, the LP-WUR device 514 cannot estimate frequency offset, so the LP-WUR device 514 is unable to estimate frequency drift.

[00166] In some embodiments, the WUR 1702 uses on-off keying modulation, which enables a simple energy detector to detect data. In some
15 embodiments, if the LP-WUR device 514 cannot estimate frequency drift or offset, which may result in a significant degradation in acquisition probability (e.g., the WUR 1702 misses the wake-up packet) or a degraded performance may be the result.

[00167] In some embodiments, MAC level signaling to assist in
20 synchronizing the WUR 1702 with the carrier frequency 1306.3 may be used. In some embodiments, the MAC level signaling does not enable the LP-WUR device 514 to track the carrier frequency 1306.3, and the MAC level signaling has a high overhead particularly since the data rate may be low for a WUR 1702 packet. The WUR 1702 may be a non-coherent receiver in accordance with
25 some embodiments. The synchronization fields 804, 1108, 1208, provide a technical solutions to one or more of the technical problems described above.

[00168] FIG. 18 illustrates a method 1800 of packets for frequency tracking in accordance with some embodiments. The method 1800 begins at
30 operation 1802 with decoding synchronize fields of a packet, the synchronize fields each comprising an identification.

[00169] For example, IoT devices 508 (or LP-WUR device 514) may decode synchronization fields 804 with IDs 806 (or synchronization fields 1108 with sequences 1110, or synchronization fields 1206 with IDs 1210).

[00170] The method 1800 may continue at operation 1804 with determining a carrier offset associated with each of the synchronize fields from a corresponding identification, where the carrier offset indicates a frequency offset from a carrier.

- 5 [00171] For example, the IDs 806 (or sequences 1110 or IDs 1210) may be used by the IoT devices 508 (or LP-WUR device 514) to determine a carrier offset 808 used to transmit the synchronization fields 804, e.g., the IoT devices 508 (or LP-WUR device 514) may use ID to carrier offset 810 or 1402.

[00172] The method 1800 may continue at operation 1806 with
10 determining signal quality metrics for signal reception by the WUR for each carrier offset indicated in the synchronize fields.

[00173] For example, IoT devices 508 (or LP-WUR device 514) may decode synchronization fields 804 with IDs 806 (or synchronization fields 1108 with sequences 1110, or synchronization fields 1206 with IDs 1210) and
15 determine signal reception by the WUR 509, e.g., SNR or signal strength.

[00174] The method 1800 may continue at operation 1808 with configuring the WUR to adjust a receive frequency in accordance with one of the carrier offsets based on the signal quality metrics. For example, IoT devices 508 (or LP-WUR device 514) may adjust a receive frequency of WUR 509 in
20 accordance with one of the carrier offsets based on the signal quality metrics of synchronize fields 804. For example, a clock 1704 (or oscillator 1706) may be adjusted. In some embodiments, a converged carrier tracking loop may be set based on the determined signal quality metrics, where the converged carrier tracking loop tunes to a frequency such that the center synchronization field will
25 be received with a highest signal to noise ratio or a strongest signal strength. In some embodiments, IoT devices 508 (or LP-WUR device 514) may adjust the clock 1704 (or oscillator 1706) to tune the frequency of the WUR 509, 1702 to a frequency such that the center synchronization field (e.g., synchronization field 1208.2) will be received with a highest signal to noise ratio or a strongest signal
30 strength.

[00175] Some embodiments have the technical effect of enabling a LP-WUR device 514 to track a carrier signal of another device by sending synchronize fields that include an indication of a carrier offset.

[00176] The following examples pertain to further embodiments.

Example 1 is an apparatus of a wireless device, the apparatus comprising: a wake-up radio (WUR); and, processing circuitry coupled to the WUR, the processing circuitry configured to: decode synchronize fields of a packet, the
5 synchronize fields each comprising an identification; determine a carrier offset associated with each of the synchronize fields from a corresponding identification, where the carrier offset indicates a frequency offset from a carrier; determine signal quality metrics for signal reception by the WUR for each carrier offset indicated in the synchronize fields; and configure the WUR to
10 adjust a receive frequency in accordance with one of the carrier offsets based on the signal quality metrics.

[00177] In Example 2, the subject matter of Example 1 optionally includes where the packet includes an Institute of Electrical and Electronic Engineers (IEEE) 802.11 legacy preamble field with a 20 MHz bandwidth, and where the
15 synchronize fields have a bandwidth of 5 MHz or less.

[00178] In Example 3, the subject matter of any one or more of Examples 1–2 optionally include where the WUR has a receive bandwidth of 5 MHz or less

[00179] In Example 4, the subject matter of any one or more of Examples
20 1–3 optionally include where the synchronize fields comprise a negative synchronize field with a negative frequency offset from the carrier, a center synchronize field with no frequency offset from the carrier, and a positive frequency synchronize field with a positive carrier offset from the carrier.

[00180] In Example 5, the subject matter of Example 4 optionally includes
25 where the processing circuitry is further configured to: determine for each of the synchronize fields one or more of the following signal quality metrics: a signal to noise ratio and a signal strength.

[00181] In Example 6, the subject matter of Example 5 optionally includes where the processing circuitry is further configured to: set a converged carrier
30 tracking loop based on the determined signal quality metrics, where the converged carrier tracking loop tunes to a frequency such that the center synchronization field will be received with a higher or highest signal to noise ratio or a stronger or strongest signal strength.

[00182] In Example 7, the subject matter of any one or more of Examples 5–6 optionally include where the wireless device includes a clock coupled to the processing circuitry, and where the processing circuitry is further configured to: adjust the clock to tune the frequency of the WUR to a frequency such that the center synchronization field will be received with a highest signal to noise ratio or a strongest signal strength.

[00183] In Example 8, the subject matter of any one or more of Examples 1–7 optionally include where the identification is a value of a field of a corresponding synchronize field, and where the field is from one bit to eight bits.

10 [00184] In Example 9, the subject matter of any one or more of Examples 1–8 optionally include where the processing circuitry is further configured to: determine the identification based on a sequence of a corresponding synchronize field of the synchronize fields.

[00185] In Example 10, the subject matter of any one or more of Examples 1–9 optionally include MHz from the carrier.

[00186] In Example 11, the subject matter of any one or more of Examples 1–10 optionally include where the carrier offset associated with each of the synchronize fields is one from the following group: a negative offset from a carrier, a positive offset from the carrier, and no offset from the carrier.

20 [00187] In Example 12, the subject matter of any one or more of Examples 1–11 optionally include transceiver circuitry coupled to the WUR; and, one or more antennas coupled to the transceiver circuitry.

[00188] In Example 13, the subject matter of Example 12 optionally includes where the processing circuitry is further configured to: generate a signal for the wireless device to wake up, if a wake-up packet is decoded.

[00189] In Example 14, the subject matter of any one or more of Examples 1–13 optionally include where the apparatus further includes memory coupled to the processing circuitry, and where the memory is configured to store the carrier offset of each of the synchronize fields and the synchronize fields.

30 [00190] In Example 15, the subject matter of any one or more of Examples 1–14 optionally include where the apparatus further includes a single receive chain for the WUR.

[00191] In Example 16, the subject matter of any one or more of Examples 1–15 optionally include access point.

[00192] Example 17 is a method performed by a wireless device, the method comprising: decoding synchronize fields of a packet, the synchronize fields each comprising an identification; determining a carrier offset associated with each of the synchronize fields from a corresponding identification, where the carrier offset indicates a frequency offset from a carrier; determining signal quality metrics for signal reception by the WUR for each carrier offset indicated in the synchronize fields; and configuring the WUR to adjust a receive frequency in accordance with one of the carrier offsets based on the signal quality metrics.

[00193] In Example 18, the subject matter of Example 17 optionally includes where the packet includes an Institute of Electrical and Electronic Engineers (IEEE) 802.11 legacy preamble field with a 20 MHz bandwidth, where the synchronize fields have a bandwidth of 5 MHz or less.

[00194] Example 19 is a non-transitory computer-readable storage medium that stores instructions for execution by one or more processors, the instructions to configure the one or more processors to cause a wireless device to: decode synchronize fields of a packet, the synchronize fields each comprising an identification; determine a carrier offset associated with each of the synchronize fields from a corresponding identification, where the carrier offset indicates a frequency offset from a carrier; determine signal quality metrics for signal reception by the WUR for each carrier offset indicated in the synchronize fields; and configure the WUR to adjust a receive frequency in accordance with one of the carrier offsets based on the signal quality metrics.

[00195] In Example 20, the subject matter of claim 19 optionally includes where the packet includes an Institute of Electrical and Electronic Engineers (IEEE) 802.11 legacy preamble field with a 20 MHz bandwidth, where the synchronize fields have a bandwidth of 5 MHz or less.

[00196] Example 21 is an apparatus of a wireless device, the apparatus comprising: memory; and, processing circuitry coupled to the memory, the processing circuitry configured to: encode synchronize fields, the synchronize fields each comprising an identification, the identification indicating a frequency the synchronize field is to be transmitted on, where the frequency is indicated by

a carrier offset; and configure the wireless device to transmit each of the synchronize fields on a frequency indicated by a corresponding identification.

[00197] In Example 22, the subject matter of Example 21 optionally includes where the processing circuitry is further configured to: configure the wireless device to transmit an Institute of Electrical and Electronic Engineers (IEEE) 802.11 legacy preamble field with a 20 MHz bandwidth before the synchronize fields; and configure the wireless device to transmit the synchronize fields with a bandwidth of 5 MHz or less.

