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(54) Title: ACCESS POINT (AP), STATION (STA) AND METHODS TO EXCHANGE SOUNDING FRAMES AND CONTROL INFORMATION FOR LOCATION MEASUREMENT

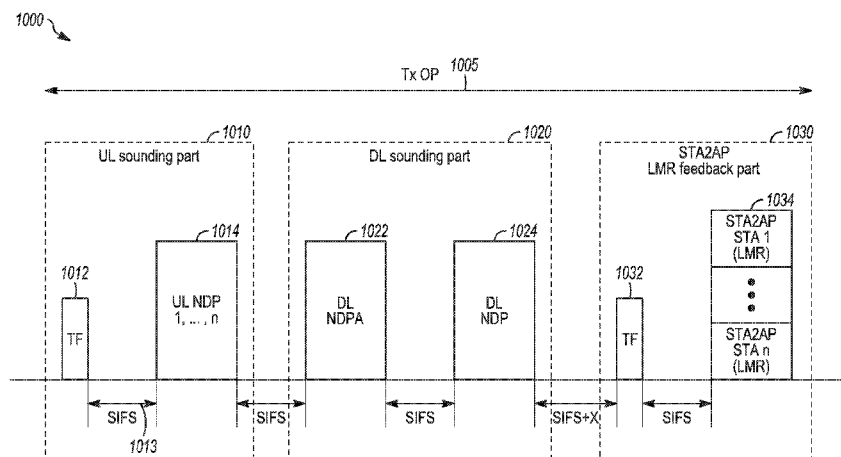


FIG. 10

(57) **Abstract:** Embodiments of an access point (AP), station (STA) and methods of communication are generally described herein. The AP may transmit a trigger frame (TF) that requests uplink sounding frames from stations (STAs). The AP may receive the uplink sounding frames multiplexed in accordance with an orthogonal frequency division multiple access (OFDMA) technique or space-division multiple access (SDMA) technique. The AP may transmit downlink sounding frames multiplexed in accordance with an OFDMA technique. The AP may transmit downlink location measurement reports (LMRs) that include per-STA arrival times of the uplink sounding frames and a departure time of the downlink sounding frames. The AP may transmit another TF that requests transmission of uplink LMRs. The uplink LMRs may include per-STA location information based on the per-STA arrival times of the uplink sounding



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ACCESS POINT (AP), STATION (STA) AND METHODS TO EXCHANGE
SOUNDING FRAMES AND CONTROL INFORMATION FOR LOCATION
5 MEASUREMENT

PRIORITY CLAIMS

[0001] This application claims priority to United States Provisional
10 Patent Application Serial No. 62/464,110, filed February 27, 2017 and to United
States Provisional Patent Application Serial No. 62/464,004, filed February 27,
2017, which are incorporated herein by reference in their entirety.

15 TECHNICAL FIELD

[0002] Embodiments pertain to 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
20 family of standards. Some embodiments relate to communication in accordance
with IEEE 802.11ax networks and/or IEEE 802.11az networks. Some
embodiments relate to measurement of location information, including
measurement of round trip time (RTT). Some embodiments relate to channel
sounding.

25

BACKGROUND

[0003] In some cases, an access point (AP) may communicate with one
30 or more stations (STAs) to exchange data and/or other information. The AP may
utilize location information of the STAs for various functions related to the
communication, such as scheduling of uplink data transmissions and/or
downlink data transmissions. Various control frames, such as sounding frames,

may be exchanged to enable determination of the location information. At least a portion of the available time resources and frequency resources may be utilized to exchange the control frames. Accordingly, the amount of data that can be exchanged between the AP and the STAs in those resources may depend on an efficiency for the exchange of control frames. Therefore, there is a general need for methods and systems to enable determination of location information in these and other scenarios.

BRIEF DESCRIPTION OF THE DRAWINGS

- [0004] FIG. 1 illustrates a wireless network in accordance with some embodiments;
- [0005] FIG. 2 illustrates an example machine in accordance with some embodiments;
- [0006] FIG. 3 illustrates a station (STA) in accordance with some embodiments and an access point (AP) in accordance with some embodiments;
- [0007] FIG. 4 is a block diagram of a radio architecture in accordance with some embodiments;
- [0008] FIG. 5 illustrates a front-end module circuitry for use in the radio architecture of FIG. 4 in accordance with some embodiments;
- [0009] FIG. 6 illustrates a radio IC circuitry for use in the radio architecture of FIG. 4 in accordance with some embodiments;
- [0010] FIG. 7 illustrates a baseband processing circuitry for use in the radio architecture of FIG. 4 in accordance with some embodiments;
- [0011] FIG. 8 illustrates the operation of a method of communication in accordance with some embodiments;
- [0012] FIG. 9 illustrates the operation of another method of communication in accordance with some embodiments;
- [0013] FIG. 10 illustrates example frames that may be exchanged in accordance with some embodiments;
- [0014] FIG. 11 illustrates example frames that may be exchanged in accordance with some embodiments;

[0015] FIGs. 12A-B illustrate an example trigger frame (TF) in accordance with some embodiments;

[0016] FIGs. 13A-B illustrate example frames that may be exchanged in accordance with some embodiments;

5 [0017] FIGs. 14A-B illustrate an example TF in accordance with some embodiments;

[0018] FIG. 15 illustrates an example null data packet announcement (NDPA) frame and an example sounding dialog token in accordance with some embodiments; and

10 [0019] FIG. 16 illustrates an example TF in accordance with some embodiments.

15 DETAILED DESCRIPTION

[0020] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other
20 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.

[0021] FIG. 1 illustrates a wireless network in accordance with some embodiments. In some embodiments, the network 100 may be a High Efficiency
25 (HE) Wireless Local Area Network (WLAN) network. In some embodiments, the network 100 may be a WLAN or a Wi-Fi network. These embodiments are not limiting, however, as some embodiments of the network 100 may include a combination of such networks. That is, the network 100 may support HE operation in some cases, non-HE operation in some cases, and a combination of
30 HE operation and non-HE operation in some cases.

[0022] Referring to FIG. 1, the network 100 may include any or all of the components shown, and embodiments are not limited to the number of each component shown in FIG. 1 and are also not limited to the types of components

shown in FIG. 1. Embodiments are also not limited by the example network 100 in terms of the arrangement of the components or the connectivity between components as shown. In addition, some embodiments may include additional components.

5 **[0023]** In some embodiments, the network 100 may include an AP 102 (which may be a master station in some embodiments) and may include any number (including zero) of stations (STAs) 103 and/or HE devices 104. In some embodiments, the AP 102 may receive and/or detect signals from one or more STAs 103, and may transmit data packets to one or more STAs 103. These
10 embodiments will be described in more detail below. In some embodiments, the AP 102 may receive and/or detect signals from one or more HE devices 104, and may transmit data packets to one or more HE devices 104.

[0024] It should be noted that embodiments are not limited to networks that include APs 102, however, as other base station components may be
15 included in some embodiments. Such components may or may not be arranged to operate in accordance with a standard, in some embodiments. As an example, an Evolved Node-B (eNB) arranged to operate in accordance with one or more Third Generation Partnership Project (3GPP) standards, including but not limited to 3GPP Long Term Evolution (LTE) standards, may be used in some cases.

20 **[0025]** In some embodiments, the STAs 103 may be arranged to operate in accordance with one or more IEEE 802.11 standards, including but not limited to 802.11ax and/or 802.11az. These embodiments are not limiting, however, as other mobile devices, portable devices and/or other devices, which may or may not be arranged to operate in accordance with a standard, may be used in some
25 embodiments. As an example, a User Equipment (UE) arranged to operate in accordance with one or more Third Generation Partnership Project (3GPP) standards, including but not limited to 3GPP LTE standards, may be used in some cases.

[0026] The AP 102 may be arranged to communicate with one or more
30 of the components shown in FIG. 1 in accordance with one or more IEEE 802.11 standards (including 802.11ax, 802.11az and/or others), other standards and/or other communication protocols. It should be noted that embodiments are not limited to usage of an AP 102. References herein to the AP 102 are not limiting

and references herein to a master station are also not limiting. In some embodiments, an STA 103, an MU operation device (device capable of MU operation), an HE device 104 and/or other device may be configurable to operate as a master station. In some embodiments, operations that may be performed by the AP 102 as described herein may be performed by the STA 103, an MU operation device, an HE device 104, a device that is configurable to operate as an AP 102 and/or a device that is configurable to operate as a master station.

[0027] In some embodiments, the STA 103 may be configured to operate as an HE device 104. References herein to an STA 103 or to an HE device 104 are not limiting. Although descriptions herein may refer to performance of one or more techniques, operations and/or methods by an STA 103, it is understood that some or all of those techniques, operations and/or methods may be performed by an HE device 104, in some embodiments. In addition, it is understood that some or all of those techniques, operations and/or methods may be performed by an STA103 configured to operate as an HE device 104, in some embodiments.

[0028] In some embodiments, communication between the AP 102 and the STAs 103 and/or communication between the STAs 103 may be performed in accordance with one or more standards, such as an 802.11 standard (including legacy 802.11 standards), a 3GPP standard (including 3GPP LTE standards) and/or other standards. These embodiments are not limiting, however, as other communication techniques and/or protocols (which may or may not be included in a standard) may be used for the communication between the AP 102 and the STAs 103 and/or the communication between the STAs 103, in some embodiments. Embodiments are not limited to communication as part of a network. In some embodiments, communication between two or more STAs 103 may not necessarily involve a network. In some cases, at least a portion of the communication may include direct communication between the STAs 103.

[0029] It should also be noted that the AP 102 may operate as an STA 103, in some embodiments. Some techniques, operations and/or methods may be described herein in terms of communication between two STAs 103, but such descriptions are not limiting. Some or all of those techniques, operations and/or methods may be applicable to scenarios in which an STA 103 and an AP 102

communicate. In addition, some techniques, operations and/or methods may be described herein in terms of communication between an STA 103 and an AP 102, but such descriptions are not limiting. Some or all of those techniques, operations and/or methods may be applicable to scenarios in which two or more
5 STAs 103 communicate.

[0030] In some embodiments, one or more of the STAs 103 may be legacy stations (for instance, a non MU operation device and/or device not capable of MU operation). These embodiments are not limiting, however, as an STA 103 may be configured to operate as an HE device 104 or may support HE
10 operation, in some embodiments. The AP 102 may be arranged to communicate with the STAs 103 and/or the HE devices 104 in accordance with one or more of the IEEE 802.11 standards, including 802.11ax, 802.11az and/or others. In accordance with some embodiments (including but not limited to HE operation embodiments), an AP 102 may operate as a master station.

15 [0031] In some embodiments, the AP 102 may be arranged to contend for a wireless medium (e.g., during a contention period) to receive exclusive control of the medium for an 802.11 air access control period (i.e., a transmission opportunity (TXOP)). The AP 102 may, for example, transmit a master-sync or control transmission at the beginning of the 802.11 air access
20 control period (including but not limited to an HE control period) to indicate, among other things, which STAs 103 and/or HE devices 104 are scheduled for communication during the 802.11 air access control period. During the 802.11 air access control period, the scheduled STAs 103 and/or HE devices 104 may communicate with the AP 102 in accordance with a non-contention based
25 multiple access technique. This is unlike conventional Wi-Fi communications in which devices communicate in accordance with a contention-based communication technique, rather than a non-contention based multiple access technique. During the 802.11 air access control period, the AP 102 may communicate with STAs 103 and/or HE devices 104 using one or more MU
30 PPDUs. During the 802.11 air access control period, STAs 103 not operating in accordance with HE operation may refrain from communicating in some cases. In some embodiments, the master-sync transmission may be referred to as a control and schedule transmission.

[0032] In some embodiments, the multiple-access technique used during the 802.11 air access control period may be a scheduled orthogonal frequency-division multiple access (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 including a multi-user (MU) multiple-input multiple-output (MIMO) (MU-MIMO) technique or combination of the above. These multiple-access techniques used during the 802.11 air access control period may be configured for uplink or downlink data communications.

[0033] The AP 102 may also communicate with STAs 103 and/or other legacy stations in accordance with legacy IEEE 802.11 communication techniques. In some embodiments, the AP 102 may also be configurable to communicate with the STAs 103 and/or legacy stations outside the 802.11 air access control period in accordance with legacy IEEE 802.11 communication techniques, although this is not a requirement.

[0034] In some embodiments, communication (including but not limited to communication during the control period) may be configurable to use one of 20MHz, 40MHz, or 80MHz contiguous bandwidths or an 80+80MHz (160MHz) non-contiguous bandwidth. In some embodiments, a 320MHz channel width may be used. In some embodiments, sub-channel bandwidths less than 20MHz may also be used. In these embodiments, each channel or sub-channel of a communication may be configured for transmitting a number of spatial streams.

[0035] In some embodiments, multi-user (MU) techniques may be used, although the scope of embodiments is not limited in this respect. As an example, MU techniques included in 802.11ax standards, 802.11az standards and/or other standards may be used. In accordance with some embodiments, an AP 102, STA 103 and/or HE device 104 may generate an MU packet in accordance with a short preamble format or a long preamble format. The MU packet may comprise a legacy signal field (L-SIG) followed by one or more MU signal fields (HE-SIG) and an MU long-training field (MU-LTF). For the short preamble format, the fields may be configured for shorter-delay spread channels. For the long preamble format, the fields may be configured for longer-delay spread channels.

These embodiments are described in more detail below. It should be noted that the terms “HEW” and “HE” may be used interchangeably and both terms may refer to high-efficiency Wireless Local Area Network operation and/or high-efficiency Wi-Fi operation.

- 5 [0036] In some embodiments, the STAs 103, AP 102, other mobile devices, other base stations and/or other devices may be configured to perform operations related to contention based communication. As an example, a communication between an STAs 103 and an AP 102 may be performed in accordance with contention based techniques. As another example, a
- 10 communication between multiple STAs 103 may be performed in accordance with contention based techniques. In these examples and other scenarios, the STAs 103 and/or AP 102 may be arranged to contend for a wireless medium (e.g., during a contention period) to receive exclusive control of the medium for a transmission period. For instance, the transmission period may include a
- 15 transmission opportunity (TXOP), which may be included in an 802.11 standard and/or other standard.

- [0037] It should be noted that embodiments are not limited to usage of contention based techniques, however, as some communication (such as that between mobile devices and/or communication between a mobile device and a
- 20 base station) may be performed in accordance with schedule based techniques. Some embodiments may include a combination of contention based techniques and schedule based techniques.

- [0038] In some embodiments, communication may be performed in accordance with any suitable multiple-access techniques and/or multiplexing
- 25 techniques. Such communication may include, but is not limited to, communication between multiple STAs 103 and/or communication between an STA 103 and an AP 102. Accordingly, one or more of orthogonal frequency division multiple access (OFDMA), orthogonal frequency division multiplexing (OFDM), code-division multiple access (CDMA), time-division multiple access
- 30 (TDMA), frequency division multiplexing (FDMA), space-division multiple access (SDMA), multiple-input multiple-output (MIMO), multi-user (MU) multiple-input multiple-output (MIMO) (MU-MIMO) and/or other techniques may be employed in some embodiments.

[0039] In some embodiments, channels used for communication between STAs 103 and/or APs 102 may be 2.16 GHz, 4.32 GHz, 6.48 GHz, 8.72 GHz and/or other suitable value. In some embodiments, channels used for communication between STAs 103 and/or APs 102 may be configurable to use one of 20 MHz, 40MHz, or 80MHz contiguous bandwidths or an 80+80MHz (160MHz) non-contiguous bandwidth. In some embodiments, a 320 MHz channel width may be used. In some embodiments, subchannel bandwidths less than 20 MHz may also be used. In these embodiments, each channel or subchannel may be configured for transmitting a number of spatial streams, in some embodiments. The values given above may be part of an 802.11 standard, in some cases, although embodiments are not limited as such. These embodiments are not limiting, however, as other suitable bandwidths may be used in some embodiments. In addition, embodiments are not limited to channel types or channel sizes that are included in a standard.