[00198] In Example 23, the subject matter of any one or more of Examples 21–22 optionally include where the processing circuitry is further configured to: encode the identification based on a sequence of signals that indicates the carrier offset.

[00199] In Example 24, the subject matter of any one or more of Examples 21–23 optionally include where the processing circuitry is further configured to: encode a value of a field of each of the synchronize fields, where the field is from one bit to eight bits and indicates a carrier offset of a corresponding synchronize field of the synchronize fields.

[00200] In Example 25, the subject matter of any one or more of Examples 21–24 optionally include access point.

[00201] Example 26 is an apparatus of a wireless device, the apparatus comprising: means for decoding synchronize fields of a packet, the synchronize fields each comprising an identification; means for determining a carrier offset associated with each of the synchronize fields from a corresponding identification, where the carrier offset indicates a frequency offset from a carrier; means for determining signal quality metrics for signal reception by the WUR for each carrier offset indicated in the synchronize fields; and means for configuring a wake-up radio (WUR) to adjust a receive frequency in accordance with one of the carrier offsets based on the signal quality metrics.

[00202] In Example 27, the subject matter of Example 26 optionally includes where the packet includes an Institute of Electrical and Electronic Engineers (IEEE) 802.11 legacy preamble field with a 20 MHz bandwidth, and where the synchronize fields have a bandwidth of 5 MHz or less.

[00203] In Example 28, the subject matter of any one or more of Examples 26–27 optionally include where the WUR has a receive bandwidth of 5 MHz or less.

[00204] In Example 29, the subject matter of any one or more of
5 Examples 26–28 optionally include where the synchronize fields comprise a negative synchronize field with a negative frequency offset from the carrier, a center synchronize field with no frequency offset from the carrier, and a positive frequency synchronize field with a positive carrier offset from the carrier.

[00205] In Example 30, the subject matter of Example 29 optionally
10 includes the apparatus further includes: means for determining for each of the synchronize fields one or more of the following signal quality metrics: a signal to noise ratio and a signal strength.

[00206] In Example 31, the subject matter of Example 30 optionally
15 includes the apparatus further comprising: means for setting a converged carrier tracking loop based on the determined signal quality metrics, where the converged carrier tracking loop tunes to a frequency such that the center synchronization field will be received with a highest signal to noise ratio or a strongest signal strength.

[00207] In Example 32, the subject matter of Example 31 optionally
20 includes where the wireless device includes a clock coupled to the processing circuitry, and where the apparatus further includes: means for adjusting the clock to tune the frequency of the WUR to a frequency such that the center synchronization field will be received with a highest signal to noise ratio or a strongest signal strength.

[00208] In Example 33, the subject matter of any one or more of
25 Examples 26–32 optionally include where the identification is a value of a field of a corresponding synchronize field, and where the field is from one bit to eight bits.

[00209] In Example 34, the subject matter of any one or more of
30 Examples 26–33 optionally include the apparatus further comprising: means for determining the identification based on a sequence of a corresponding synchronize field of the synchronize fields.

[00210] In Example 35, the subject matter of any one or more of Examples 26–34 optionally include MHz from the carrier.

[00211] In Example 36, the subject matter of any one or more of Examples 26–35 optionally include where the carrier offset associated with each
5 of the synchronize fields is one from the following group: a negative offset from a carrier, a positive offset from the carrier, and no offset from the carrier.

[00212] In Example 37, the subject matter of any one or more of Examples 26–36 optionally include means for processing radio-frequency signals; and, means for transmitting and receiving radio-frequency signals.

10 [00213] In Example 38, the subject matter of Example 37 optionally includes the apparatus further comprising: means for generating a signal for the wireless device to wake up, if a wake-up packet is decoded.

[00214] In Example 39, the subject matter of any one or more of Examples 26–38 optionally include where the apparatus further includes means
15 for a single receive chain for the WUR.

[00215] In Example 40, the subject matter of any one or more of Examples 26–39 optionally include access point.

[00216] Example 41 is an apparatus of a wireless device, where the apparatus includes: means for configuring the wireless device to transmit an
20 Institute of Electrical and Electronic Engineers (IEEE) 802.11 legacy preamble field with a 20 MHz bandwidth before the synchronize fields; and means for configuring the wireless device to transmit the synchronize fields with a bandwidth of 5 MHz or less.

[00217] In Example 42, the subject matter of Example 41 optionally
25 includes the apparatus further comprising: means for encoding the identification based on a sequence of signals that indicates the carrier offset.

[00218] In Example 43, the subject matter of any one or more of Examples 41–42 optionally include the apparatus further comprising: means for encoding a value of a field of each of the synchronize fields, where the field is
30 from one bit to eight bits and indicates a carrier offset of a corresponding synchronize field of the synchronize fields.

[00219] Example 44 is a non-transitory computer-readable storage medium that stores instructions for execution by one or more processors, the

- instructions to configure the one or more processors to cause a wireless device to: encode synchronize fields, the synchronize fields each comprising an identification, the identification indicating a frequency the synchronize field is to be transmitted on, where the frequency is indicated by a carrier offset; and
- 5 configure the wireless device to transmit each of the synchronize fields on a frequency indicated by a corresponding identification.

[00220] In Example 45, the subject matter of Example 44 optionally includes where the instructions further configure the one or more processors to cause the wireless device to: configure the wireless device to transmit an

10 Institute of Electrical and Electronic Engineers (IEEE) 802.11 legacy preamble field with a 20 MHz bandwidth before the synchronize fields; and configure the wireless device to transmit the synchronize fields with a bandwidth of 5 MHz or less.

[00221] In Example 46, the subject matter of any one or more of

15 Examples 44–45 optionally include where the instructions further configure the one or more processors to cause the wireless device to: encode the identification based on a sequence of signals that indicates the carrier offset.

[00222] In Example 47, the subject matter of any one or more of

20 Examples 44–46 optionally include where the instructions further configure the one or more processors to cause the wireless device to: encode a value of a field of each of the synchronize fields, where the field is from one bit to eight bits and indicates a carrier offset of a corresponding synchronize field of the synchronize fields.

[00223] In Example 48, the subject matter of any one or more of

25 Examples 44–47 optionally include access point.

[00224] Example 49 is a method performed by a wireless device, the method comprising: encoding synchronize fields, the synchronize fields each comprising an identification, the identification indicating a frequency the synchronize field is to be transmitted on, where the frequency is indicated by a

30 carrier offset; and configuring the wireless device to transmit each of the synchronize fields on a frequency indicated by a corresponding identification.

[00225] In Example 50, the subject matter of Example 49 optionally includes where the processing circuitry is further configured to: configure the

wireless device to transmit an Institute of Electrical and Electronic Engineers (IEEE) 802.11 legacy preamble field with a 20 MHz bandwidth before the synchronize fields; and configure the wireless device to transmit the synchronize fields with a bandwidth of 5 MHz or less.

5 **[00226]** In Example 51, the subject matter of any one or more of Examples 49–50 optionally include where the method further includes: encode the identification based on a sequence of signals that indicates the carrier offset.

10 **[00227]** In Example 52, the subject matter of any one or more of Examples 49–51 optionally include where the method further includes: encoding a value of a field of each of the synchronize fields, where the field is from one bit to eight bits and indicates a carrier offset of a corresponding synchronize field of the synchronize fields.

15 **[00228]** In Example 53, the subject matter of any one or more of Examples 49–52 optionally include access point.

20 **[00229]** 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.

CLAIMS

What is claimed is:

1. An apparatus of a wireless device, the apparatus comprising: a
5 wake-up radio (WUR); and, processing circuitry coupled to the WUR, the
processing circuitry configured to:
decode synchronize fields of a packet, the synchronize fields each
comprising an identification;
determine a carrier offset associated with each of the synchronize
10 fields from a corresponding identification, wherein the carrier offset indicates a
frequency offset from a carrier;
determine signal quality metrics for signal reception by the WUR
for each carrier offset indicated in the synchronize fields; and
configure the WUR to adjust a receive frequency in accordance
15 with one of the carrier offsets based on the signal quality metrics.
2. The apparatus of claim 1, wherein the packet comprises an
Institute of Electrical and Electronic Engineers (IEEE) 802.11 legacy preamble
field with a 20 MHz bandwidth, and wherein the synchronize fields have a
20 bandwidth of 5 MHz or less.
3. The apparatus of claim 1, wherein the WUR has a receive
bandwidth of 5 MHz or less.
- 25 4. The apparatus of claim 1, wherein the synchronize fields
comprise a negative synchronize field with a negative frequency offset from the
carrier, a center synchronize field with no frequency offset from the carrier, and
a positive frequency synchronize field with a positive carrier offset from the
carrier.
30
5. The apparatus of claim 4, wherein the processing circuitry is
further configured to:

determine for each of the synchronize fields one or more of the following signal quality metrics: a signal to noise ratio and a signal strength.

6. The apparatus of claim 5, wherein the processing circuitry is
5 further configured to:

set a converged carrier tracking loop based on the determined signal quality metrics, wherein the converged carrier tracking loop tunes to a frequency such that the center synchronization field will be received with a higher or highest signal to noise ratio or a stronger or strongest signal strength.

10

7. The apparatus of claim 5, wherein the wireless device comprises a clock coupled to the processing circuitry, and wherein the processing circuitry is further configured to:

adjust the clock to tune the frequency of the WUR to a frequency
15 such that the center synchronization field will be received with a highest signal to noise ratio or a strongest signal strength.

8. The apparatus of claim 1, wherein the identification is a value of a field of a corresponding synchronize field, and wherein the field is from one bit
20 to eight bits.

9. The apparatus of claim 1, wherein the processing circuitry is further configured to:

determine the identification based on a sequence of a
25 corresponding synchronize field of the synchronize fields.

10. The apparatus of claim 1, wherein the carrier offset associated with each of the synchronize fields is from a negative 1 MHz offset from a carrier to a positive 1 MHz from the carrier.

30

11. The apparatus of claim 1, wherein the carrier offset associated with each of the synchronize fields is one from the following group: a negative

offset from a carrier, a positive offset from the carrier, and no offset from the carrier.

12. The apparatus of claim 1, further comprising transceiver circuitry
5 coupled to the WUR; and, one or more antennas coupled to the transceiver circuitry.

13. The apparatus of claim 12, wherein the is processing circuitry is further configured to:
10 generate a signal for the wireless device to wake up, if a wake-up packet is decoded.

14. The apparatus of claim 1, wherein the apparatus further comprises memory coupled to the processing circuitry, and wherein the memory is
15 configured to store the carrier offset of each of the synchronize fields and the synchronize fields.

15. The apparatus of claim 1, wherein the apparatus further comprises a single receive chain for the WUR.
20

16. The apparatus of claim 1, wherein the wireless device is one from the following group: an Institute of Electrical and Electronic Engineers (IEEE) 802.11ax access point, an IEEE 802.11ax station, an IEEE 802.11ba station, an IEEE 802.11ba access point, an IEEE 802.11 station, and an IEEE 802.11 access
25 point.

17. A method performed by a wireless device, the method comprising:
decoding synchronize fields of a packet, the synchronize fields
30 each comprising an identification;
determining a carrier offset associated with each of the synchronize fields from a corresponding identification, wherein the carrier offset indicates a frequency offset from a carrier;

determining signal quality metrics for signal reception by the WUR for each carrier offset indicated in the synchronize fields; and
configuring the WUR to adjust a receive frequency in accordance with one of the carrier offsets based on the signal quality metrics.

5

18. The method of claim 17, wherein the packet comprises an Institute of Electrical and Electronic Engineers (IEEE) 802.11 legacy preamble field with a 20 MHz bandwidth, wherein the synchronize fields have a bandwidth of 5 MHz or less.

10

19. A non-transitory computer-readable storage medium that stores instructions for execution by one or more processors, the instructions to configure the one or more processors to cause a wireless device to:
decode synchronize fields of a packet, the synchronize fields each
comprising an identification;
determine a carrier offset associated with each of the synchronize fields from a corresponding identification, wherein the carrier offset indicates a frequency offset from a carrier;
determine signal quality metrics for signal reception by the WUR
for each carrier offset indicated in the synchronize fields; and
configure the WUR to adjust a receive frequency in accordance with one of the carrier offsets based on the signal quality metrics.

15

20

20. The non-transitory computer-readable storage medium of claim 19, wherein the packet comprises an Institute of Electrical and Electronic Engineers (IEEE) 802.11 legacy preamble field with a 20 MHz bandwidth, wherein the synchronize fields have a bandwidth of 5 MHz or less.

25

21. An apparatus of a wireless device, the apparatus comprising:
memory; and, processing circuitry coupled to the memory, the processing circuitry configured to:

30

encode synchronize fields, the synchronize fields each comprising an identification, the identification indicating a frequency the synchronize field is to be transmitted on, wherein the frequency is indicated by a carrier offset; and
configure the wireless device to transmit each of the synchronize
5 fields on a frequency indicated by a corresponding identification.

22. The apparatus of claim 21, wherein the processing circuitry is further configured to:
configure the wireless device to transmit an Institute of Electrical
10 and Electronic Engineers (IEEE) 802.11 legacy preamble field with a 20 MHz bandwidth before the synchronize fields; and
configure the wireless device to transmit the synchronize fields with a bandwidth of 5 MHz or less.

15 23. The apparatus of claim 21, wherein the processing circuitry is further configured to:
encode the identification based on a sequence of signals that indicates the carrier offset.

20 24. The apparatus of claim 21, wherein the processing circuitry is further configured to:
encode a value of a field of each of the synchronize fields,
wherein the field is from one bit to eight bits and indicates a carrier offset of a
corresponding synchronize field of the synchronize fields.

25 25. The apparatus of claim 21, wherein the wireless device is one from the following group: an Institute of Electrical and Electronic Engineers (IEEE) 802.11ax access point, an IEEE 802.11ax station, an IEEE 802.11ba
station, an IEEE 802.11ba access point, an IEEE 802.11 station, and an IEEE
30 802.11 access point.

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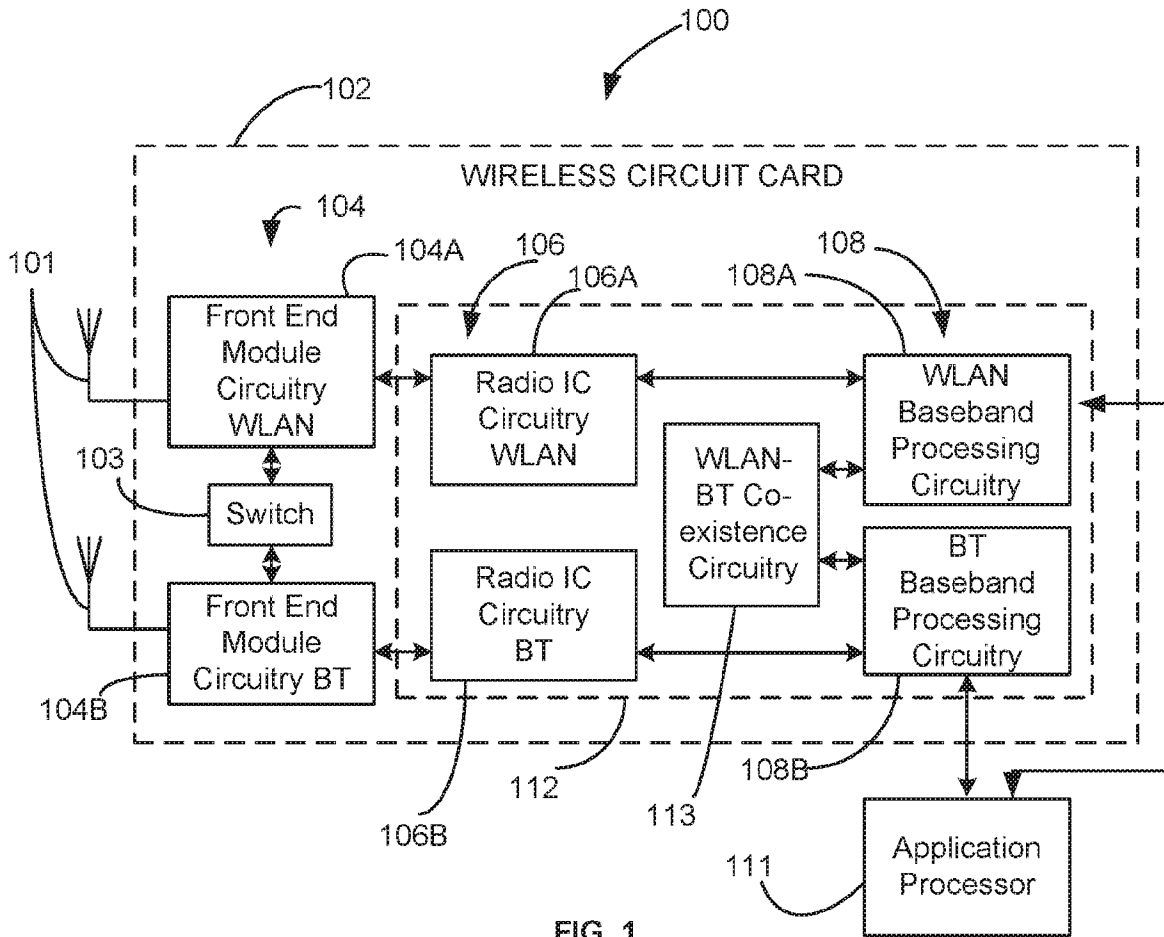