[0040] As used herein, the term "circuitry" may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable hardware components that provide the described functionality. In some embodiments, the circuitry may be implemented in, or functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware. Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software.

[0041] FIG. 2 illustrates a block diagram of an example machine in accordance with some embodiments. The machine 200 is an example machine upon which any one or more of the techniques and/or methodologies discussed herein may be performed. In alternative embodiments, the machine 200 may operate as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine 200 may operate in the capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine 200 may act as a peer machine in

peer-to-peer (P2P) (or other distributed) network environment. The machine 200 may be an AP 102, STA 103, HE device 104, User Equipment (UE), Evolved Node-B (eNB), mobile device, base station, personal computer (PC), a tablet PC, a set-top box (STB), a personal digital assistant (PDA), 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.

[0042] 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.

[0043] 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.

5 **[0044]** The machine (e.g., computer system) 200 may include a hardware processor 202 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 204 and a static memory 206, some or all of which may communicate with each other via an interlink (e.g., bus) 208. The machine 200 may further include a
10 display unit 210, an alphanumeric input device 212 (e.g., a keyboard), and a user interface (UI) navigation device 214 (e.g., a mouse). In an example, the display unit 210, input device 212 and UI navigation device 214 may be a touch screen display. The machine 200 may additionally include a storage device (e.g., drive unit) 216, a signal generation device 218 (e.g., a speaker), a network interface
15 device 220, and one or more sensors 221, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The machine 200 may include an output controller 228, 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
20 peripheral devices (e.g., a printer, card reader, etc.).

[0045] The storage device 216 may include a machine readable medium 222 on which is stored one or more sets of data structures or instructions 224 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 224 may also reside, completely or
25 at least partially, within the main memory 204, within static memory 206, or within the hardware processor 202 during execution thereof by the machine 200. In an example, one or any combination of the hardware processor 202, the main memory 204, the static memory 206, or the storage device 216 may constitute machine readable media. In some embodiments, the machine readable
30 medium may be or may include a non-transitory computer-readable storage medium.

[0046] While the machine readable medium 222 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 224. The term “machine readable medium” may include any medium that is capable of storing, encoding, or carrying instructions for execution by the machine 200 and that cause the machine 200 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.

[0047] The instructions 224 may further be transmitted or received over a communications network 226 using a transmission medium via the network interface device 220 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. In an example, the network interface device 220 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 226. In an example, the

network interface device 220 may include a plurality of antennas 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 220 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 200, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

10 [0048] FIG. 3 illustrates a station (STA) in accordance with some embodiments and an access point (AP) in accordance with some embodiments. It should be noted that in some embodiments, an STA, HE device and/or other mobile device may include one or more components shown in any of FIG. 2, FIG. 3 (as in 300) or FIGs. 4-7. In some embodiments, the STA 300 may be suitable for use as an STA 103 as depicted in FIG. 1, although the scope of
15 embodiments is not limited in this respect. In some embodiments, the STA 300 may be suitable for use as an HE device 104 as depicted in FIG. 1, although the scope of embodiments is not limited in this respect. It should also be noted that in some embodiments, an AP or other base station may include one or more
20 components shown in any of FIG. 2, FIG. 3 (as in 350) or FIGs. 4-7. In some embodiments, the AP 350 may be suitable for use as an AP 102 as depicted in FIG. 1, although the scope of embodiments is not limited in this respect.

[0049] The STA 300 may include physical layer circuitry 302 and a transceiver 305, one or both of which may enable transmission and reception of
25 signals to and from components such as the AP 102 (FIG. 1), other STAs or other devices using one or more antennas 301. As an example, the physical layer circuitry 302 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 305 may perform various
30 transmission and reception functions such as conversion of signals between a baseband range and a Radio Frequency (RF) range. Accordingly, the physical layer circuitry 302 and the transceiver 305 may be separate components or may be part of a combined component. 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 physical layer circuitry 302, the transceiver 305, and other components or layers. The STA 300 may also include medium access control (MAC) layer circuitry 304 for controlling
5 access to the wireless medium. The STA 300 may also include processing circuitry 306 and memory 308 arranged to perform the operations described herein.

[0050] The AP 350 may include physical layer circuitry 352 and a transceiver 355, one or both of which may enable transmission and reception of
10 signals to and from components such as the STA 103 (FIG. 1), other APs or other devices using one or more antennas 351. As an example, the physical layer circuitry 352 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 355 may perform various
15 transmission and reception functions such as conversion of signals between a baseband range and a Radio Frequency (RF) range. Accordingly, the physical layer circuitry 352 and the transceiver 355 may be separate components or may be part of a combined component. In addition, some of the described functionality related to transmission and reception of signals may be performed
20 by a combination that may include one, any or all of the physical layer circuitry 352, the transceiver 355, and other components or layers. The AP 350 may also include medium access control (MAC) layer circuitry 354 for controlling access to the wireless medium. The AP 350 may also include processing circuitry 356 and memory 358 arranged to perform the operations described herein.

25 [0051] The antennas 301, 351, 230 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 301, 351, 230 may be
30 effectively separated to take advantage of spatial diversity and the different channel characteristics that may result.

[0052] In some embodiments, the STA 300 may be configured to communicate using OFDM and/or OFDMA communication signals over a

multicarrier communication channel. In some embodiments, the AP 350 may be configured to communicate using OFDM and/or OFDMA communication signals over a multicarrier communication channel. Accordingly, in some cases, the STA 300 and/or AP 350 may be configured to receive signals in accordance with specific communication standards, such as the Institute of Electrical and Electronics Engineers (IEEE) standards including IEEE 802.11-2012, 802.11n-2009, 802.11ac-2013 standards, 802.11ax standards (and/or proposed standards), 802.11ay standards (and/or proposed standards) and/or other, although the scope of the embodiments is not limited in this respect as they may also be suitable to transmit and/or receive communications in accordance with other techniques and standards. In some other embodiments, the AP 350 and/or the STA 300 may be configured to receive signals that were transmitted using one or more other modulation techniques such as spread spectrum modulation (e.g., direct sequence code division multiple access (DS-CDMA) and/or frequency hopping code division multiple access (FH-CDMA)), time-division multiplexing (TDM) modulation, and/or frequency-division multiplexing (FDM) modulation, although the scope of the embodiments is not limited in this respect.

[0053] In some embodiments, the STA 300 and/or AP 350 may be a mobile device and may be a portable wireless communication device, such as a personal digital assistant (PDA), a laptop or portable computer with wireless communication capability, a web tablet, a wireless telephone, a smartphone, a wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, a wearable device such as a medical device (e.g., a heart rate monitor, a blood pressure monitor, etc.), or other device that may receive and/or transmit information wirelessly. In some embodiments, the STA 300 and/or AP 350 may be configured to operate in accordance with 802.11 standards, although the scope of the embodiments is not limited in this respect. Mobile devices or other devices in some embodiments may be configured to operate according to other protocols or standards, including other IEEE standards, Third Generation Partnership Project (3GPP) standards or other standards. In some embodiments, the STA 300 and/or AP 350 may include one or more of a keyboard, a display, a non-volatile memory port, multiple antennas,

a graphics processor, an application processor, speakers, and other mobile device elements. The display may be an LCD screen including a touch screen.

[0054] Although the STA 300 and the AP 350 are each 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.

[0055] Embodiments may be implemented in one or a combination of hardware, firmware and software. Embodiments may also be implemented as instructions stored on a computer-readable storage device, which may be read and executed by at least one processor to perform the operations described herein. A computer-readable storage device may include any non-transitory mechanism for storing information in a form readable by a machine (e.g., a computer). For example, a computer-readable storage device may include read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and other storage devices and media. Some embodiments may include one or more processors and may be configured with instructions stored on a computer-readable storage device.

[0056] It should be noted that in some embodiments, an apparatus of the STA 300 may include various components of the STA 300 as shown in FIG. 3 and/or the example machine 200 as shown in FIG. 2 and/or various components shown in FIGs. 4-7. Accordingly, techniques and operations described herein that refer to the STA 300 (or 103) may be applicable to an apparatus of an STA, in some embodiments. In addition, techniques and operations described herein that refer to the STA 300 (or 103) may be applicable to an apparatus of an HE device, in some embodiments.

[0057] It should also be noted that in some embodiments, an apparatus of the AP 350 may include various components of the AP 350 as shown in FIG. 3 and/or the example machine 200 as shown in FIG. 2 and/or various components shown in FIGs. 4-7. Accordingly, techniques and operations described herein that refer to the AP 350 (or 102) may be applicable to an apparatus of an AP, in some embodiments. In addition, an apparatus of a mobile device and/or base station may include one or more components shown in FIGs. 2-7, in some embodiments. Accordingly, techniques and operations described herein that refer to a mobile device and/or base station may be applicable to an apparatus of a mobile device and/or base station, in some embodiments.

[0058] FIG. 4 is a block diagram of a radio architecture 400 in accordance with some embodiments. Radio architecture 400 may include radio front-end module (FEM) circuitry 404, radio IC circuitry 406 and baseband processing circuitry 408. Radio architecture 400 as shown includes both Wireless Local Area Network (WLAN) functionality and Bluetooth (BT) functionality although embodiments are not so limited. In this disclosure, “WLAN” and “Wi-Fi” are used interchangeably.

[0059] It should be noted that the radio architecture 400 and components shown in FIGs. 5-7 support WLAN and BT, but embodiments are not limited to WLAN or BT. In some embodiments, two technologies supported by the radio architecture 400 may or may not include WLAN or BT. Other technologies may be supported. In some embodiments, WLAN and a second technology may be supported. In some embodiments, BT and a second technology may be supported. In some embodiments, two technologies other than WLAN and BT may be supported. In addition, the radio architecture 400 may be extended to support more than two protocols, technologies and/or standards, in some embodiments. Embodiments are also not limited to the frequencies illustrated in FIGs. 4-7.

[0060] FEM circuitry 404 may include a WLAN or Wi-Fi FEM circuitry 404a and a Bluetooth (BT) FEM circuitry 404b. The WLAN FEM circuitry 404a may include a receive signal path comprising circuitry configured to operate on WLAN RF signals received from one or more antennas 401, to amplify the received signals and to provide the amplified versions of the

received signals to the WLAN radio IC circuitry 406a for further processing. The BT FEM circuitry 404b may include a receive signal path which may include circuitry configured to operate on BT RF signals received from one or more antennas 402, to amplify the received signals and to provide the amplified versions of the received signals to the BT radio IC circuitry 406b for further processing. FEM circuitry 404a may also include a transmit signal path which may include circuitry configured to amplify WLAN signals provided by the radio IC circuitry 406a for wireless transmission by one or more of the antennas 401. In addition, FEM circuitry 404b may also include a transmit signal path which may include circuitry configured to amplify BT signals provided by the radio IC circuitry 406b for wireless transmission by the one or more antennas. In the embodiment of FIG. 4, although FEM 404a and FEM 404b are shown as 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.

[0061] Radio IC circuitry 406 as shown may include WLAN radio IC circuitry 406a and BT radio IC circuitry 406b. The WLAN radio IC circuitry 406a may include a receive signal path which may include circuitry to down-convert WLAN RF signals received from the FEM circuitry 404a and provide baseband signals to WLAN baseband processing circuitry 408a. BT radio IC circuitry 406b may in turn include a receive signal path which may include circuitry to down-convert BT RF signals received from the FEM circuitry 404b and provide baseband signals to BT baseband processing circuitry 408b. WLAN radio IC circuitry 406a may also include a transmit signal path which may include circuitry to up-convert WLAN baseband signals provided by the WLAN baseband processing circuitry 408a and provide WLAN RF output signals to the FEM circuitry 404a for subsequent wireless transmission by the one or more antennas 401. BT radio IC circuitry 406b may also include a transmit signal path which may include circuitry to up-convert BT baseband signals provided by the BT baseband processing circuitry 408b and provide BT RF output signals to the FEM circuitry 404b for subsequent wireless transmission by the one or more

antennas 401. In the embodiment of FIG. 4, although radio IC circuitries 406a and 406b 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.

[0062] Baseband processing circuitry 408 may include a WLAN baseband processing circuitry 408a and a BT baseband processing circuitry 408b. The WLAN baseband processing circuitry 408a 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 408a. Each of the WLAN baseband circuitry 408a and the BT baseband circuitry 408b 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 406, and to also generate corresponding WLAN or BT baseband signals for the transmit signal path of the radio IC circuitry 406. Each of the baseband processing circuitries 408a and 408b may further include physical layer (PHY) and medium access control layer (MAC) circuitry, and may further interface with application processor 410 for generation and processing of the baseband signals and for controlling operations of the radio IC circuitry 406.

[0063] Referring still to FIG. 4, according to the shown embodiment, WLAN-BT coexistence circuitry 413 may include logic providing an interface between the WLAN baseband circuitry 408a and the BT baseband circuitry 408b to enable use cases requiring WLAN and BT coexistence. In addition, a switch 403 may be provided between the WLAN FEM circuitry 404a and the BT FEM circuitry 404b to allow switching between the WLAN and BT radios according to application needs. In addition, although the antennas 401 are depicted as being respectively connected to the WLAN FEM circuitry 404a and the BT FEM circuitry 404b, 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 404a or 404b.

[0064] In some embodiments, the front-end module circuitry 404, the radio IC circuitry 406, and baseband processing circuitry 408 may be provided on a single radio card, such as wireless radio card 402. In some other embodiments, the one or more antennas 401, the FEM circuitry 404 and the radio IC circuitry 406 may be provided on a single radio card. In some other embodiments, the radio IC circuitry 406 and the baseband processing circuitry 408 may be provided on a single chip or integrated circuit (IC), such as IC 412.

[0065] In some embodiments, the wireless radio card 402 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 400 may be configured to receive and transmit orthogonal frequency division multiplexed (OFDM) or orthogonal frequency division multiple access (OFDMA) communication signals over a multicarrier communication channel. The OFDM or OFDMA signals may comprise a plurality of orthogonal subcarriers.

[0066] In some of these multicarrier embodiments, radio architecture 400 may be part of a Wi-Fi communication station (STA) such as a wireless access point (AP), a base station or a mobile device including a Wi-Fi device. In some of these embodiments, radio architecture 400 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, 802.11n-2009, IEEE 802.11-2012, 802.11n-2009, 802.11ac, and/or 802.11ax standards and/or proposed specifications for WLANs, although the scope of embodiments is not limited in this respect. Radio architecture 400 may also be suitable to transmit and/or receive communications in accordance with other techniques and standards.

[0067] In some embodiments, the radio architecture 400 may be configured for high-efficiency (HE) Wi-Fi (HEW) communications in accordance with the IEEE 802.11ax standard and/or IEEE 802.11az standard. In these embodiments, the radio architecture 400 may be configured to communicate in accordance with an OFDMA technique, although the scope of the embodiments is not limited in this respect.

[0068] In some other embodiments, the radio architecture 400 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.

[0069] In some embodiments, as further shown in FIG. 4, the BT baseband circuitry 408b 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. 4, the radio architecture 400 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 400 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. 4, 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 402, although embodiments are not so limited, and include within their scope discrete WLAN and BT radio cards.

[0070] In some embodiments, the radio-architecture 400 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).

[0071] In some IEEE 802.11 embodiments, the radio architecture 400 may be configured for communication over various channel bandwidths including bandwidths having center frequencies of about 900 MHz, 2.4 GHz, 5 GHz. In some embodiments, the bandwidths may be 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. In some embodiments, the bandwidths may be about 2.16 GHz, 4.32 GHz, 6.48 GHz, 8.72 GHz and/or other suitable value. The scope of the embodiments is not limited with respect to the above center frequencies or bandwidths,

5 however.

[0072] FIG. 5 illustrates FEM circuitry 500 in accordance with some embodiments. The FEM circuitry 500 is one example of circuitry that may be suitable for use as the WLAN and/or BT FEM circuitry 404a/404b (FIG. 4), although other circuitry configurations may also be suitable.