FIG. 1

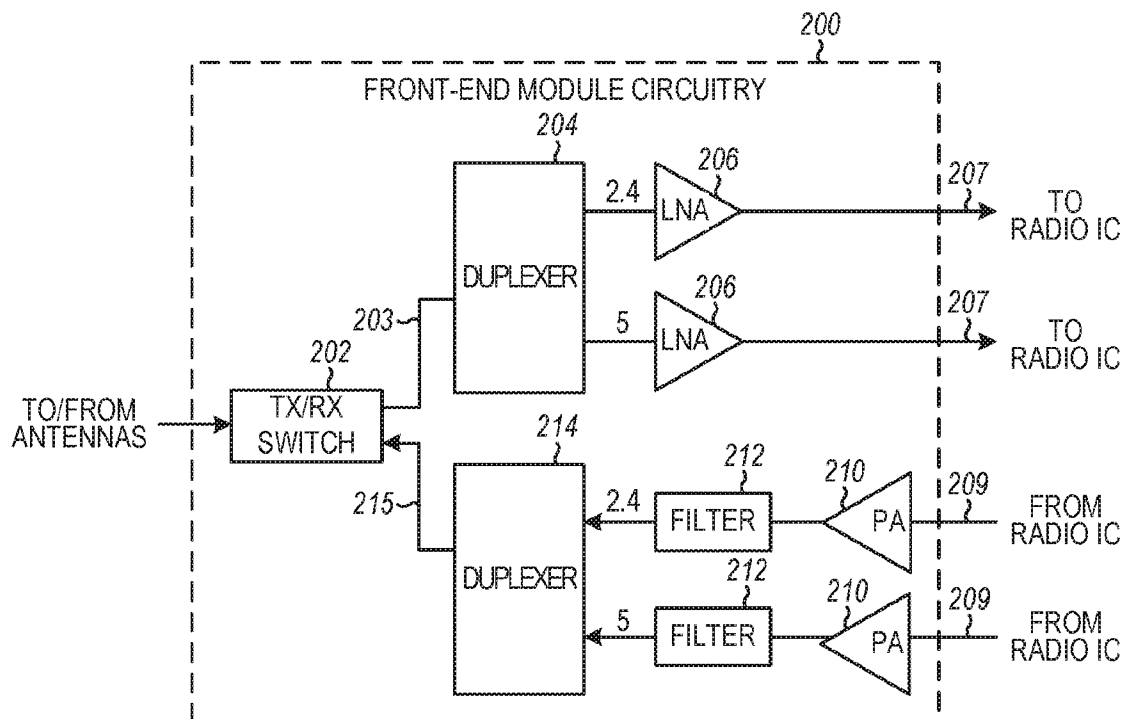


FIG. 2

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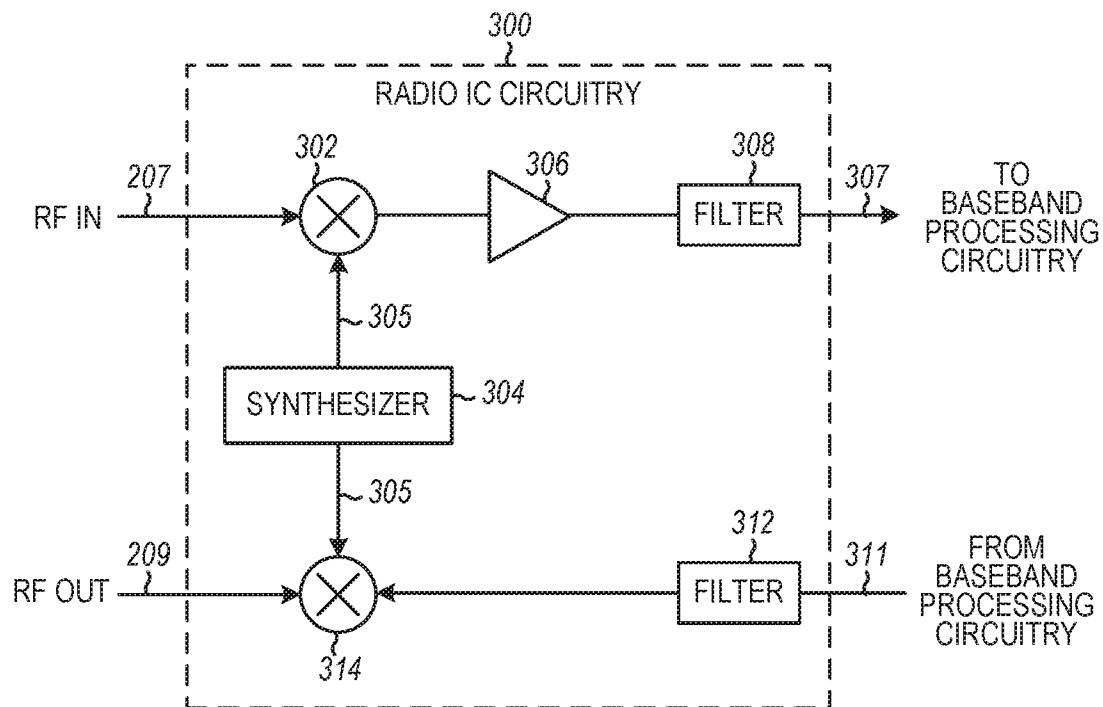


FIG. 3

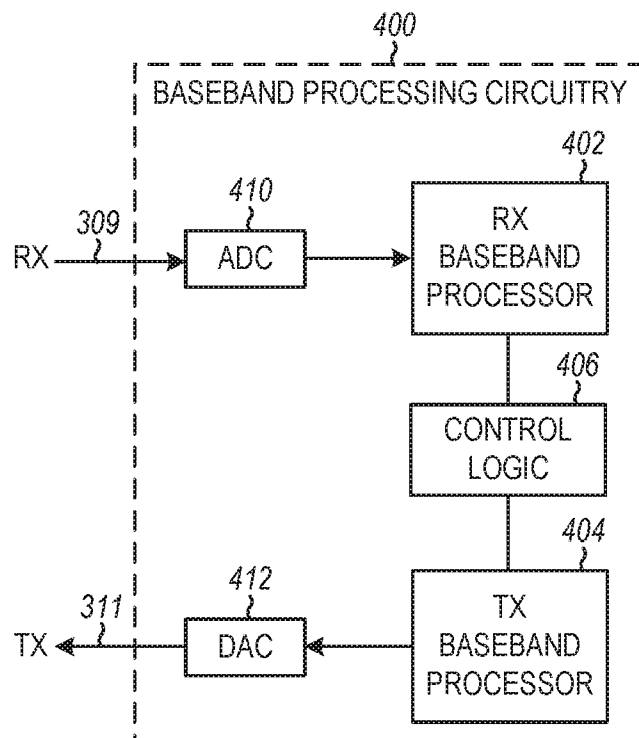


FIG. 4

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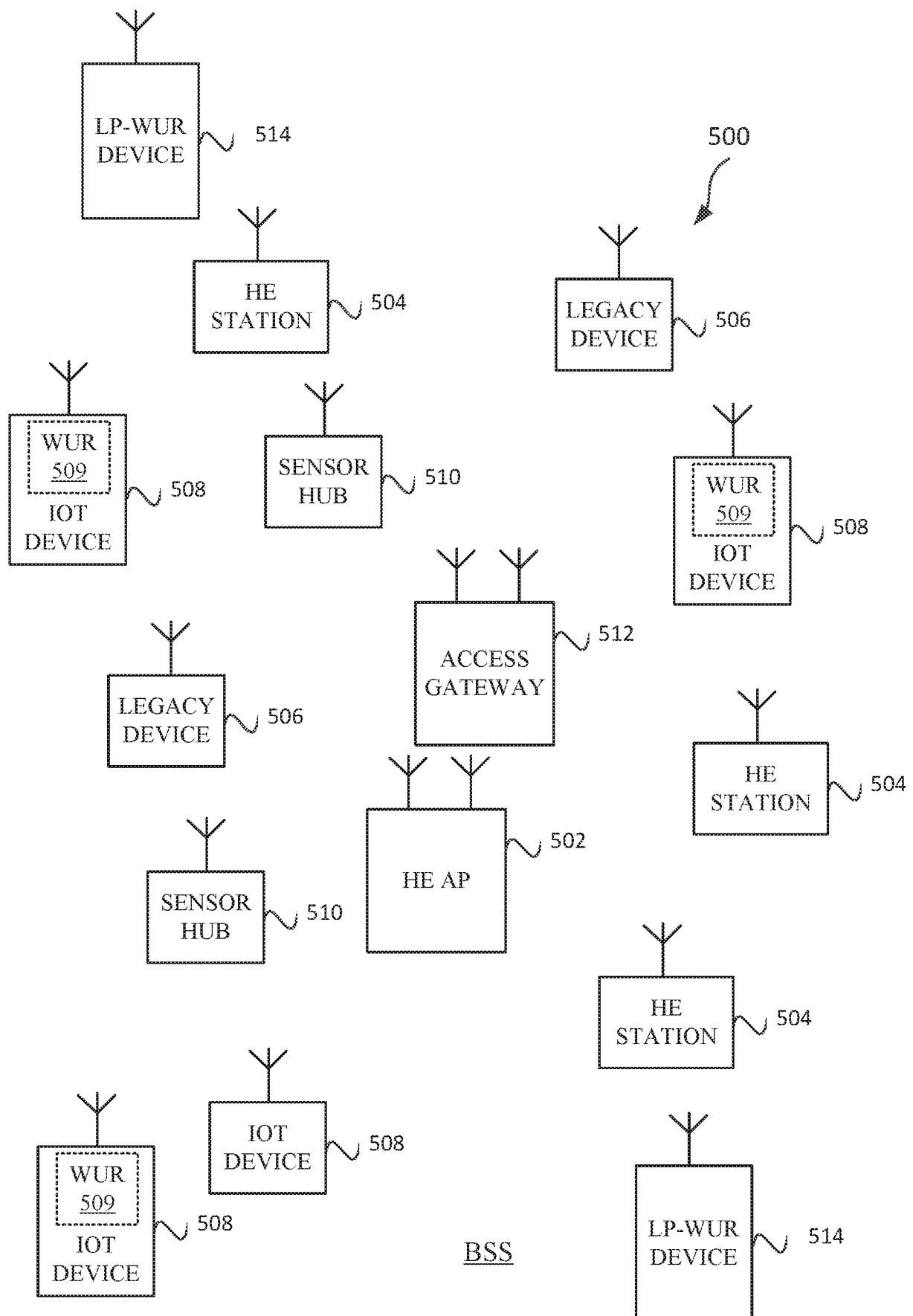