10 [0073] In some embodiments, the FEM circuitry 500 may include a TX/RX switch 502 to switch between transmit mode and receive mode operation. The FEM circuitry 500 may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry 500 may include a low-noise amplifier (LNA) 506 to amplify received RF signals 503 and
15 provide the amplified received RF signals 507 as an output (e.g., to the radio IC circuitry 406 (FIG. 4)). The transmit signal path of the circuitry 500 may include a power amplifier (PA) to amplify input RF signals 509 (e.g., provided by the radio IC circuitry 406), and one or more filters 512, such as band-pass filters (BPFs), low-pass filters (LPFs) or other types of filters, to generate RF signals
20 515 for subsequent transmission (e.g., by one or more of the antennas 401 (FIG. 4)).

[0074] In some dual-mode embodiments for Wi-Fi communication, the FEM circuitry 500 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 500 may include a receive signal path duplexer 504 to separate the signals from each spectrum as well as provide a separate LNA 506 for each spectrum as shown. In these embodiments, the transmit signal path of the FEM circuitry 500 may also include a power amplifier 510 and a filter 512, such as a BPF, a LPF or another type of filter for each frequency
30 spectrum and a transmit signal path duplexer 514 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 401 (FIG. 4). In some embodiments, BT

communications may utilize the 2.4 GHZ signal paths and may utilize the same FEM circuitry 500 as the one used for WLAN communications.

[0075] FIG. 6 illustrates radio IC circuitry 600 in accordance with some embodiments. The radio IC circuitry 600 is one example of circuitry that may be
5 suitable for use as the WLAN or BT radio IC circuitry 406a/406b (FIG. 4), although other circuitry configurations may also be suitable.

[0076] In some embodiments, the radio IC circuitry 600 may include a receive signal path and a transmit signal path. The receive signal path of the radio IC circuitry 600 may include at least mixer circuitry 602, such as, for
10 example, down-conversion mixer circuitry, amplifier circuitry 606 and filter circuitry 608. The transmit signal path of the radio IC circuitry 600 may include at least filter circuitry 612 and mixer circuitry 614, such as, for example, up-conversion mixer circuitry. Radio IC circuitry 600 may also include synthesizer circuitry 604 for synthesizing a frequency 605 for use by the mixer circuitry 602
15 and the mixer circuitry 614. The mixer circuitry 602 and/or 614 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. 6 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 620 and/or 614 may each include one or more mixers, and filter circuitries 608 and/or 612 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.

[0077] In some embodiments, mixer circuitry 602 may be configured to down-convert RF signals 507 received from the FEM circuitry 404 (FIG. 4)
30 based on the synthesized frequency 605 provided by synthesizer circuitry 604. The amplifier circuitry 606 may be configured to amplify the down-converted signals and the filter circuitry 608 may include a LPF configured to remove unwanted signals from the down-converted signals to generate output baseband

signals 607. Output baseband signals 607 may be provided to the baseband processing circuitry 408 (FIG. 4) for further processing. In some embodiments, the output baseband signals 607 may be zero-frequency baseband signals, although this is not a requirement. In some embodiments, mixer circuitry 602
5 may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[0078] In some embodiments, the mixer circuitry 614 may be configured to up-convert input baseband signals 611 based on the synthesized frequency 605 provided by the synthesizer circuitry 604 to generate RF output signals 509
10 for the FEM circuitry 404. The baseband signals 611 may be provided by the baseband processing circuitry 408 and may be filtered by filter circuitry 612. The filter circuitry 612 may include a LPF or a BPF, although the scope of the embodiments is not limited in this respect.

[0079] In some embodiments, the mixer circuitry 602 and the mixer circuitry 614 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 604. In some embodiments, the mixer circuitry 602 and the mixer circuitry 614 may each include two or more mixers each configured for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer
15 circuitry 602 and the mixer circuitry 614 may be arranged for direct down-conversion and/or direct up-conversion, respectively. In some embodiments, the mixer circuitry 602 and the mixer circuitry 614 may be configured for super-heterodyne operation, although this is not a requirement.

[0080] Mixer circuitry 602 may comprise, according to one embodiment: quadrature passive mixers (e.g., for the in-phase (I) and quadrature phase (Q) paths). In such an embodiment, RF input signal 507 from Fig. 6 may be down-converted to provide I and Q baseband output signals to be sent to the baseband processor.
25

[0081] Quadrature passive mixers may be driven by zero and ninety 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 605 of synthesizer 604 (FIG. 6). In some embodiments, the LO frequency may be the carrier frequency, while in other
30

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 limited in this respect.

[0082] 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.

[0083] The RF input signal 507 (FIG. 5) 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 606 (FIG. 6) or to filter circuitry 608 (FIG. 6).

[0084] In some embodiments, the output baseband signals 607 and the input baseband signals 611 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 607 and the input baseband signals 611 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.

[0085] 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.

[0086] In some embodiments, the synthesizer circuitry 604 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 604 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 604 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 604 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 408 (FIG. 4) or the application processor 410 (FIG. 4) depending on the desired output frequency 605. 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 410.

[0087] In some embodiments, synthesizer circuitry 604 may be configured to generate a carrier frequency as the output frequency 605, while in other embodiments, the output frequency 605 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 605 may be a LO frequency (f_{LO}).

[0088] FIG. 7 illustrates a functional block diagram of baseband processing circuitry 700 in accordance with some embodiments. The baseband processing circuitry 700 is one example of circuitry that may be suitable for use as the baseband processing circuitry 408 (FIG. 4), although other circuitry configurations may also be suitable. The baseband processing circuitry 700 may include a receive baseband processor (RX BBP) 702 for processing receive baseband signals 609 provided by the radio IC circuitry 406 (FIG. 4) and a transmit baseband processor (TX BBP) 704 for generating transmit baseband signals 611 for the radio IC circuitry 406. The baseband processing circuitry 700 may also include control logic 706 for coordinating the operations of the baseband processing circuitry 700.

[0089] In some embodiments (e.g., when analog baseband signals are exchanged between the baseband processing circuitry 700 and the radio IC circuitry 406), the baseband processing circuitry 700 may include ADC 710 to convert analog baseband signals received from the radio IC circuitry 406 to digital baseband signals for processing by the RX BBP 702. In these

embodiments, the baseband processing circuitry 700 may also include DAC 712 to convert digital baseband signals from the TX BBP 704 to analog baseband signals.

[0090] In some embodiments that communicate OFDM signals or
5 OFDMA signals, such as through baseband processor 408a, the transmit baseband processor 704 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 702 may be configured to process received OFDM signals or OFDMA signals by performing an FFT. In
10 some embodiments, the receive baseband processor 702 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.

[0091] Referring back to FIG. 4, in some embodiments, the antennas 401
15 (FIG. 4) 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 401 may each include a set of phased-array antennas, although embodiments are not so limited.

[0092] Although the radio-architecture 400 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.

[0093] Embodiments may be implemented in one or a combination of hardware, firmware and software. Embodiments may also be implemented as instructions stored on a computer-readable storage device, which may be read and executed by at least one processor to perform the operations described herein. A computer-readable storage device may include any non-transitory mechanism for storing information in a form readable by a machine (e.g., a computer). For example, a computer-readable storage device may include read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and other storage devices and media. Some embodiments may include one or more processors and may be configured with instructions stored on a computer-readable storage device.

[0094] In accordance with some embodiments, the AP 102 may transmit, during a transmission opportunity (TXOP) obtained by the AP 102, a first trigger frame (TF) that requests uplink sounding frames from a plurality of STAs 103. The AP 102 may receive the uplink sounding frames from the STAs 103 during the TXOP. The uplink sounding frames may be multiplexed in accordance with an OFDMA technique or space-division multiple access technique (SDMA). The AP 102 may transmit downlink sounding frames during the TXOP. The downlink sounding frames may be full-band or multiplexed in accordance with an OFDMA technique. The AP 102 may transmit, during the TXOP, downlink location measurement reports (LMRs) that include per-STA arrival times of the uplink sounding frames and a departure time of the downlink sounding frames. The AP 102 may transmit, during the TXOP, a second TF that requests transmission of uplink LMRs by at least one of the STAs 103. The uplink LMRs may include per-STA location information based on the per-STA arrival times of the uplink sounding frames and the departure time of the downlink sounding frames. These embodiments will be described in more detail below.

[0095] FIG. 8 illustrates the operation of a method of communication in accordance with some embodiments. It is important to note that embodiments of the method 800 may include additional or even fewer operations or processes in comparison to what is illustrated in FIG. 8. In addition, embodiments of the

method 800 are not necessarily limited to the chronological order that is shown in FIG. 8. In describing the method 800, reference may be made to FIGs. 1-7 and 9-16, although it is understood that the method 800 may be practiced with any other suitable systems, interfaces and components.

5 [0096] In some embodiments, an AP 102 may perform one or more operations of the method 800, but embodiments are not limited to performance of the method 800 and/or operations of it by the AP 102. In some embodiments, an STA 103 may perform one or more operations of the method 800 (and/or similar operations). Accordingly, although references may be made to
10 performance of one or more operations of the method 800 by the AP 102 in descriptions herein, it is understood that the STA 103 may perform the same operation(s), similar operation(s) and/or reciprocal operation(s), in some embodiments. In some embodiments, an HE device 104 may perform one or more operations of the method 800 (and/or similar operations). Accordingly,
15 although references may be made to performance of one or more operations of the method 800 by the AP 102 in descriptions herein, it is understood that the HE device 104 may perform the same operation(s), similar operation(s) and/or reciprocal operation(s), in some embodiments

[0097] In addition, the method 800 and other methods described herein
20 may refer to STAs 103 or APs 102 operating in accordance with an 802.11 standard, protocol and/or specification and/or WLAN standard, protocol and/or specification, in some cases. Embodiments of those methods are not limited to just those STAs 103 or APs 102 and may also be practiced on other devices, such as a User Equipment (UE), an Evolved Node-B (eNB) and/or other device.
25 In addition, the method 800 and other methods described herein may be practiced by wireless devices configured to operate in other suitable types of wireless communication systems, including systems configured to operate according to various Third Generation Partnership Protocol (3GPP) standards, including but not limited to Long Term Evolution (LTE). The method 800 may
30 also be practiced by an apparatus of an STA 103, an apparatus of an AP 102, an apparatus of an HE device 104 and/or an apparatus of another device, in some embodiments.

[0098] It should also be noted that embodiments are not limited by references herein (such as in descriptions of the methods 800, 900 and/or other descriptions herein) to transmission, reception and/or exchanging of elements such as frames, messages, requests, indicators, signals or other elements. In some embodiments, such an element may be generated, encoded or otherwise processed by processing circuitry (such as by a baseband processor included in the processing circuitry) for transmission. The transmission may be performed by a transceiver or other component, in some cases. In some embodiments, such an element may be decoded, detected or otherwise processed by the processing circuitry (such as by the baseband processor). The element may be received by a transceiver or other component, in some cases. In some embodiments, the processing circuitry and the transceiver may be included in a same apparatus. The scope of embodiments is not limited in this respect, however, as the transceiver may be separate from the apparatus that comprises the processing circuitry, in some embodiments.

[0099] At operation 805, the AP 102 may contend for a transmission opportunity (TXOP) to obtain access to a channel. In some embodiments, the AP 102 may contend for a TXOP during which the AP 102 is to control access to the channel. In some embodiments, the AP 102 may contend for a wireless medium during a contention period to receive exclusive control of the medium during a period, including but not limited to a TXOP and/or HE control period. The AP 102 may transmit, receive and/or schedule one or more frames and/or signals during the period. The AP 102 may transmit and/or receive one or more frames, signals and/or other elements during the period. However, it should be noted that embodiments are not limited to scheduled transmission and/or reception. Embodiments are also not limited to transmission and/or reception in accordance with the exclusive control of the medium. A frame, signal and/or other element may be transmitted/received in contention-based scenarios and/or other scenarios, in some embodiments. Any suitable contention methods, operations and/or techniques may be used, which may or may not be part of a standard. In a non-limiting example, one or more contention methods, operations and/or techniques of an 802.11 standard/protocol and/or W-LAN standard/protocol may be used.

- [00100] At operation 810, the AP 102 may transmit a trigger frame (TF). In some embodiments, the TF may request uplink sounding frames from a plurality of STAs 103. In some embodiments, the TF may indicate that one or more STAs 103 are to transmit uplink sounding frames. In some embodiments, the TF may be transmitted during the TXOP. In some embodiments, the TF may include (and/or indicate) a location measurement report (LMR) type parameter that indicates when the AP 102 is to transmit downlink LMRs (to be described below). The scope of embodiments is not limited in this respect, however, as the TF may not necessarily include the LMR type parameter in some embodiments.
- 10 [00101] In some embodiments, the TF may indicate information to be used by the STA 103 to exchange one or more frames, signals and/or other elements with the AP 102. In some embodiments, the TF may indicate information to be used by the STA 103 to exchange one or more frames, signals and/or other elements with the AP 102 during the TXOP, although the scope of
- 15 embodiments is not limited in this respect. Example information of the TF may include, but is not limited to, time resources to be used for transmission and/or reception, channel resources (such as resource units (RUs) and/or other) to be used for transmission and/or reception, identifiers of STAs 103 that are to transmit, identifiers of STAs 103 that are to receive and/or other information.
- 20 Additional examples of such information will be given below. It should be noted that embodiments are not limited to usage of the TF, and some embodiments may not necessarily include the usage of the TF.
- [00102] In a non-limiting example, the TF may indicate a specific allocation of RUs of the channel to be used by one or more associated STAs 103
- 25 for transmission of frames, signals and/or other elements. In another non-limiting example, the TF may indicate one or more RUs of the channel to be used by one or more associated STAs 103 for transmission of frames, signals and/or other elements and may further indicate one or more RUs of the channel to be used by one or more unassociated STAs 103 for transmission of frames,
- 30 signals and/or other elements. In another non-limiting example, the TF may indicate one or more RUs of the channel to be used by one or more unassociated STAs 103 for transmission of frames, signals and/or other elements. In another non-limiting example, the TF may indicate information related to uplink

transmission by associated STAs 103, unassociated STAs 103 or a combination thereof. For instance, the TF may be configurable to allocate at least a first RU to a particular associated STA 103 and may be further configurable to allocate at least a second RU for unassociated STAs 103. It should be noted that multiple
5 STAs 103 may be supported. For instance, the TF may allocate one or more RUs to each of multiple STAs 103 for transmissions, in some cases.

[00103] At operation 815, the AP 102 may receive one or more uplink sounding frames. At operation 820, the AP 102 may determine one or more uplink channel estimates based at least partly on the uplink sounding frames. At
10 operation 825, the AP 102 may determine one or more arrival times of the uplink sounding frames. It should be noted that some embodiments may not necessarily include all operations shown in FIG. 8.

[00104] In some embodiments, the uplink sounding frames may be received from the STAs 103 during the TXOP. In some embodiments, the
15 uplink sounding frames may be multiplexed in accordance with an OFDMA technique or SDMA technique, although the scope of embodiments is not limited in this respect. In some embodiments, the AP 102 may determine per-STA arrival times of the uplink sounding frames. In some embodiments, the uplink sounding frames may include one or more uplink null data packets (NDPs). In
20 some embodiments, the uplink sounding frames may be uplink NDPs. In some embodiments, the uplink sounding frames may be based on one or more uplink NDPs.

[00105] In a non-limiting example, the AP 102 may determine the arrival times of the uplink sounding frames based at least partly on one or more channel
25 estimate. For instance, the channel estimate(s) may be based on uplink sounding frame(s), although the scope of embodiments is not limited in this respect. In another non-limiting example, the AP 102 may determine the arrival times of the uplink sounding frames based at least partly on one or more correlation operations between the uplink sounding frames and one or more predetermined
30 symbol patterns. Additional operation(s) may be used, in some embodiments, in addition to or instead of the correlation operation(s).

[00106] At operation 830, the AP 102 may transmit a frame to indicate that the AP 102 is to transmit one or more downlink sounding frames. In some

embodiments, the frame may be an NDP announcement (NDPA) frame, although the scope of embodiments is not limited in this respect. In some embodiments, the AP 102 may transmit the frame during the TXOP.

[00107] In some embodiments, the AP 102 may transmit an LMR type parameter that indicates when the AP 102 is to transmit downlink LMRs. In some embodiments, the AP 102 may transmit an LMR type parameter that includes information related to transmission of the downlink LMRs by the AP 102. The AP 102 may include the LMR type parameter in one or more frames, examples of which are given below.

[00108] In a non-limiting example, the AP 102 may include the LMR type parameter in the TF transmitted at operation 810. In another non-limiting example, the AP 102 may include the LMR type parameter in the frame (NDPA and/or other frame) transmitted at operation 830. In another non-limiting example, the AP 102 may include the LMR type parameter in an STA information field of an NDPA. In another non-limiting example, the AP 102 may include the LMR type parameter in the TF transmitted at operation 810, but may not necessarily include the LMR type parameter in the frame transmitted at operation 830. In another non-limiting example, the AP 102 may include the LMR type parameter in the frame transmitted at operation 830, but may not necessarily include the LMR type parameter in the TF transmitted at operation 810. In some embodiments, the AP 102 may include the LMR parameter in one or more of: the TF transmitted at operation 810, the frame transmitted at operation 830 and/or other frame.

[00109] In some embodiments, the TF may include the LMR type parameter in a common information portion of the TF, although the scope of embodiments is not limited in this respect. In some embodiments, the TF may include a minimum waiting time that the STAs 103 are to wait to receive the downlink LMRs, and a maximum waiting time that the STAs 103 are to wait to receive the downlink LMRs. The minimum waiting time, maximum waiting time and/or other information may be included in the common information portion of the TF in some embodiments, although the scope of embodiments is not limited in this respect. In some embodiments, an LMR type may be included in a per-user information field of the TF. Inclusion of the LMR type in the per-

user information field may enable indication of different LMR types to different STAs 103, in some cases.

[00110] In a non-limiting example, a first value of the LMR type parameter may indicate immediate LMR feedback, wherein the AP 102 is to transmit the downlink LMRs in the TXOP after transmission of the downlink sounding frames. A second value of the LMR type parameter may indicate delayed LMR feedback, wherein the AP 102 is to transmit the downlink LMRs in a subsequent TXOP (including but not limited to a next TXOP). A third value of the LMR type parameter may indicate aggregated LMR feedback, wherein the downlink LMRs are included in a null data packet announcement (NDPA) (to be described below). Embodiments are not limited to the assignments in this example. Embodiments are also not limited to usage of three values for the LMR type parameter. In some embodiments, possible values of the LMR type parameter may include one or more of the example values given above. In some embodiments, possible values of the LMR type parameter may include one or more values in addition to any number (including zero) of the example values given above. In some embodiments, possible values of the LMR type parameter may not necessarily include all three example values given above.

[00111] In some embodiments, when immediate LMR feedback is used, it may be assumed that a computation time for the AP 102 to compute arrival time(s) is low enough to enable the AP 102 to transmit LMR(s) after SIFS of the DL NDP. If the STA 103 does not receive the LMR, the STA 103 may request a new round of measurement phase. In some embodiments, when delayed LMR feedback is used, the DL NDP and downlink LMRs may be transmitted in two different TXOPs. The AP 102 may use a channel estimate based on a received UL NDP to calculate an arrival time of the UL NDP. When the arrival time is available, the AP 102 may transmit the information in an LMR to the STA 103. To avoid scenarios in which the STA 103 may wait for a long time and/or an indefinite time, the AP 102 may set minimum and maximum waiting times for the STA 103. The STA 103 may begin to wait for the LMR report after the minimum waiting time. If after the maximum waiting time, the STA 103 has not received the LMR, the STA 103 may request a new round of measurement phase. In some embodiments, when aggregated LMR feedback is used, the AP

102 may aggregate the LMR with the DL NDPA frame. In some cases, the AP 102 may have a sufficient computation capability to finish the arrival time determination before the transmission of the DL NDPA. In addition, the AP 102 may be able to predict a departure time of the DL NDP. The LMR may be
5 aggregated with the DL NDPA frame. If the STA 103 does not receive the LMR, the STA 103 may request a new round of measurement phase.

[00112] At operation 835, the AP 102 may transmit one or more downlink sounding frames. In some embodiments, the downlink sounding frames may be transmitted during the TXOP. In some embodiments, the downlink sounding
10 frames may be transmitted to the STAs 103 during the TXOP. In some embodiments, the downlink sounding frames may be multiplexed in accordance with an OFDMA technique, although the scope of embodiments is not limited in this respect. In some embodiments, a full-band transmission of the downlink sounding frames may be performed, although the scope of embodiments is not
15 limited in this respect. In some embodiments, the downlink sounding frames may include one or more downlink NDPs. In some embodiments, the downlink sounding frames may be downlink NDPs. In some embodiments, the downlink sounding frames may be based on one or more downlink NDPs. In some embodiments, the AP 102 may transmit an NDPA to indicate that the AP 102 is
20 to transmit one or more downlink NDPs, and may transmit the one or more downlink NDPs.

[00113] In some embodiments, the AP 102 may include a sounding dialog token. In a non-limiting example, the sounding dialog token may be included in the TF transmitted at operation 810. For instance, the sounding dialog token
25 may be included in a trigger dependent common information field of the TF or in a trigger dependent user information field of the TF. In some embodiments, the sounding dialog token may indicate a measurement sequence to be used by at least one of the STAs 103 to determine the round trip time between STAs 103 and AP 102. Other information related to the downlink sounding frames may be
30 included, in addition to or instead of the measurement sequence.

[00114] At operation 840, the AP 102 may transmit one or more downlink LMRs. In some embodiments, the AP 102 may transmit the downlink LMRs during the TXOP. In some embodiments, the downlink LMRs may be

multiplexed in accordance with an OFDMA technique, although the scope of embodiments is not limited in this respect.

[00115] In a non-limiting example, the downlink LMRs may include per-STA arrival times of uplink sounding frames. The downlink LMRs may include
5 other information, in some cases, in addition to or instead of the per-STA arrival times of the uplink sounding frames. Information included in the downlink LMRs may include, but is not limited to, one or more of: per-STA arrival times of the uplink sounding frames, a departure time of the downlink sounding frames, multiple departure times of the downlink sounding frames and/or other
10 information. In some embodiments, the AP 102 may transmit the downlink LMR(s) in accordance with a value indicated by the LMR type parameter, although the scope of embodiments is not limited in this respect.

[00116] At operation 845, the AP 102 may transmit a TF. In some embodiments, the AP 102 may transmit the TF at operation 845 to request
15 transmission of uplink LMRs by the STAs 103, although the scope of embodiments is not limited in this respect. In some embodiments, the TF transmitted at operation 845 may be transmitted during the TXOP, although the scope of embodiments is not limited in this respect.

[00117] In some embodiments, the TF transmitted at operation 810 may
20 be a first TF and the TF transmitted at operation 845 may be a second TF. Accordingly, the TF transmitted at operation 845 may be referred to in descriptions herein as the “second TF” for clarity, but it is understood that such references are not limiting. For instance, in some embodiments, the transmission of the TF at operation 810 may not necessarily be performed. In such
25 embodiments, some or all of the operations, properties and/or other aspects described herein for the “second TF” may be applicable to the TF transmitted at operation 845.

[00118] In some cases, the second TF may be transmitted after transmission of the downlink LMRs, although the scope of embodiments is not
30 limited in this respect. In some embodiments, the second TF may be a different type of TF than the first TF. For instance, a TF type parameter included in the second TF may indicate that the second TF is a TF that requests transmission of

uplink LMRs. It should be noted that embodiments are not limited to usage of a TF type for either the first TF or the second TF.

[00119] In some embodiments, the second TF may include a trigger type field in a common information portion of the second TF. A value of the trigger type field may indicate a request for transmission of the uplink LMRs by the STAs 103. For instance, a particular value of the trigger type field may be reserved for such an indication.

[00120] In some embodiments, the second TF may be configurable to request transmission of uplink LMRs from STAs 103 that are unassociated with the AP 102. In some embodiments, the second TF may request transmission of uplink LMRs from one or more STAs 103 that are associated with the AP 102. For instance, the second TF may include one or more user information fields that include association identifiers (AIDs) for STAs 103 that are associated with the AP 102. In some embodiments, the second TF may be configurable to request transmission of uplink LMRs from associated STA(s) 103, unassociated STA(s) 103 or a combination thereof. In some embodiments, the second TF may indicate resource units (RUs) to be used by STAs 103 for OFDMA transmission of the uplink LMRs.

[00121] At operation 850, the AP 102 may receive one or more uplink LMRs. In some embodiments, the uplink LMRs may be received during the TXOP. In some embodiments, the uplink LMRs may be received from the STAs 103. In some embodiments, the uplink LMRs may be received in accordance with an OFDMA technique. Accordingly, the STAs 103 may transmit the uplink LMRs in accordance with an OFDMA technique.

[00122] In some embodiments, the uplink LMRs may include per-STA location information. In a non-limiting example, the per-STA location information may include round trip time (RTT) measurements from the STAs 103. For a particular STA 103, the RTT may be based on a first difference between an arrival time of a downlink sounding frame at the particular STA 103 and a departure time of the downlink sounding frame from the AP. The RTT for the particular STA 103 may be further based on a second difference between an arrival time of an uplink sounding frame at the AP 102 and a departure time of the uplink sounding frame from the particular STA 103. In some embodiments,

the uplink LMR may include the departure time of the uplink sounding frame and the arrival time of the downlink sounding frame.

[00123] In some embodiments, the determination of location information or range information (such as the RTT in the example above) may be performed
5 at the STA 103. In some embodiments, the determination of location information or range information (such as the RTT in the example above) may be performed at the AP 102. In some embodiments, the determination of location information or range information (such as the RTT in the example above) may be performed at either or both of the STA 103 and the AP 102.

10 [00124] At operation 855, the AP 102 may determine range information or location information for one or more STAs 103. It should be noted that some embodiments may not necessarily include operation 855. For instance, the uplink LMRs may include the range information or location information and the AP 102 may not necessarily determine the range information or location
15 information. Accordingly, in some cases, the STAs 103 may determine the range information or location information and may transmit it to the AP 102. In other cases, the AP 102 may determine the range information or location information based at least partly on timing indicated in the uplink LMRs. In some cases, one or more STAs 103 may transmit the range information or
20 location information, and the AP 102 may determine the range information or location information for one or more other STAs 103.

[00125] It should be noted that in the example above and in other operations described herein, timing information (such as arrival times, departure times, time differences and/or other) may be given in any suitable unit. For
25 instance, picoseconds, microseconds, milliseconds, and/or other unit may be used. In some embodiments, a suitable reference time (such as a system reference time, a reference time of the STA 103, a reference time of the AP 102 and/or other) may be used to indicate the departure time, arrival time and/or difference between times.

30 [00126] In some embodiments, sounding waveforms may be included in the uplink sounding frames and/or downlink sounding frames. The sounding waveforms may be based on training symbols, in some cases, although the scope of embodiments is not limited in this respect. Uplink channel state information

(CSI) may be determined at the AP 102 based on sounding waveform(s) transmitted by the STAs 103, in some embodiments. Downlink channel state information (CSI) may be determined at an STA 103 based on sounding waveform(s) transmitted by the AP 102, in some embodiments.

- 5 [00127] At operation 860, the AP 102 may transmit downlink data to one or more STAs 103. In some embodiments, the downlink data may be transmitted in accordance with an OFDMA technique, although the scope of embodiments is not limited in this respect. At operation 865, the AP 102 may transmit downlink data to one or more STAs 103. In some embodiments, the
- 10 uplink data may be received by the AP 102 in accordance with an OFDMA technique, although the scope of embodiments is not limited in this respect. In some embodiments, the uplink data may be transmitted by one or more STAs 103 in accordance with an OFDMA technique, although the scope of embodiments is not limited in this respect. In some embodiments, the AP 102
- 15 may schedule the uplink data and/or downlink data of operations 860-865 based at least partly on range information or location information of one or more STAs 103.

- [00128] In some embodiments, the AP 102 may perform one or more operations as part of a positioning protocol for determination of the per-STA
- 20 location information. For instance, the AP 102 may transmit one or more of the first TF, the downlink sounding frames, the downlink LMRs, the second TF and/or other element(s) as part of the positioning protocol. The AP 102 may receive the uplink sounding frames and/or other element(s) as part of the positioning protocol.

- 25 [00129] In some embodiments, an apparatus of an AP 102 may comprise memory. The memory may be configurable to store the arrival times of the uplink sounding frames. The memory may store one or more other elements and the apparatus may use them for performance of one or more operations. The apparatus may include processing circuitry, which may perform one or more
- 30 operations (including but not limited to operation(s) of the method 800 and/or other methods described herein). The processing circuitry may include a baseband processor. The baseband circuitry and/or the processing circuitry may perform one or more operations described herein, including but not limited to

decoding of the uplink sounding frames. The apparatus of the AP 102 may include a transceiver. In some embodiments, the transceiver may receive one or more elements (such as the uplink sounding frames and/or other). In some embodiments, the transceiver may transmit one or more elements (such as the first TF, the downlink sounding frames, the downlink LMRs, the second TF and/or other). The transceiver may transmit and/or receive other frames, messages and/or other elements, in some embodiments.

[00130] FIG. 9 illustrates the operation of another method of communication in accordance with some embodiments. Embodiments of the method 900 may include additional or even fewer operations or processes in comparison to what is illustrated in FIG. 9 and embodiments of the method 900 are not necessarily limited to the chronological order that is shown in FIG. 9. In describing the method 900, reference may be made to any of FIGs. 1-16, although it is understood that the method 900 may be practiced with any other suitable systems, interfaces and components. In addition, embodiments of the method 900 may be applicable to APs 102, STAs 103, HE devices 104, UEs, eNBs and/or other wireless or mobile devices. The method 1300 may also be applicable to an apparatus of an AP 102, STA 103, HE device 104 and/or other device, in some embodiments.

[00131] In some embodiments, an STA 103 may perform one or more operations of the method 900, but embodiments are not limited to performance of the method 900 and/or operations of it by the STA 103. In some embodiments, the AP 102 may perform one or more operations of the method 900 (and/or similar operations). Accordingly, although references may be made to performance of one or more operations of the method 900 by the STA 103 in descriptions herein, it is understood that the AP 102 may perform the same operation(s), similar operation(s) and/or reciprocal operation(s), in some embodiments. In some embodiments, an HE device 104 may perform one or more operations of the method 900 (and/or similar operations). Accordingly, although references may be made to performance of one or more operations of the method 900 by the STA 103 in descriptions herein, it is understood that the HE device 104 may perform the same operation(s), similar operation(s) and/or reciprocal operation(s), in some embodiments.

[00132] It should be noted that the method 900 may be practiced by an STA 103 and may include exchanging of elements, such as frames, signals, messages and/or other elements with an AP 102. The method 800 may be practiced by an AP 102 and may include exchanging of elements, such as frames, signals, messages and/or other elements with an STA 103. In some cases, operations and techniques described as part of the method 800 may be relevant to the method 900. In some cases, operations and techniques described as part of the method 900 may be relevant to the method 800. In addition, embodiments of the method 900 may include one or more operations that may be the same as, similar to or reciprocal to one or more operations of the method 800 (and/or other operation(s) described herein). For instance, an operation of the method 900 may include reception of an element (such as a frame, block, message and/or other) by an STA 103 and the method 800 may include transmission of a same or similar element by the AP 102. In addition, one or more operations included in the method 800 may be the same as, or similar to, one of more operations included in the method 900.

[00133] In addition, previous discussion of various techniques, operations and/or concepts may be applicable to the method 900, in some cases, including location information, positioning protocol, TF, downlink sounding frame, uplink sounding frame, channel estimation, RTT, arrival time, departure time, NDP, NDPA, LMR, contention for access, TXOP, OFDMA transmission, OFDMA reception and/or others.

[00134] At operation 905, the STA 103 may receive a first TF. In some embodiments, the first TF may request an uplink sounding frame. In some embodiments, the first TF may be received during a TXOP obtained by the AP 102.