FIG. 5

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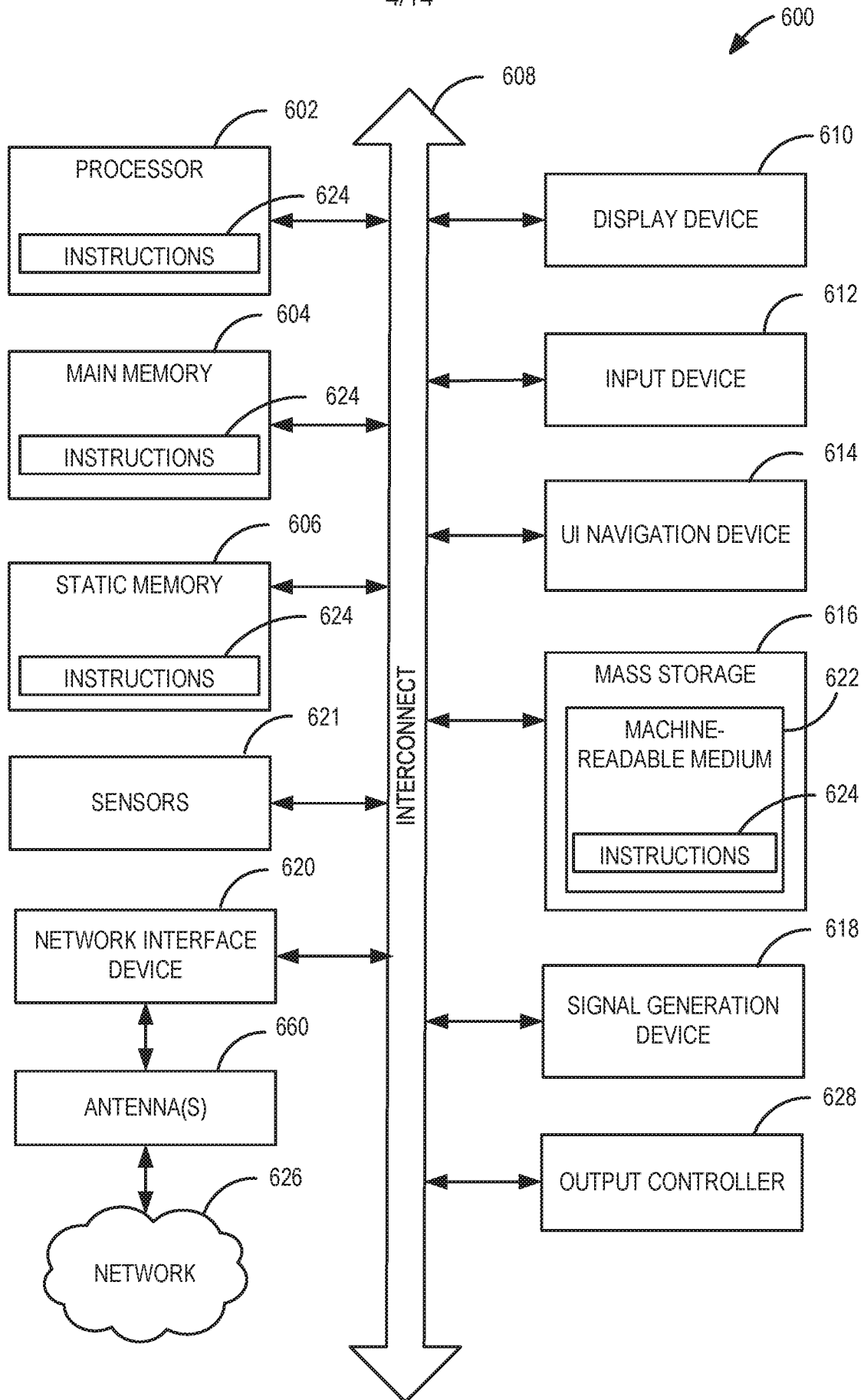
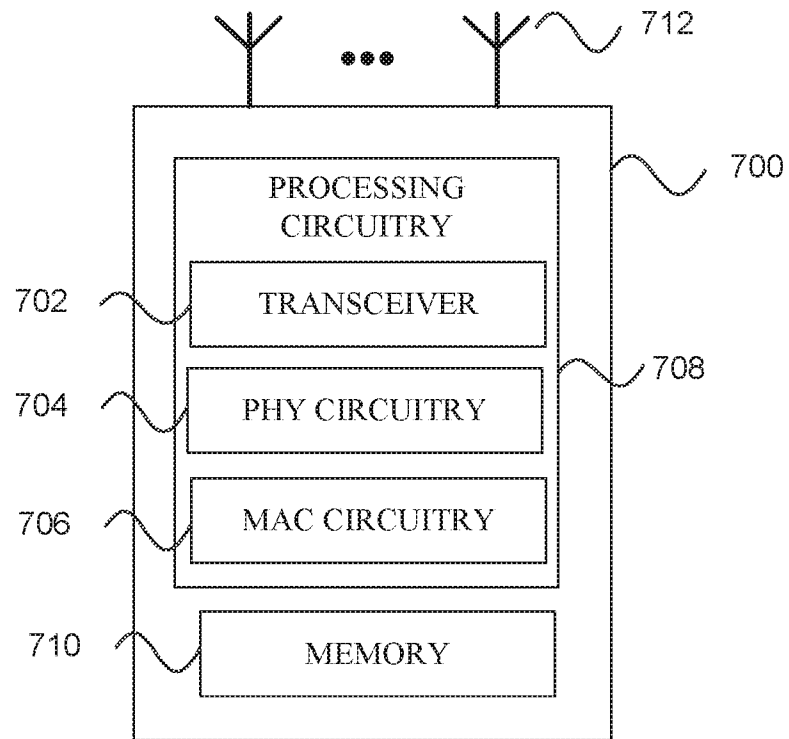
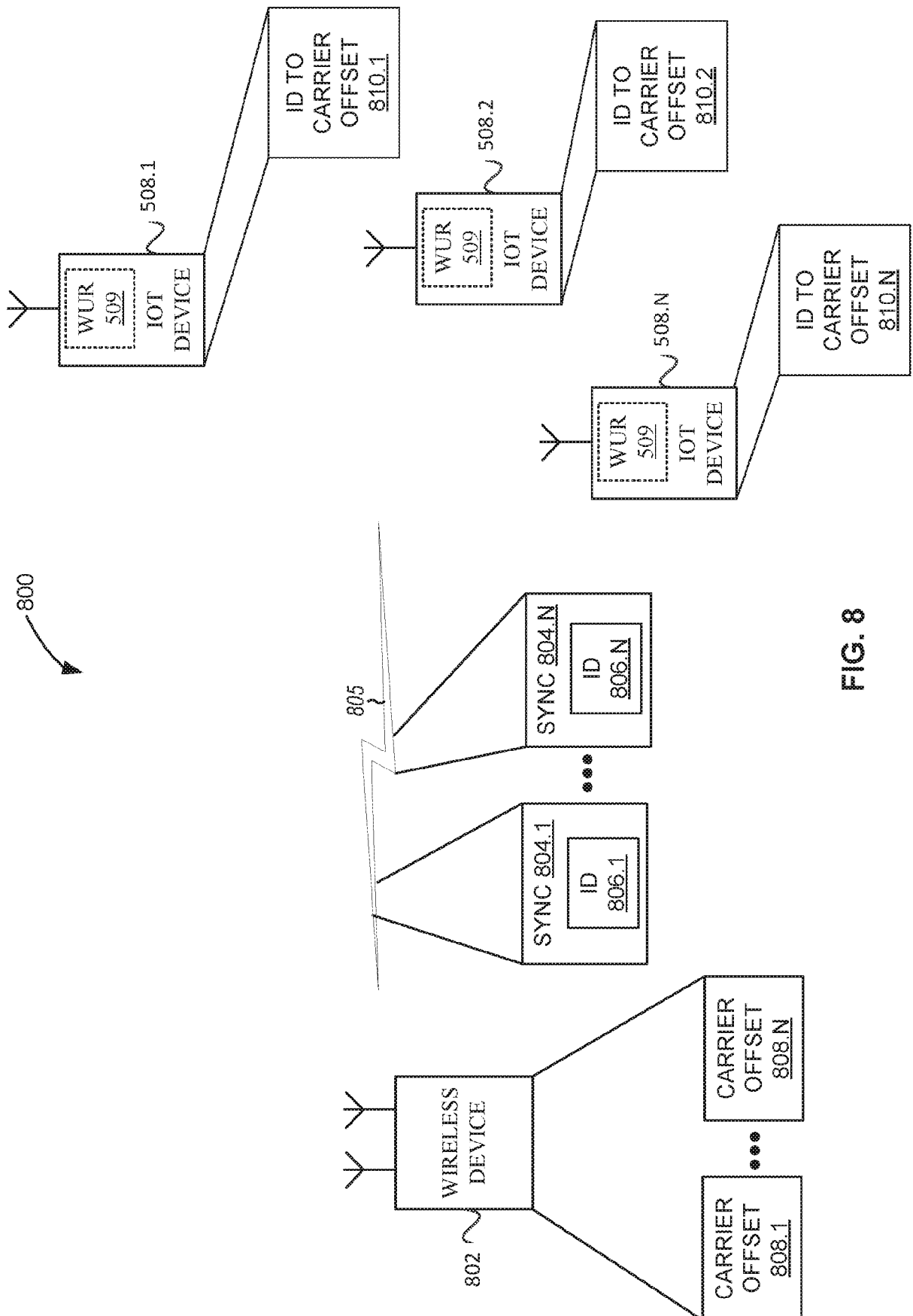