[00135] At operation 910, the STA 103 may transmit an uplink sounding frame. In some embodiments, the STA 103 may transmit the uplink sounding frame in accordance with an OFDMA technique. In some embodiments, the STA 103 may transmit the uplink sounding frame during the TXOP. In a non-limiting example, the uplink sounding frame may be or may be based on an NDP.

[00136] At operation 915, the STA 103 may receive a frame that indicates that the AP 102 is to transmit one or more downlink sounding frames. In some embodiments, the frame may be received during the TXOP. In a non-limiting example, the frame may be an NDPA.

- 5 [00137] At operation 920, the STA 103 may receive a downlink sounding frame. In some embodiments, the STA 103 may receive the downlink sounding frame in accordance with an OFDMA technique. In some embodiments, the STA 103 may receive the downlink sounding frame during the TXOP. In a non-limiting example, the downlink sounding frame may be an NDP. In another
10 non-limiting example, the downlink sounding frame may be based on an NDP.

[00138] At operation 925, the STA 103 may determine a downlink channel estimate. At operation 930, the STA 103 may determine an arrival time of the downlink sounding frame based on channel estimate. At operation 935, the STA 103 may receive a downlink LMR.

- 15 [00139] At operation 940, the STA 103 may receive a second TF. In some embodiments, the STA 103 may receive the second TF during the TXOP. In some embodiments, the second TF may include an arrival time of the uplink sounding frame at the AP 102 and/or a departure time of the downlink sounding frame from the AP 102. In some embodiments, a trigger type field may be
20 included in the second TF. A value of the trigger type field may indicate a request, by the AP 102, to receive per-STA range information or location information from multiple STAs 103 multiplexed in accordance with an OFDMA technique.

- [00140] In some embodiments, another frame may be used by the AP 102
25 to transmit the arrival time of the uplink sounding frame at the AP 102 and/or the departure time of the downlink sounding frame from the AP 102. For instance, a downlink LMR may include such information.

- [00141] At operation 945, the STA 103 may determine location information of the STA 103. At operation 950, the STA 103 may transmit an
30 uplink LMR. In some embodiments, the STA 103 may transmit the uplink LMR in accordance with an OFDMA technique. The uplink LMR may include range information or location information of the STA 103, timing information of the STA 103 and/or other information. At operation 955, the STA 103 may receive

downlink data. In some embodiments, the STA 103 may receive the downlink data in accordance with an OFDMA technique. At operation 960, the STA 103 may transmit uplink data. In some embodiments, the STA 103 may transmit the uplink data in accordance with an OFDMA technique.

- 5 **[00142]** In a non-limiting example, the STA 103 may determine range information or location information based on one or more of: a departure time of the uplink sounding frame from the STA 103, the arrival time of the uplink sounding frame at the AP 102, the departure time of the downlink sounding frame from the AP 102, and the arrival time of the downlink sounding frame at
10 the STA 103. For instance, the STA 103 may determine the location information based on: a first difference between the arrival time of the uplink sounding frame at the AP 102 and the departure time of the uplink sounding frame from the STA 103; and a second difference between the arrival time of the downlink sounding frame at the STA 103 and the departure time of the downlink
15 sounding frame from the AP 102. For example, an RTT may be determined based on a sum of the first difference and the second difference.

- [00143]** In some embodiments, a trigger type field may be included in the second TF. A value of the trigger type field may indicate a request, by the AP 102, to receive per-STA location information from multiple STAs 103
20 multiplexed in accordance with an OFDMA technique. The STA 103 may, if the trigger type field indicates the request to receive the per-STA location information, transmit an uplink LMR that includes the location information. The uplink LMR may be transmitted in accordance with an OFDMA technique, in some embodiments. The uplink LMR may be transmitted during the TXOP, in
25 some embodiments.

- [00144]** FIG. 10 illustrates example frames that may be exchanged in accordance with some embodiments. FIG. 11 illustrates example frames that may be exchanged in accordance with some embodiments. FIG. 12 illustrates an example trigger frame (TF) in accordance with some embodiments. FIG. 13
30 illustrates example frames that may be exchanged in accordance with some embodiments. FIG. 14 illustrates an example TF in accordance with some embodiments. FIG. 15 illustrates an example null data packet announcement (NDPA) frame and an example sounding dialog token in accordance with some

embodiments. FIG. 16 illustrates an example TF in accordance with some embodiments. It should be noted that the examples shown in FIGs. 10-16 may illustrate some or all of the concepts and techniques described herein in some cases, but embodiments are not limited by the examples of FIGs. 10-16. For instance, embodiments are not limited by the name, number, type, size, ordering, arrangement and/or other aspects of the frames, signals, fields, data blocks, operations, time resources and other elements as shown in FIGs. 10-16.

Although some of the elements shown in the examples of FIGs. 10-16 may be included in a standard, such as 802.11, 802.11ax, 802.11az, WLAN and/or other, embodiments are not limited to usage of such elements that are included in standards.

[00145] Referring to FIG. 10, during the TXOP 1005, the AP 102 may transmit a TF 1012 and may receive one or more UL NDPs 1014. The TF 1012 and UL NDPs 1014 may be exchanged during an UL sounding part 1010, although the scope of embodiments is not limited in this respect.

[00146] During the TXOP 1005, the AP 102 may transmit a DL NDPA 1022 and may transmit one or more DL NDPs 1024. The DL NDPA 1022 and the DL NDPs 1024 may be exchanged during a DL sounding part 1020, although the scope of embodiments is not limited in this respect.

[00147] During the TXOP 1005, the AP 102 may transmit a second TF 1032 and may receive one or more uplink LMRs 1034. The second TF 1032 and the uplink LMRs 1034 may be exchanged during an LMR feedback part 1030, although the scope of embodiments is not limited in this respect.

[00148] Although FIGs. 10, 11 and 13 illustrate usage of UL NDP, DL NDPA, and DL NDP, it is understood that embodiments are not limited to these particular frames. In some embodiments, an uplink sounding frame may be used, and the frame is not limited to a UL NDP. In some embodiments, a downlink sounding frame may be used, and the frame is not limited to a DL NDP. In some embodiments, a frame to indicate the downlink sounding frames (and/or DL NDP) may be used, and that frame is not limited to a DL NDPA.

[00149] In addition, in FIGs. 10, 11, and 13, various frames may be exchanged in accordance with a separation in time between consecutive frames. For instance, two frames may be separated by a short inter-frame spacing (SIFS),

such as 1013 in FIG. 10. Embodiments are not limited to this particular spacing, as any suitable spacing may be used.

[00150] Referring to FIG. 11, various frames may be exchanged between the AP 102 and an STA 103. The AP 102 may transmit the TF 1105. The STA 103 may transmit the UL NDP 1110. In some embodiments, the TF 1105 may request transmission of UL NDP frames from one or more STAs 103. In some embodiments, the STA 103 may transmit the UL NDP 1110 in response to reception of the TF 1105. The value “t1” indicated by 1130 may be the same as or similar to a departure time of an uplink sounding frame described elsewhere herein, although the scope of embodiments is not limited in this respect. The AP 102 may receive the UL NDP 1110. The value “t2” indicated by 1132 may be the same as or similar to an arrival time of an uplink sounding frame described elsewhere herein, although the scope of embodiments is not limited in this respect.

[00151] The AP 102 may transmit the NDPA 1115. The AP may transmit the DL NDP 1120. In some embodiments, the NDPA 1115 may indicate that the AP 102 is to transmit one or more DL NDPs (such as 1120). The value “t3” indicated by 1134 may be the same as or similar to a departure time of a downlink sounding frame described elsewhere herein, although the scope of embodiments is not limited in this respect. The STA 103 may receive the DL NDP 1120. The value “t4” indicated by 1136 may be the same as or similar to an arrival time of a downlink sounding frame described elsewhere herein, although the scope of embodiments is not limited in this respect.

[00152] A single STA 103 is shown for clarity, but it is understood that multiple STAs 103 may be supported in some embodiments. In some embodiments, the TF 1105 may be transmitted by the AP 102 to request UL NDPs from multiple STAs 103. The UL NDP 1110 transmitted by the STA 103 may be multiplexed in accordance with an OFDMA technique, and one or more other STAs 103 may also transmit UL NDP(s) concurrently to the UL NDP 1110. The NDPA 1115 may indicate transmission of DL NDPs to multiple STAs 103. The DL NDP 1120 transmitted by the AP 102 may be full-band or multiplexed in accordance with an OFDMA technique, and the AP 102 may

transmit a DL NDP to one or more other STAs 103 concurrently to the DL NDP 1120.

[00153] In some embodiments, an RTT measurement may be based at least partly on arrival times and departure times. The times t_1 , t_2 , t_3 , and t_4 in the example of FIG. 11 may be used to illustrate an RTT measurement. In a non-limiting example, the RTT measurement may be based on a first difference ($t_4 - t_1$) between the arrival time (t_4) of the DL NDP 1120 at the STA 103 and the departure time (t_1) of the UL NDP 1110 from the STA 103. The RTT measurement may be further based on a second difference ($t_3 - t_2$) between the departure time (t_3) of the DL NDP 1120 from the AP 102 and the arrival time (t_2) of the UL NDP 1110 from the STA 103. In some cases, the RTT measurement may be determined as $((t_4 - t_1) - (t_3 - t_2))$. Embodiments are not limited to this particular equation, as other similar or equivalent computations may be performed, in some embodiments.

[00154] In some embodiments, the STA 103 may provide the AP 102 with t_1 and t_4 (and/or the difference $(t_4 - t_1)$), and the values of t_2 and t_3 may be known (and/or determinable) at the AP 102. Accordingly, the AP 102 may determine the RTT.

[00155] In some embodiments, the AP 102 may provide the STA 103 with t_2 and t_3 (and/or the difference $(t_3 - t_2)$), and the values of t_1 and t_4 may be known (and/or determinable) at the STA 103. Accordingly, the STA 103 may determine the RTT.

[00156] FIG. 12 includes FIG. 12A and FIG. 12B. Referring to FIG. 12, the example TF 1200 may include common information 1205 and may further include user information 1210 for one or more STAs 103. The common information 1205 may include a trigger type 1215. Example assignments of the trigger type 1215 are shown in the table 1220. Embodiments are not limited to these particular cases and are also not limited to the assignment shown in the table 1220. In some embodiments, one or more of the parameters 1205, 1210 and 1215 may be used to communicate information from the AP 102 to one or more STAs 103, including but not limited to information described herein.

[00157] FIG. 13 includes FIG. 13A and FIG. 13B. Referring to FIG. 13, examples 1300, 1330, and 1360 illustrate different techniques for

communication of downlink LMRs from the AP 102 to one or more STAs 103.

The example 1300 illustrates immediate LMR feedback, wherein the AP 102 transmits the downlink LMRs 1325 in the TXOP 1305 after transmission of the DL NDP(s) 1320. The example 1330 illustrates delayed LMR feedback,

5 wherein the AP 102 transmits one or more frames during the TXOP 1335 (such as the downlink LMRs 1350 and/or others shown), and transmits the downlink LMRs 1355 in a subsequent TXOP 1337. The example 1360 illustrates aggregated LMR feedback, wherein the downlink LMRs are included in the NDPA 1385.

10 [00158] FIG. 14 includes FIG. 14A and FIG. 14B. Referring to FIG. 14, the example TF 1400 may include trigger dependent common information 1410. The trigger dependent common information 1410 may include one or more of an LMR type 1412, a minimum waiting time 1414, and a maximum waiting time 1416. The minimum waiting time 1414 may indicate a minimum time for which
15 the STA 103 is to wait to receive downlink LMRs, although the scope of embodiments is not limited in this respect. The maximum waiting time 1416 may indicate a maximum time for which the STA 103 is to wait to receive downlink LMRs, although the scope of embodiments is not limited in this respect. Example assignments of the LMR type 1412 are shown in the table
20 1420. Embodiments are not limited to these particular cases and are also not limited to the assignment shown in the table 1420. In some embodiments, one or more of the parameters 1410, 1412, 1414, and 1416 may be used to communicate information from the AP 102 to one or more STAs 103, including but not limited to information described herein.

25 [00159] Referring to FIG. 15, the example NDPA 1500 may include a sounding dialog token 1510. The sounding dialog token 1510 may include a sounding dialog token number 1515. In some embodiments, reserved bits 1525 of an STA info field 1520 of the NDPA frame 1500 may be used to indicate a measurement report type (such as an LMR type). In some embodiments, one or
30 more of the parameters 1510, 1515, 1520 and 1525 may be used to communicate information from the AP 102 to one or more STAs 103, including but not limited to information described herein.

[00160] Referring to FIG. 16, the example TF 1600 may include common information 605 and may include trigger frame user information 1610. The trigger frame user information 1610 may include trigger dependent user information 1615. In some embodiments, a measurement report type (such as an LMR type) may be indicated in the trigger dependent user info field of a TF (such as the field 1615 of TF 1600). In some embodiments, one or more of the parameters 1605, 1610 and 1615 may be used to communicate information from the AP 102 to one or more STAs 103, including but not limited to information described herein.

10 [00161] In some embodiments, a sounding dialog token field may be used to identify measurement report feedback. In some embodiments, the sounding dialog token may be included in the trigger dependent common info field 1605 (for this case, each STA 103 may report the LMR corresponding to the same measurement sequence identified by the token). In some embodiments, the
15 sounding dialog token may be included in the trigger dependent user info field 1615 (for this case, each STA 103 may report the LMR corresponding to the measurement sequence identified by the token).

[00162] In Example 1, an apparatus of an access point (AP) may comprise memory. The apparatus may further comprise processing circuitry. The
20 processing circuitry may be configured to encode, for transmission during a transmission opportunity (TXOP) obtained by the AP, a first trigger frame (TF) that requests uplink sounding frames from a plurality of stations (STAs). The processing circuitry may be further configured to decode the uplink sounding frames received from the STAs during the TXOP. The processing circuitry may
25 be further configured to encode, for transmission during the TXOP, downlink sounding frames. The processing circuitry may be further configured to encode, for transmission during the TXOP, a second TF that requests transmission of uplink location measurement reports (LMRs) by at least one of the STAs of the plurality. The processing circuitry may be further configured to decode the
30 uplink LMRs received during the TXOP. The uplink LMRs may include per-STA location information based on per-STA departure times of the uplink sounding frames and per-STA arrival times of the downlink sounding frames.

The processing circuitry may be further configured to store the per-STA location information in the memory.

[00163] In Example 2, the subject matter of Example 1, wherein the processing circuitry may be further configured to encode the second TF to include a trigger type field in a common information portion of the second TF. A value of the trigger type field may indicate a request for transmission of the uplink LMRs by the STAs.

[00164] In Example 3, the subject matter of one or any combination of Examples 1-2, wherein the second TF may be configurable to request the transmission of the uplink LMRs from STAs that are unassociated with the AP.

[00165] In Example 4, the subject matter of one or any combination of Examples 1-3, wherein the processing circuitry may be further configured to encode the second TF to include one or more user information fields that include association identifiers (AIDs) for STAs of the plurality that are associated with the AP.

[00166] In Example 5, the subject matter of one or any combination of Examples 1-4, wherein the per-STA location information may include round trip time (RTT) measurements from the STAs.

[00167] In Example 6, the subject matter of one or any combination of Examples 1-5, wherein the processing circuitry may be further configured to decode the uplink LMRs received in accordance with an OFDMA technique.

[00168] In Example 7, the subject matter of one or any combination of Examples 1-6, wherein the processing circuitry may be further configured to encode the second TF to indicate resource units (RUs) to be used by the STAs for OFDMA transmission of the uplink LMRs.

[00169] In Example 8, the subject matter of one or any combination of Examples 1-7, wherein the processing circuitry may be further configured to encode the first TF, the downlink sounding frames, and the second TF for transmission as part of a positioning protocol for determination of the per-STA location information. The processing circuitry may be further configured to decode the uplink sounding frames as part of the positioning protocol.

[00170] In Example 9, the subject matter of one or any combination of Examples 1-8, wherein the processing circuitry may be further configured to

encode, for transmission during the TXOP, downlink LMRs that include per-STA arrival times of the uplink sounding frames at the AP and a departure time of the downlink sounding frames from the AP.

[00171] In Example 10, the subject matter of one or any combination of Examples 1-9, wherein the processing circuitry may be further configured to determine uplink channel estimates based on the uplink sounding frames. The processing circuitry may be further configured to determine the arrival times of the uplink sounding frames based at least partly on the uplink channel estimates.

[00172] In Example 11, the subject matter of one or any combination of Examples 1-10, wherein the uplink sounding frames may include uplink null data packets (NDPs). The downlink sounding frames may include downlink NDPs.

[00173] In Example 12, the subject matter of one or any combination of Examples 1-11, wherein the processing circuitry may be further configured to encode, in a trigger dependent common information field of the first TF or in a trigger dependent user information field of the first TF, a sounding dialog token that indicates a measurement sequence to be used by at least one of the STAs to determine a round trip time between the STAs and the AP.

[00174] In Example 13, the subject matter of one or any combination of Examples 1-12, wherein the processing circuitry may be further configured to encode the downlink sounding frames for transmission in accordance with an OFDMA technique.

[00175] In Example 14, the subject matter of one or any combination of Examples 1-13, wherein the processing circuitry may be further configured to decode the uplink sounding frames multiplexed in accordance with an orthogonal frequency division multiple access (OFDMA) technique or space-division multiple access (SDMA) technique.

[00176] In Example 15, the subject matter of one or any combination of Examples 1-14, wherein the apparatus may further include a transceiver to: transmit the first TF, the downlink sounding frames, and the second TF; and receive the uplink sounding waveforms.

[00177] In Example 16, the subject matter of one or any combination of Examples 1-15, wherein the processing circuitry may include a baseband

processor to: encode the first TF, the downlink sounding frames, and the second TF; and decode the uplink sounding frames.

[00178] In Example 17, a non-transitory computer-readable storage medium may store instructions for execution by one or more processors to

5 perform operations for communication by a station (STA). The operations may configure the one or more processors to decode a first trigger frame (TF) that requests an uplink sounding frame, the first TF received during a transmission opportunity (TXOP). The operations may further configure the one or more

10 processors to encode the uplink sounding frame for transmission during the TXOP. The operations may further configure the one or more processors to decode a downlink sounding frame received during the TXOP. The downlink sounding frame may be multiplexed in accordance with an OFDMA technique. The operations may further configure the one or more processors to determine an arrival time of the downlink sounding frame at the STA. The operations may

15 further configure the one or more processors to decode a second TF received during the TXOP. The second TF may include an arrival time of the uplink sounding frame at the AP and further includes a departure time of the downlink sounding frame from the AP. The operations may further configure the one or more processors to determine location information based on a departure time of

20 the uplink sounding frame from the STA, the arrival time of the uplink sounding frame at the AP, the departure time of the downlink sounding frame from the AP, and the arrival time of the downlink sounding frame at the STA.

[00179] In Example 18, the subject matter of Example 17, wherein the operations may further configure the one or more processors to decode a trigger

25 type field in the second TF. A value of the trigger type field may indicate a request, by the AP, to receive per-STA location information from multiple STAs multiplexed in accordance with an OFDMA technique. The operations may further configure the one or more processors to, if the trigger type field indicates the request (by the AP) to receive the per-STA location information, encode (for

30 transmission in accordance with an OFDMA technique during the TXOP) an uplink LMR that includes: a departure time of the uplink sounding frame and an arrival time of the downlink sounding frame, or the location information.

[00180] In Example 19, the subject matter of one or any combination of Examples 17-18, wherein the operations may further configure the one or more processors to determine the location information based on: a first difference between the arrival time of the uplink sounding frame at the AP and the
5 departure time of the uplink sounding frame from the STA, and a second difference between the arrival time of the downlink sounding frame at the STA and the departure time of the downlink sounding frame from the AP.

[00181] In Example 20, the subject matter of one or any combination of Examples 17-19, wherein the operations may further configure the one or more
10 processors to encode the uplink sounding frame for transmission in accordance with an orthogonal frequency division multiple access (OFDMA) technique or space-division multiple access (SDMA) technique.

[00182] In Example 21, a method of communication by an access point (AP) may comprise encoding, for transmission during a transmission opportunity
15 (TXOP) obtained by the AP, a trigger frame (TF) that indicates: that a plurality of stations (STAs) are to transmit uplink sounding frames, and a location measurement report (LMR) type parameter that indicates when the AP is to transmit downlink LMRs that include per-STA arrival times of the uplink sounding frames. The method may further comprise decoding the uplink
20 sounding frames received during the TXOP, the uplink sounding frames multiplexed in accordance with an orthogonal frequency division multiple access (OFDMA) technique. The method may further comprise determining the per-STA arrival times of the uplink sounding frames. The method may further comprise encoding the downlink LMRs for transmission during the TXOP.

[00183] In Example 22, the subject matter of Example 21, wherein a first value of the LMR type parameter may indicate immediate LMR feedback, wherein the AP is to transmit the downlink LMRs in the TXOP after
25 transmission of the downlink sounding frames. A second value of the LMR type parameter may indicate delayed LMR feedback, wherein the AP is to transmit the downlink LMRs in a subsequent TXOP. A third value of the LMR type
30 parameter may indicate aggregated LMR feedback, wherein the downlink LMRs are included in the NDPA.

[00184] In Example 23, the subject matter of one or any combination of Examples 21-22, wherein the method may further comprise encoding the downlink sounding frames for transmission during the TXOP in accordance with an OFDMA technique. The method may further comprise encoding the
5 downlink LMRs to include the per-STA arrival times of the uplink sounding frames and a departure time of the downlink sounding frames.

[00185] In Example 24, the subject matter of one or any combination of Examples 21-23, wherein the method may further comprise decoding, from the STAs, uplink LMRs that include per-STA location information. The per-STA
10 location information may include per-STA departure times of the uplink sounding frames from the STAs and per-STA arrival times of the downlink sounding frames at the STAs.

[00186] In Example 25, the subject matter of one or any combination of Examples 21-24, wherein the method may further comprise encoding the TF to
15 include the LMR type parameter in a common information portion or the per user information field of the TF.

[00187] In Example 26, the subject matter of one or any combination of Examples 21-25, wherein the method may further comprise encoding the TF to
20 include, in the common information portion or the per user information field of the TF: a minimum waiting time that the STAs are to wait to receive the downlink LMRs, and a maximum waiting time that the STAs are to wait to receive the downlink LMRs.

[00188] In Example 27, an apparatus of an access point (AP) may comprise memory. The apparatus may further comprise processing circuitry.
25 The processing circuitry may be configured to encode, for transmission during a transmission opportunity (TXOP) obtained by the AP, a trigger frame (TF) that requests uplink sounding frames from a plurality of stations (STAs). The processing circuitry may be further configured to decode the uplink sounding frames received during the TXOP, the uplink sounding frames multiplexed in
30 accordance with an orthogonal frequency division multiple access (OFDMA) technique or space-division multiple access (SDMA) technique. The processing circuitry may be further configured to determine per-STA arrival times of the uplink sounding frames. The processing circuitry may be further configured to

5 encode a null data packet announcement (NDPA) for transmission during the TXOP, wherein the NDPA indicates: that the AP is to transmit downlink sounding frames during the TXOP, and a location measurement report (LMR) type parameter that indicates when the AP is to transmit downlink LMRs that include the per-STA arrival times of the uplink sounding frames.

[00189] In Example 28, the subject matter of Example 27, wherein a first value of the LMR type parameter may indicate immediate LMR feedback, wherein the AP is to transmit the downlink LMRs in the TXOP after transmission of the downlink sounding frames. A second value of the LMR type parameter may indicate delayed LMR feedback, wherein the AP is to transmit the downlink LMRs in a subsequent TXOP. A third value of the LMR type parameter may indicate aggregated LMR feedback, wherein the downlink LMRs are included in the NDPA.

[00190] In Example 29, the subject matter of one or any combination of Examples 27-28, wherein the processing circuitry may be further configured to encode the downlink sounding frames for transmission during the TXOP in accordance with an OFDMA technique. The processing circuitry may be further configured to encode the downlink LMRs to include the per-STA arrival times of the uplink sounding frames and a departure time of the downlink sounding frames.

[00191] In Example 30, the subject matter of one or any combination of Examples 27-29, wherein the processing circuitry may be further configured to encode the LMR type parameter in an STA information field of the NDPA.

[00192] In Example 31, an apparatus of a station (STA) may comprise means for decoding a first trigger frame (TF) that requests an uplink sounding frame, the first TF received during a transmission opportunity (TXOP). The apparatus may further comprise means for encoding the uplink sounding frame for transmission during the TXOP. The apparatus may further comprise means for decoding a downlink sounding frame received during the TXOP. The downlink sounding frame may be multiplexed in accordance with an OFDMA technique. The apparatus may further comprise means for determining an arrival time of the downlink sounding frame at the STA. The apparatus may further comprise means for decoding a second TF received during the TXOP. The

second TF may include an arrival time of the uplink sounding frame at the AP and may further include a departure time of the downlink sounding frame from the AP. The apparatus may further comprise means for determining location information based on a departure time of the uplink sounding frame from the STA, the arrival time of the uplink sounding frame at the AP, the departure time of the downlink sounding frame from the AP, and the arrival time of the downlink sounding frame at the STA.

[00193] In Example 32, the subject matter of Example 31, wherein the apparatus may further comprise means for decoding a trigger type field in the second TF, wherein a value of the trigger type field indicates a request, by the AP, to receive per-STA location information from multiple STAs multiplexed in accordance with an OFDMA technique. The apparatus may further comprise means for, if the trigger type field indicates the request (by the AP) to receive the per-STA location information, encoding (for transmission in accordance with an OFDMA technique during the TXOP) an uplink LMR that includes: a departure time of the uplink sounding frame and an arrival time of the downlink sounding frame, or the location information.

[00194] In Example 33, the subject matter of one or any combination of Examples 31-32, wherein the apparatus may further comprise means for determining the location information based on: a first difference between the arrival time of the uplink sounding frame at the AP and the departure time of the uplink sounding frame from the STA, and a second difference between the arrival time of the downlink sounding frame at the STA and the departure time of the downlink sounding frame from the AP.

[00195] In Example 34, the subject matter of one or any combination of Examples 31-33, wherein the apparatus may further comprise means for encoding the uplink sounding frame for transmission in accordance with an orthogonal frequency division multiple access (OFDMA) technique or space-division multiple access (SDMA) technique.

[00196] 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 an access point (AP), the apparatus comprising:
5 memory; and processing circuitry, configured to:
 encode, for transmission during a transmission opportunity (TXOP)
 obtained by the AP, a first trigger frame (TF) that requests uplink sounding
 frames from a plurality of stations (STAs);
 decode the uplink sounding frames received from the STAs during the
10 TXOP;
 encode, for transmission during the TXOP, downlink sounding frames;
 encode, for transmission during the TXOP, a second TF that requests
 transmission of uplink location measurement reports (LMRs) by at least one of
 the STAs of the plurality;
15 decode the uplink LMRs received during the TXOP, wherein the uplink
 LMRs include per-STA location information based on per-STA departure times
 of the uplink sounding frames and per-STA arrival times of the downlink
 sounding frames; and
 store the per-STA location information in the memory.
20
2. The apparatus according to claim 1, the processing circuitry further
configured to:
 encode the second TF to include a trigger type field in a common
information portion of the second TF,
25 wherein a value of the trigger type field indicates a request for
transmission of the uplink LMRs by the STAs.
3. The apparatus according to claim 1, wherein the second TF is
configurable to request the transmission of the uplink LMRs from STAs that are
30 unassociated with the AP.
4. The apparatus according to claim 1, the processing circuitry further
configured to:

encode the second TF to include one or more user information fields that include association identifiers (AIDs) for STAs of the plurality that are associated with the AP.

5 5. The apparatus according to any of claims 1-4, wherein the per-STA location information includes round trip time (RTT) measurements from the STAs.

10 6. The apparatus according to claim 1, the processing circuitry further configured to decode the uplink LMRs received in accordance with an OFDMA technique.

15 7. The apparatus according to claim 1 or 6, the processing circuitry further configured to encode the second TF to indicate resource units (RUs) to be used by the STAs for OFDMA transmission of the uplink LMRs.

8. The apparatus according to claim 1, the processing circuitry further configured to:

20 encode the first TF, the downlink sounding frames, and the second TF for transmission as part of a positioning protocol for determination of the per-STA location information; and

 decode the uplink sounding frames as part of the positioning protocol.

25 9. The apparatus according to claim 1, the processing circuitry further configured to:

 encode, for transmission during the TXOP, downlink LMRs that include per-STA arrival times of the uplink sounding frames at the AP and a departure time of the downlink sounding frames from the AP.

30 10. The apparatus according to any of claims 1, 8, and 9, the processing circuitry further configured to:

 determine uplink channel estimates based on the uplink sounding frames;
and

determine the arrival times of the uplink sounding frames based at least partly on the uplink channel estimates.

11. The apparatus according to claim 1, wherein:
5 the uplink sounding frames include uplink null data packets (NDPs), and the downlink sounding frames include downlink NDPs.

12. The apparatus according to claim 1, the processing circuitry further configured to:
10 encode, in a trigger dependent common information field of the first TF or in a trigger dependent user information field of the first TF, a sounding dialog token that indicates a measurement sequence to be used by at least one of the STAs to determine a round trip time between the STAs and the AP.

13. The apparatus according to claim 1, the processing circuitry further configured to:
encode the downlink sounding frames for transmission in accordance with an OFDMA technique.

14. The apparatus according to any of claims 1 and 11-13, the processing circuitry further configured to:
decode the uplink sounding frames multiplexed in accordance with an orthogonal frequency division multiple access (OFDMA) technique or space-division multiple access (SDMA) technique.

15. The apparatus according to claim 1, wherein the apparatus further includes a transceiver to:
transmit the first TF, the downlink sounding frames, and the second TF;
and
25 receive the uplink sounding waveforms.

16. The apparatus according to claim 1, wherein the processing circuitry includes a baseband processor to:

encode the first TF, the downlink sounding frames, and the second TF;
and
decode the uplink sounding frames.

- 5 17. A computer-readable storage medium that stores instructions for execution by one or more processors to perform operations for communication by a station (STA), the operations to configure the one or more processors to:
- decode a first trigger frame (TF) that requests an uplink sounding frame, the first TF received during a transmission opportunity (TXOP);
- 10 encode the uplink sounding frame for transmission during the TXOP;
 decode a downlink sounding frame received during the TXOP, the downlink sounding frame multiplexed in accordance with an OFDMA technique;
- determine an arrival time of the downlink sounding frame at the STA;
- 15 decode a second TF received during the TXOP, wherein the second TF includes an arrival time of the uplink sounding frame at the AP and further includes a departure time of the downlink sounding frame from the AP; and
- determine location information based on a departure time of the uplink sounding frame from the STA, the arrival time of the uplink sounding frame at
- 20 the AP, the departure time of the downlink sounding frame from the AP, and the arrival time of the downlink sounding frame at the STA.

18. The computer-readable storage medium according to claim 17, the operations to further configure the one or more processors to:
- 25 decode a trigger type field in the second TF, wherein a value of the trigger type field indicates a request, by the AP, to receive per-STA location information from multiple STAs multiplexed in accordance with an OFDMA technique; and
- if the trigger type field indicates the request, by the AP, to receive the
- 30 per-STA location information:
- encode, for transmission in accordance with an OFDMA technique during the TXOP, an uplink LMR that includes:

a departure time of the uplink sounding frame and an arrival time of the downlink sounding frame, or the location information.

5 19. The computer-readable storage medium according to claim 17, the operations to further configure the one or more processors to:

 determine the location information based on:

 a first difference between the arrival time of the uplink sounding frame at the AP and the departure time of the uplink sounding frame from the
10 STA, and

 a second difference between the arrival time of the downlink sounding frame at the STA and the departure time of the downlink sounding frame from the AP.

15 20. The computer-readable storage medium according to any of claims 17-19, the operations to further configure the one or more processors to:

 encode the uplink sounding frame for transmission in accordance with an orthogonal frequency division multiple access (OFDMA) technique or space-division multiple access (SDMA) technique.