FIG. 6

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**FIG. 7**



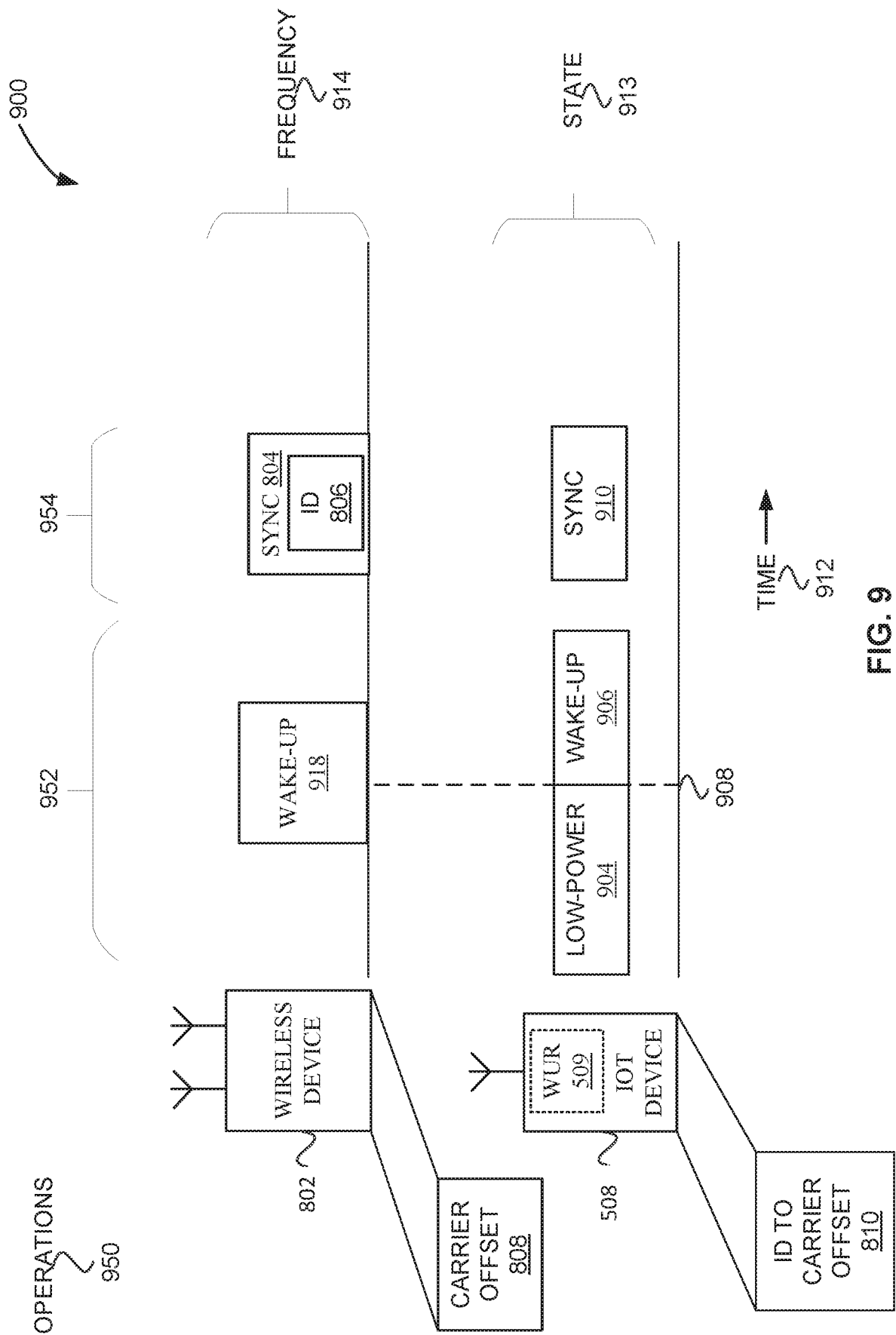


FIG. 9

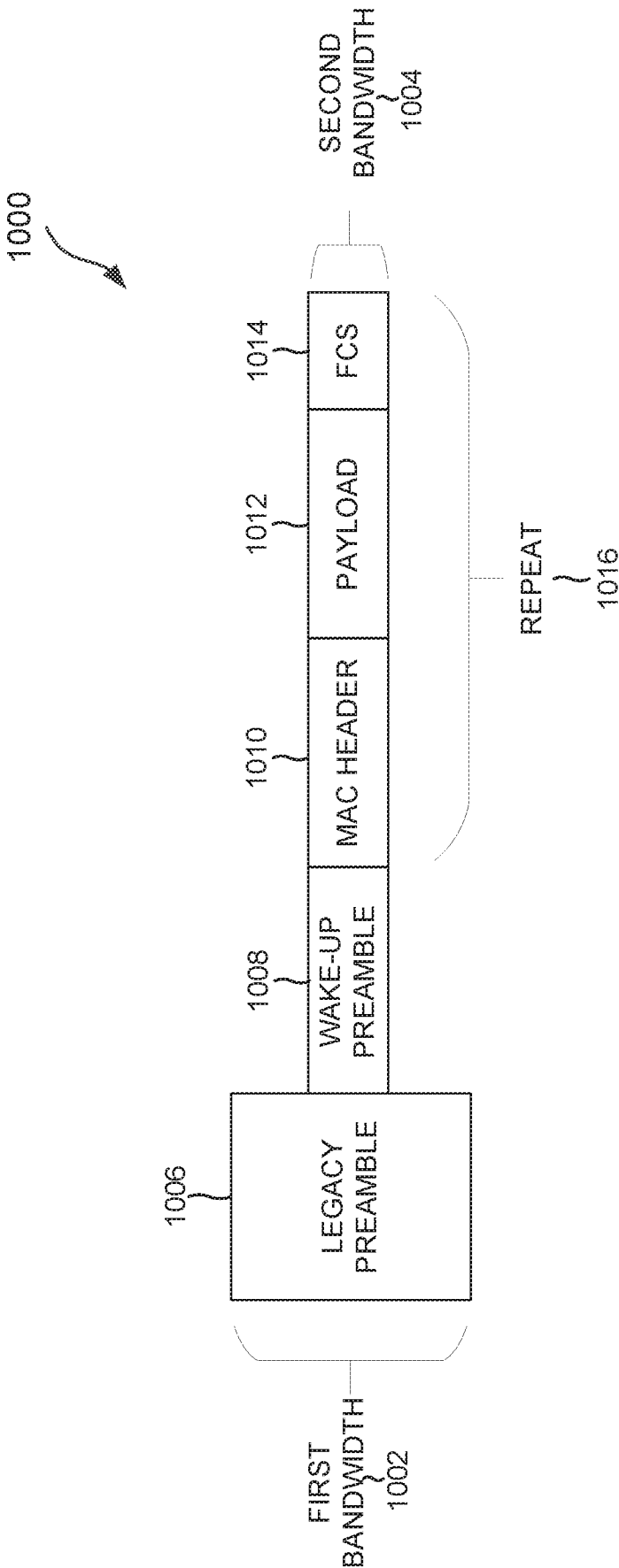


FIG. 10

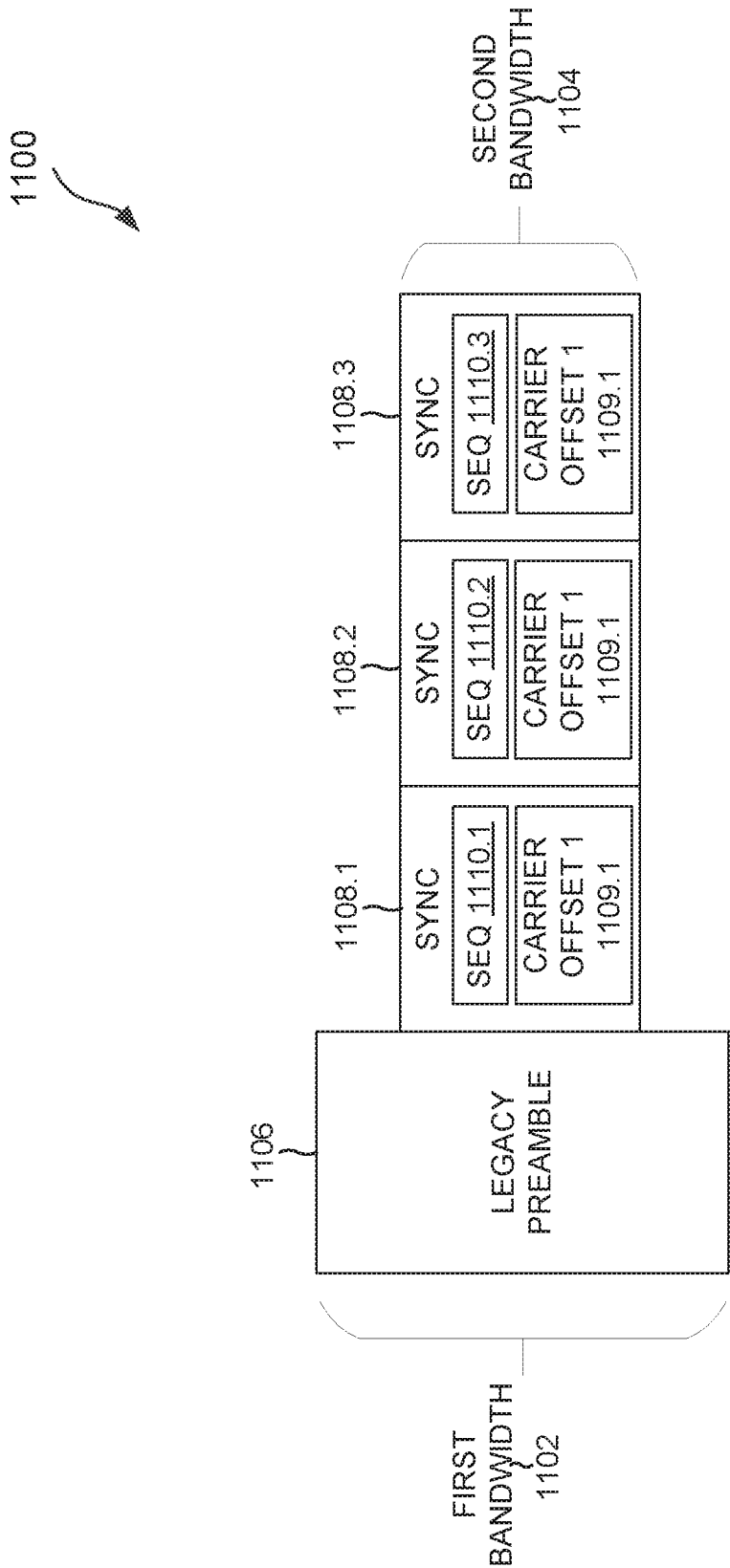