20

 21. A method of communication by an access point (AP), the method comprising:

 encoding, for transmission during a transmission opportunity (TXOP) obtained by the AP, a trigger frame (TF) that indicates:

25 that a plurality of stations (STAs) are to transmit uplink sounding frames, and

 a location measurement report (LMR) type parameter that indicates when the AP is to transmit downlink LMRs that include per-STA arrival times of the uplink sounding frames;

30 decoding the uplink sounding frames received during the TXOP, the uplink sounding frames multiplexed in accordance with an orthogonal frequency division multiple access (OFDMA) technique;

determining the per-STA arrival times of the uplink sounding frames;
and
encoding the downlink LMRs for transmission during the TXOP.

5 22. The method according to claim 21, wherein:

 a first value of the LMR type parameter indicates immediate LMR
feedback, wherein the AP is to transmit the downlink LMRs in the TXOP after
transmission of the downlink sounding frames,

 a second value of the LMR type parameter indicates delayed LMR
10 feedback, wherein the AP is to transmit the downlink LMRs in a subsequent
TXOP, and

 a third value of the LMR type parameter indicates aggregated LMR
feedback, wherein the downlink LMRs are included in the NDPA.

15 23. The method according to claim 21, the method further comprising:

 encoding the downlink sounding frames for transmission during the
TXOP in accordance with an OFDMA technique; and

 encoding the downlink LMRs to include the per-STA arrival times of the
uplink sounding frames and a departure time of the downlink sounding frames.

20

 24. The method according to any of claims 21-23, the method further
comprising:

 decoding, from the STAs, uplink LMRs that include per-STA location
information,

25 wherein the per-STA location information includes per-STA departure
times of the uplink sounding frames from the STAs and per-STA arrival times of
the downlink sounding frames at the STAs.

 25. The method according to claim 21, the method further comprising:

30 encoding the TF to include the LMR type parameter in a common
information portion or the per user information field of the TF.

 26. The method according to claim 25, the method further comprising:

encoding the TF to include, in the common information portion or the per user information field of the TF:

a minimum waiting time that the STAs are to wait to receive the downlink LMRs, and

5 a maximum waiting time that the STAs are to wait to receive the downlink LMRs.

27. An apparatus of an access point (AP), the apparatus comprising: memory; and processing circuitry, configured to:

10 encode, for transmission during a transmission opportunity (TXOP) obtained by the AP, a trigger frame (TF) that requests uplink sounding frames from a plurality of stations (STAs);

decode the uplink sounding frames received during the TXOP, the uplink sounding frames multiplexed in accordance with an orthogonal frequency
15 division multiple access (OFDMA) technique or space-division multiple access (SDMA) technique;

determine per-STA arrival times of the uplink sounding frames;

encode a null data packet announcement (NDPA) for transmission during the TXOP, wherein the NDPA indicates:

20 that the AP is to transmit downlink sounding frames during the TXOP, and

a location measurement report (LMR) type parameter that indicates when the AP is to transmit downlink LMRs that include the per-STA arrival times of the uplink sounding frames.

25

28. The apparatus according to claim 27, wherein:

a first value of the LMR type parameter indicates immediate LMR feedback, wherein the AP is to transmit the downlink LMRs in the TXOP after transmission of the downlink sounding frames,

30 a second value of the LMR type parameter indicates delayed LMR feedback, wherein the AP is to transmit the downlink LMRs in a subsequent TXOP, and

a third value of the LMR type parameter indicates aggregated LMR feedback, wherein the downlink LMRs are included in the NDPA.

29. The apparatus according to claim 27, the processing circuitry further
5 configured to:

encode the downlink sounding frames for transmission during the TXOP in accordance with an OFDMA technique; and

encode the downlink LMRs to include the per-STA arrival times of the uplink sounding frames and a departure time of the downlink sounding frames.

10

30. The apparatus according to any of claims 27-29, the processing circuitry further configured to:

encode the LMR type parameter in an STA information field of the NDPA.

15

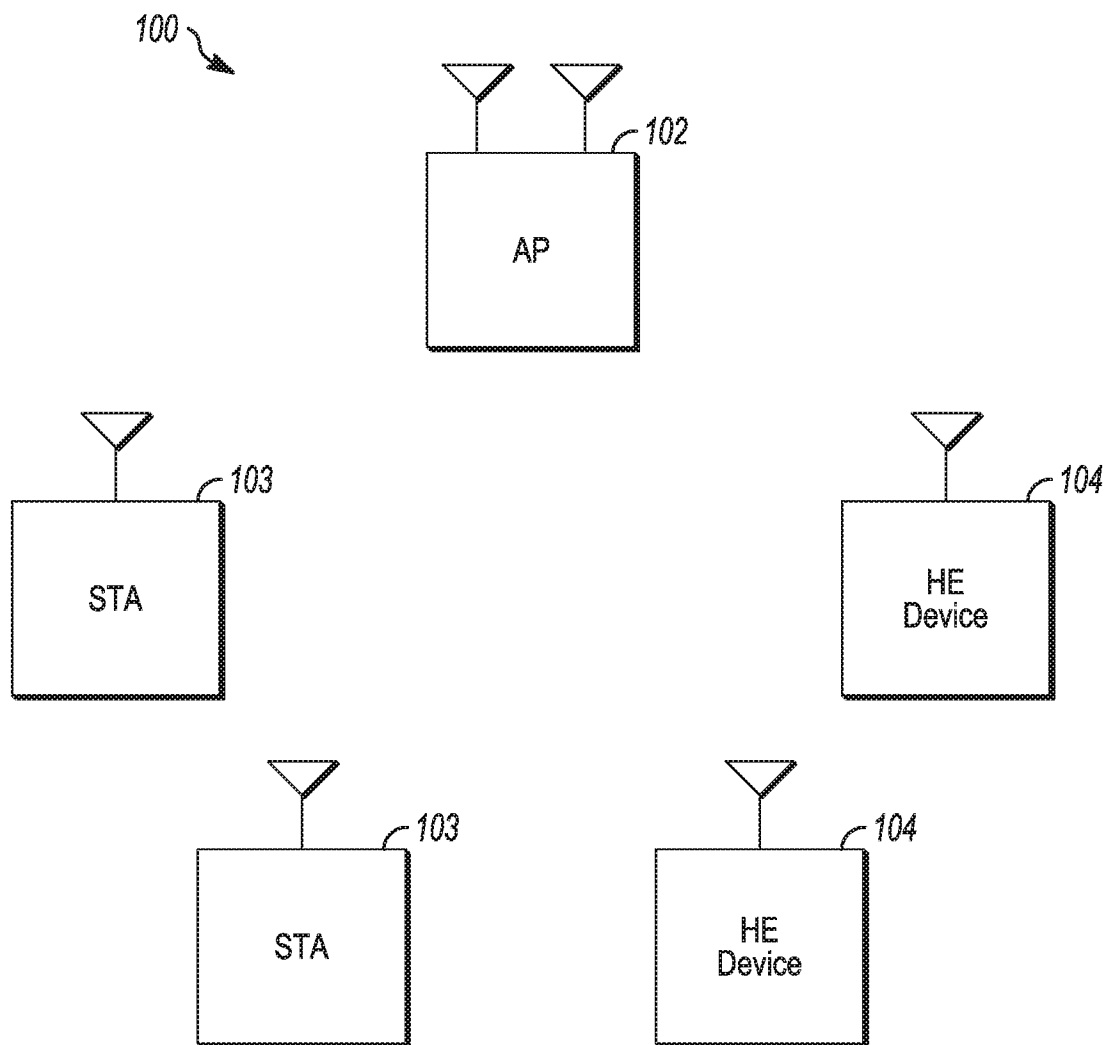
1/19

FIG. 1

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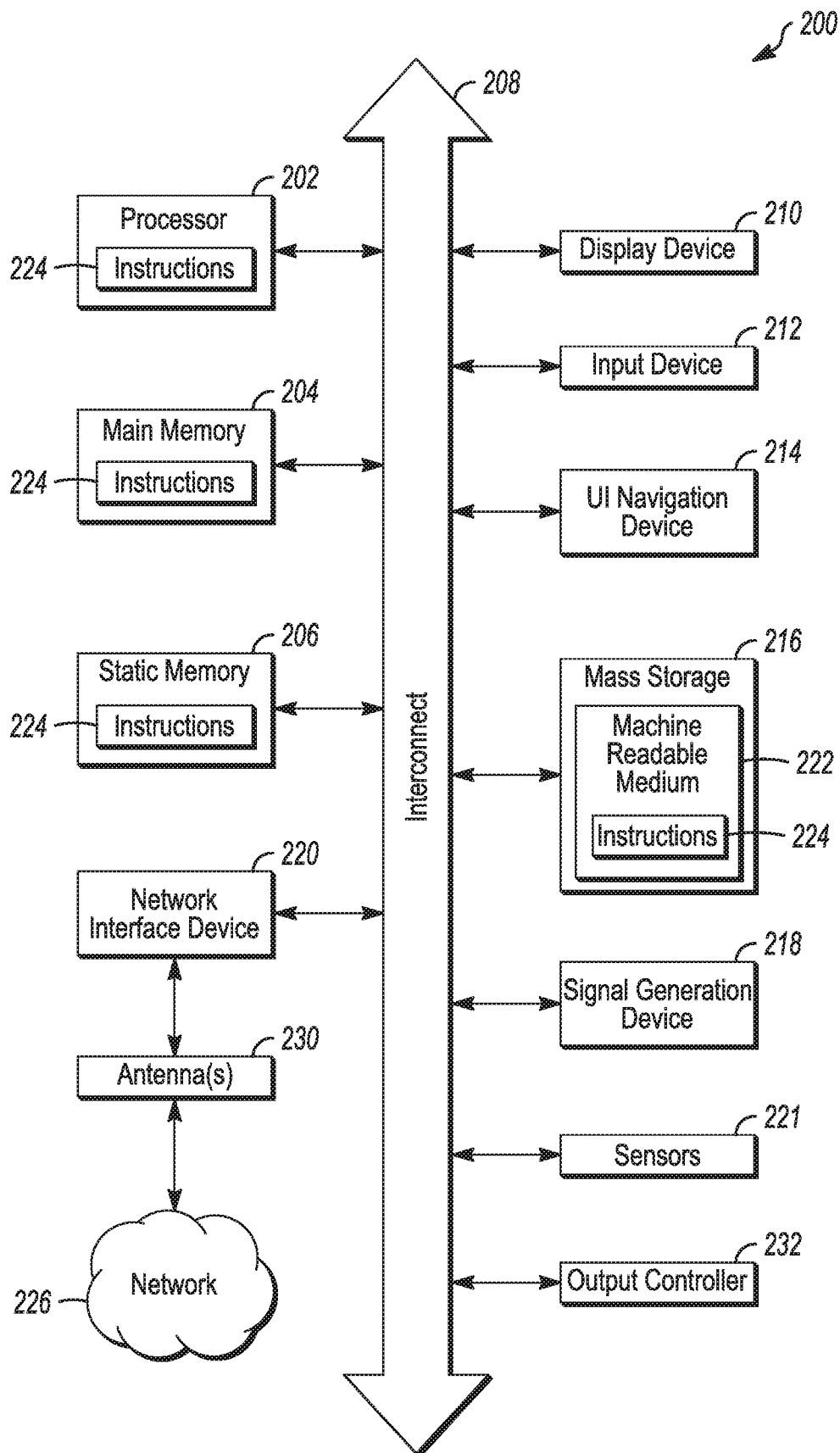
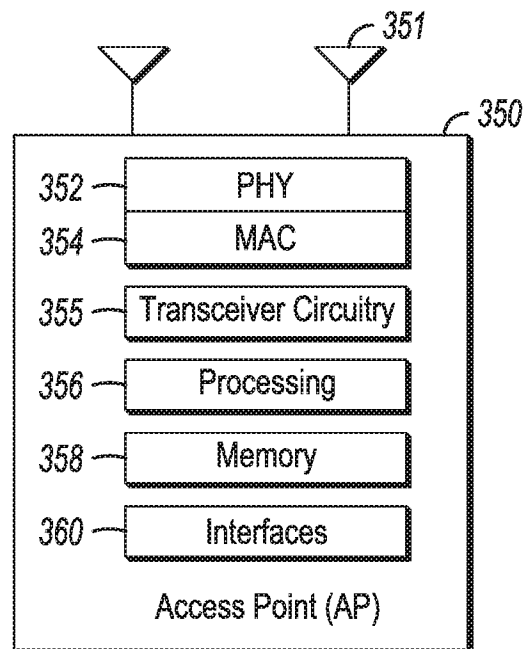
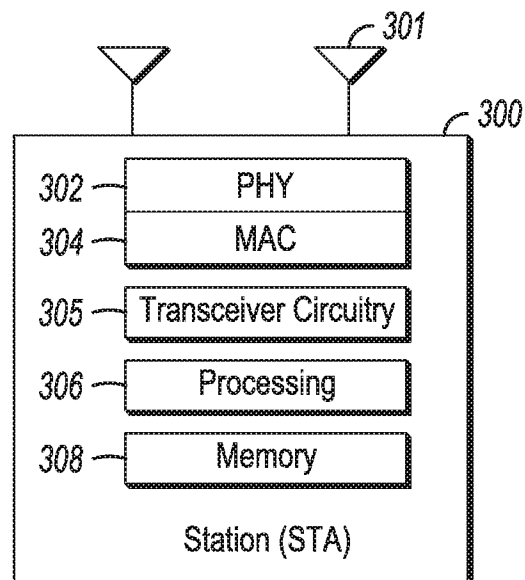


FIG. 2

3/19**FIG. 3**

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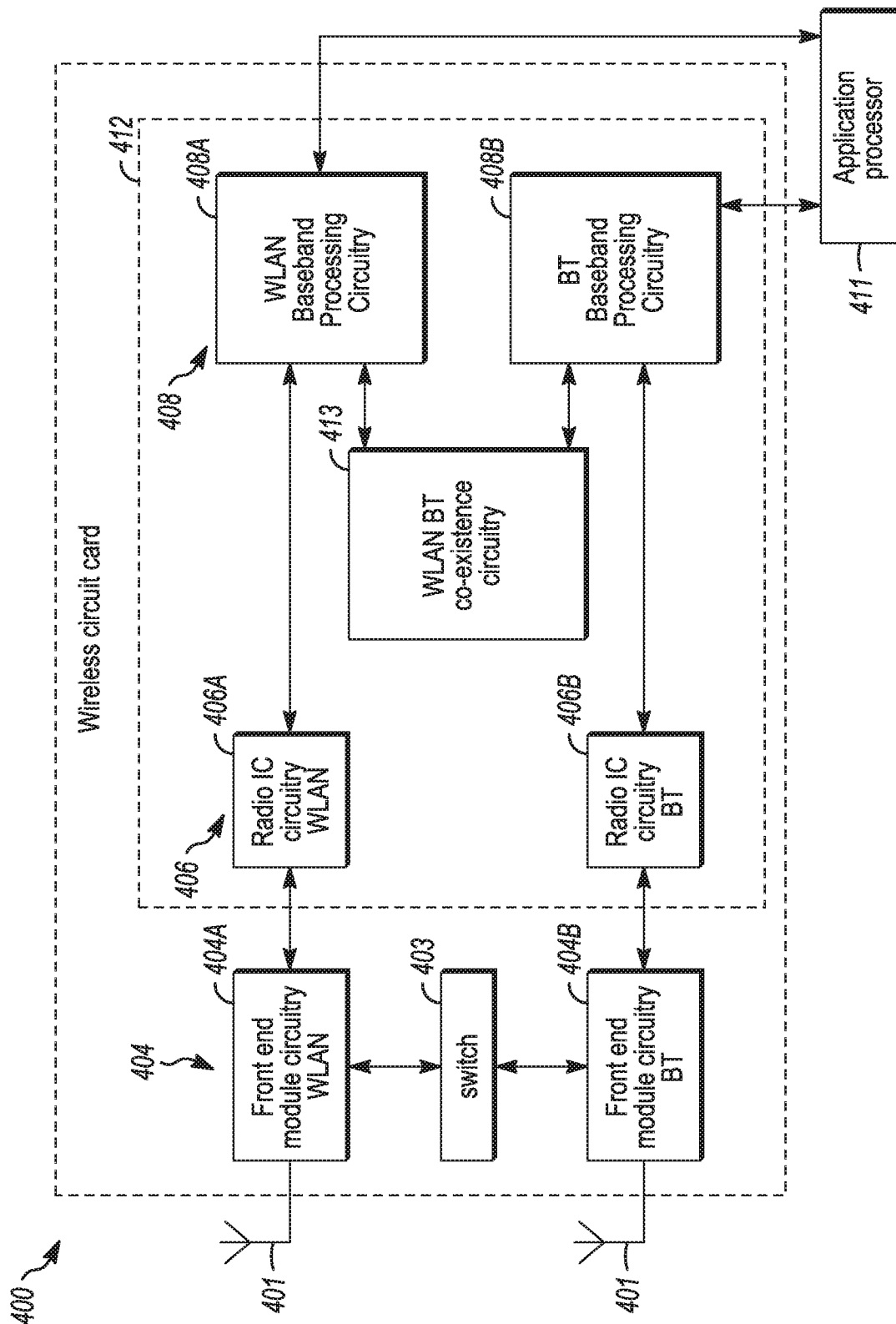