FIG. 11

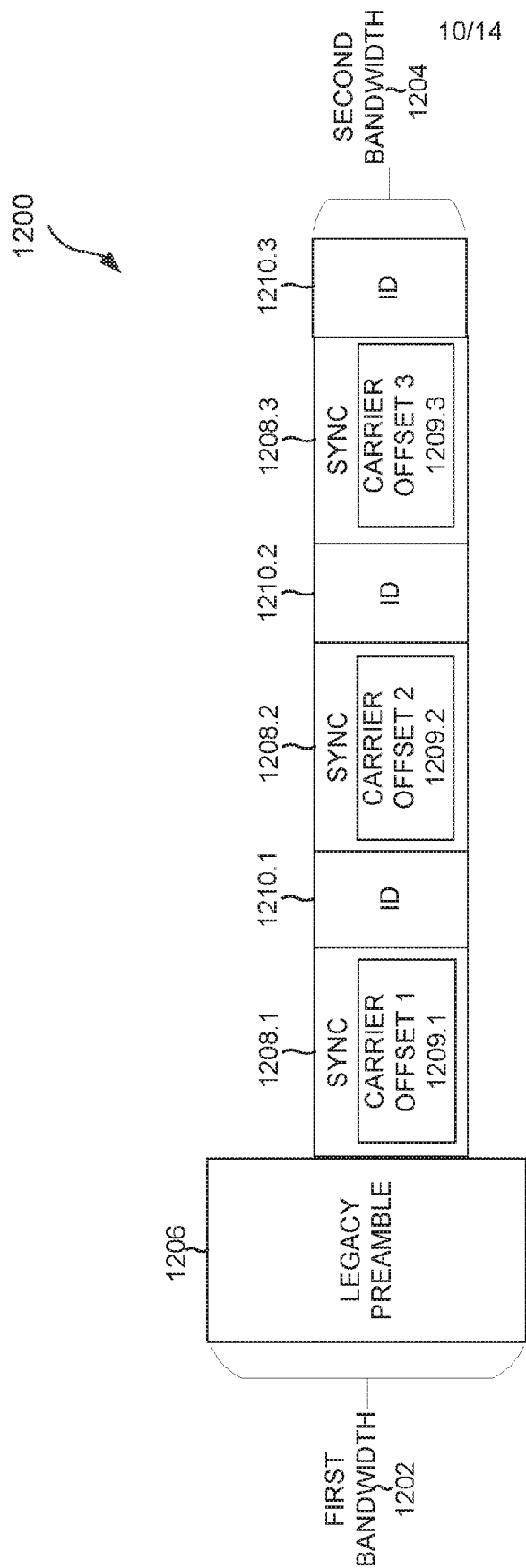


FIG. 12

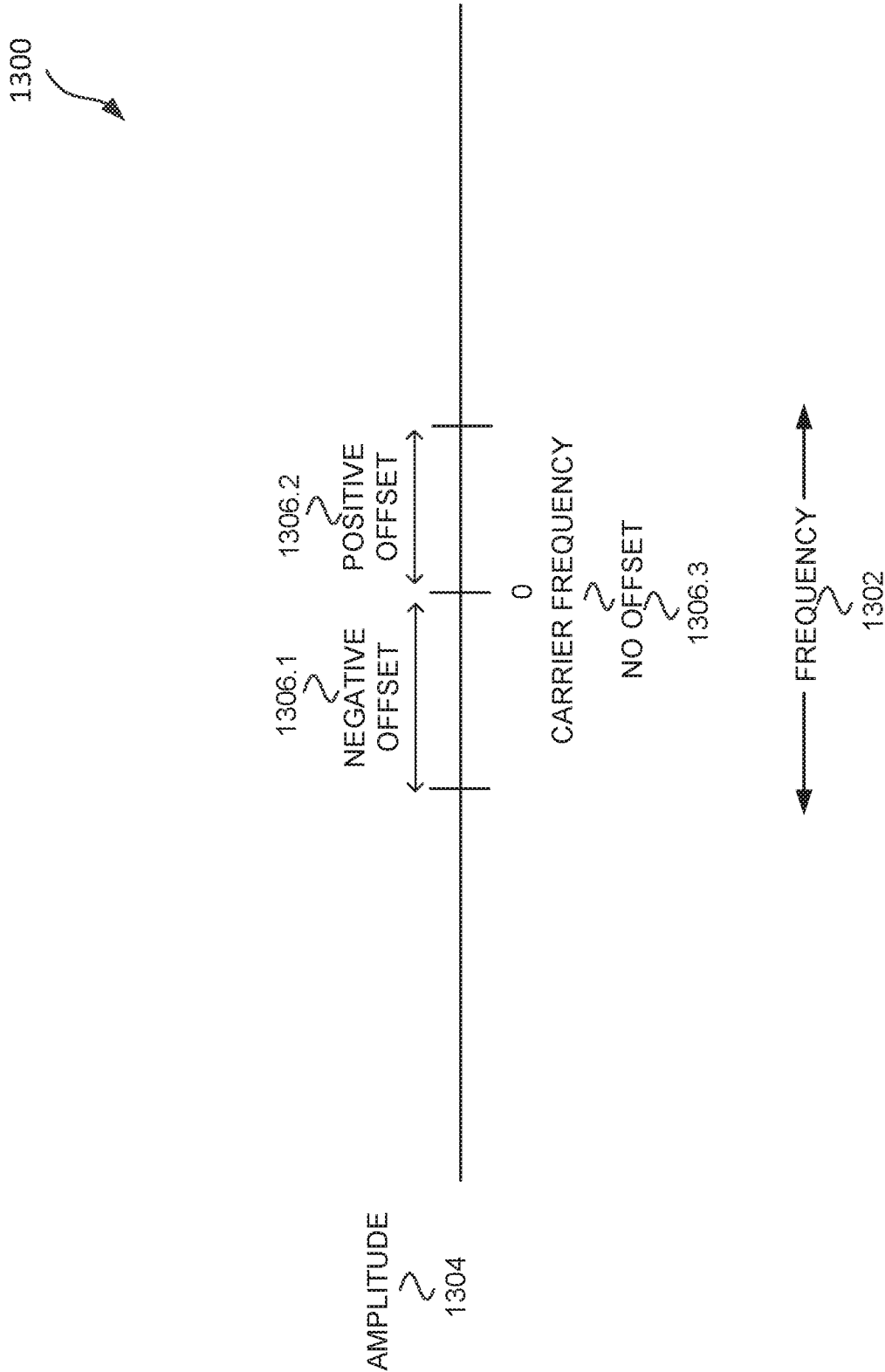
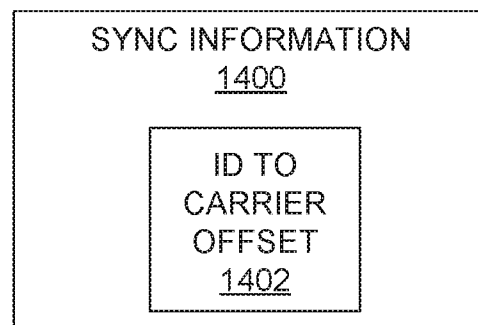
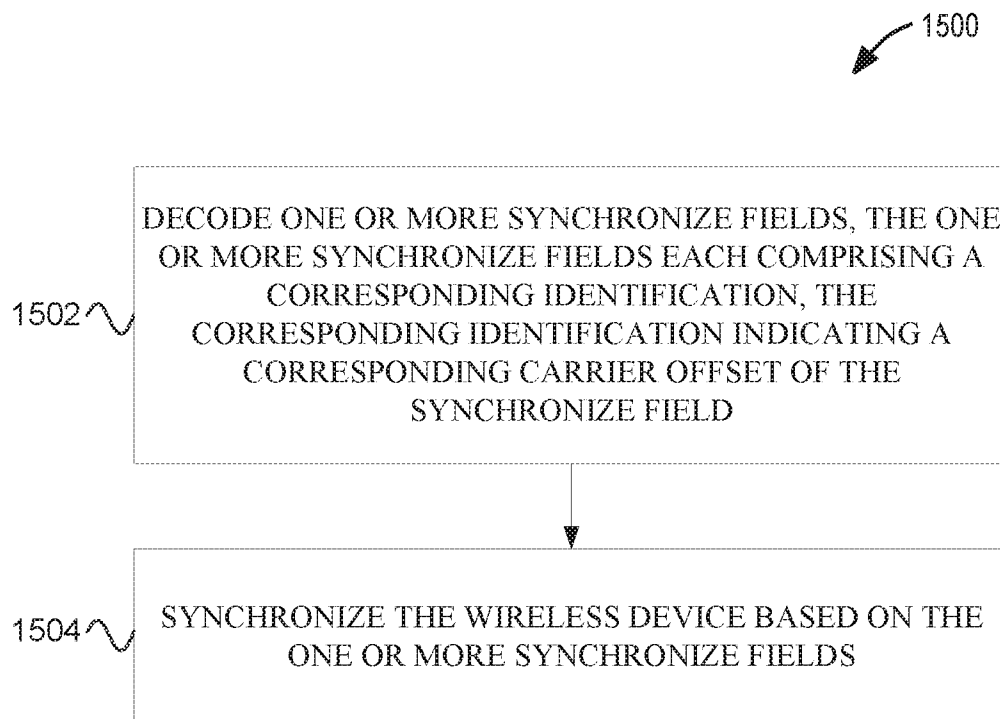


FIG. 13

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**FIG. 14****FIG. 15**

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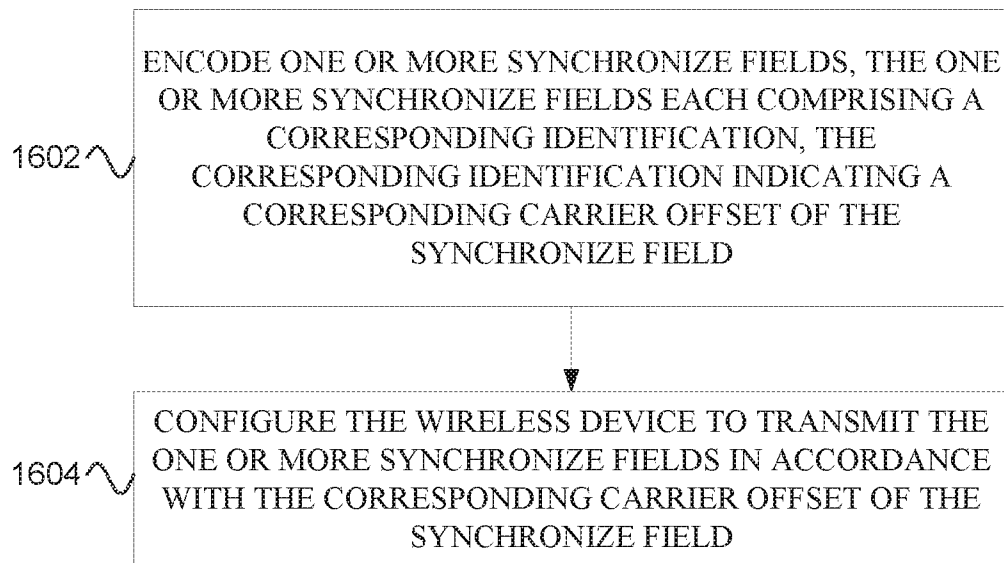


FIG. 16

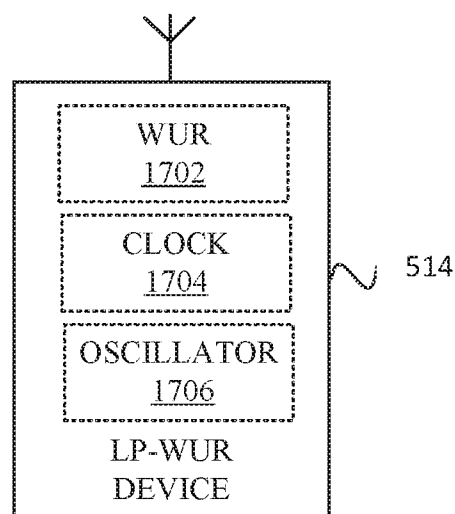


FIG. 17

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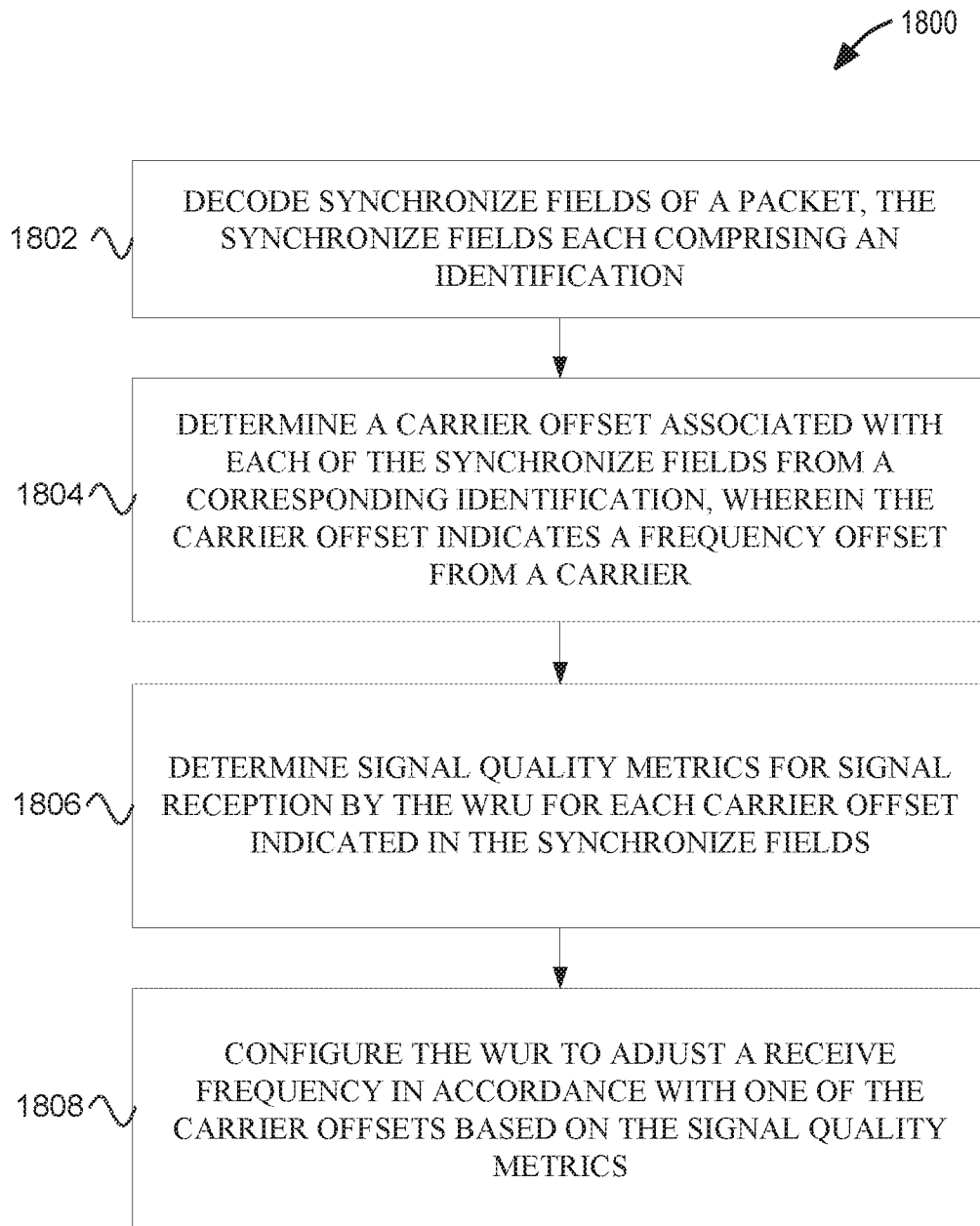


FIG. 18

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/054085**A. CLASSIFICATION OF SUBJECT MATTER****H04W 56/00(2009.01)i, H04W 52/02(2009.01)i, H04W 84/12(2009.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W 56/00; H04L 27/00; H03M 1/00; H04L 25/02; H04W 52/02; H04L ; H04W 72/04; H04W 12/08; H04W 60/00; H04W 84/12

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: WUR(Wake Up Radio), synchronize field, carrier offset, one or more IoT device, frequency offset, identifiers**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2016-0142227 A1 (QINGHUA LI et al.) 19 May 2016 See paragraphs [0022]-[0024], [0027], [0034]-[0035], [0069]; and figure 1B.	21, 23-25
Y		22
A		1-20
Y	US 2016-0366644 A1 (CHITTABRATA GHOSH et al.) 15 December 2016 See claims 1, 3.	22
A	US 2015-0327174 A1 (BROADCOM CORPORATION) 12 November 2015 See paragraph [0019]; and figure 1.	1-25
A	US 2015-0071151 A1 (MICROSEMI CORPORATION) 12 March 2015 See paragraphs [0046]-[0052]; and figure 1.	1-25
A	WO 2016-148773 A1 (INTEL IP CORPORATION) 22 September 2016 See paragraphs [0026], [0072]; and claim 18.	1-25
A	WO 2005-034409 A2 (MOTOROLA, INC. et al.) 14 April 2005 See claims 1-9.	1-25



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

16 January 2018 (16.01.2018)

Date of mailing of the international search report

16 January 2018 (16.01.2018)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

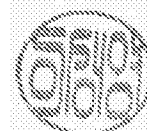
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/054085

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