FIG. 4

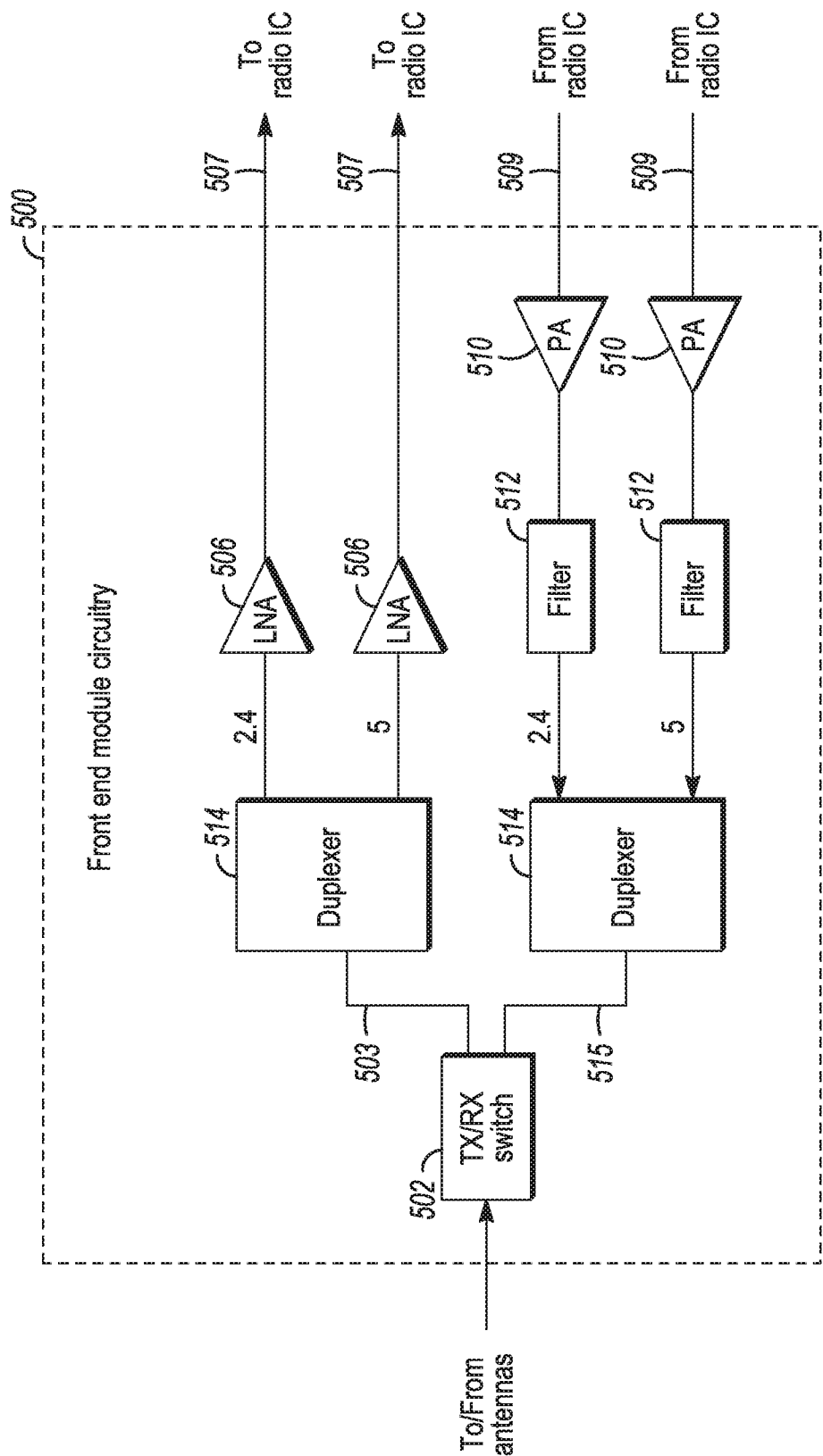


FIG. 5

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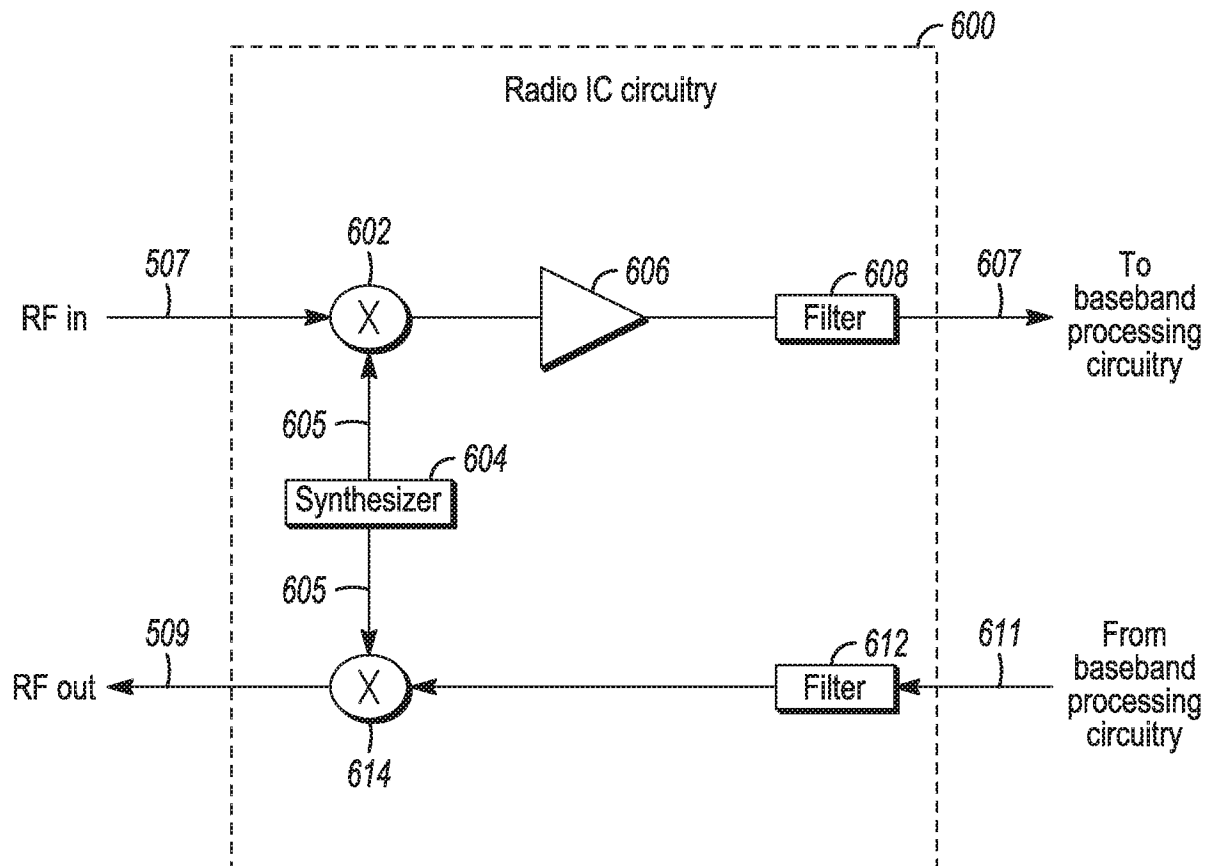


FIG. 6

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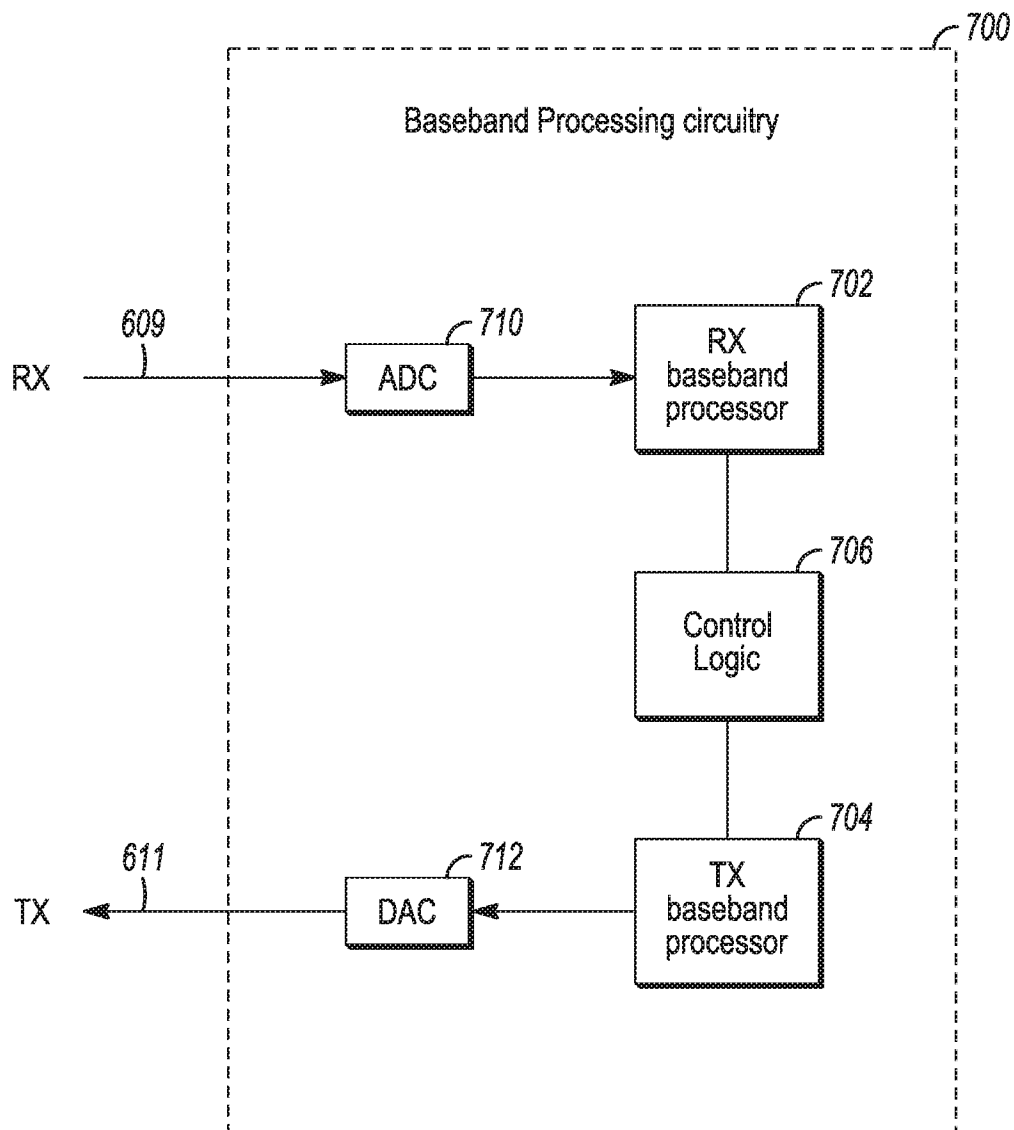
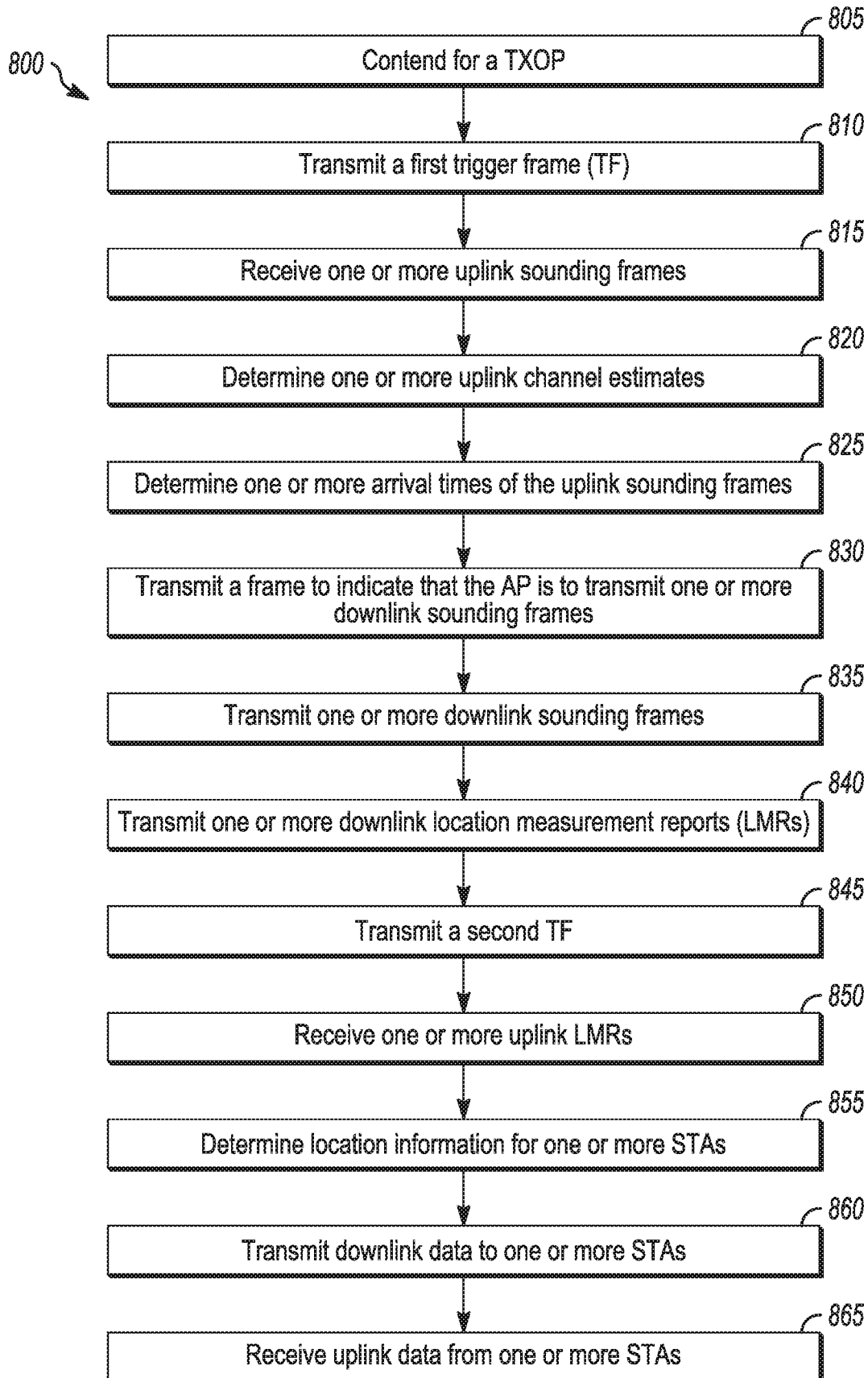


FIG. 7

8/19**FIG. 8**

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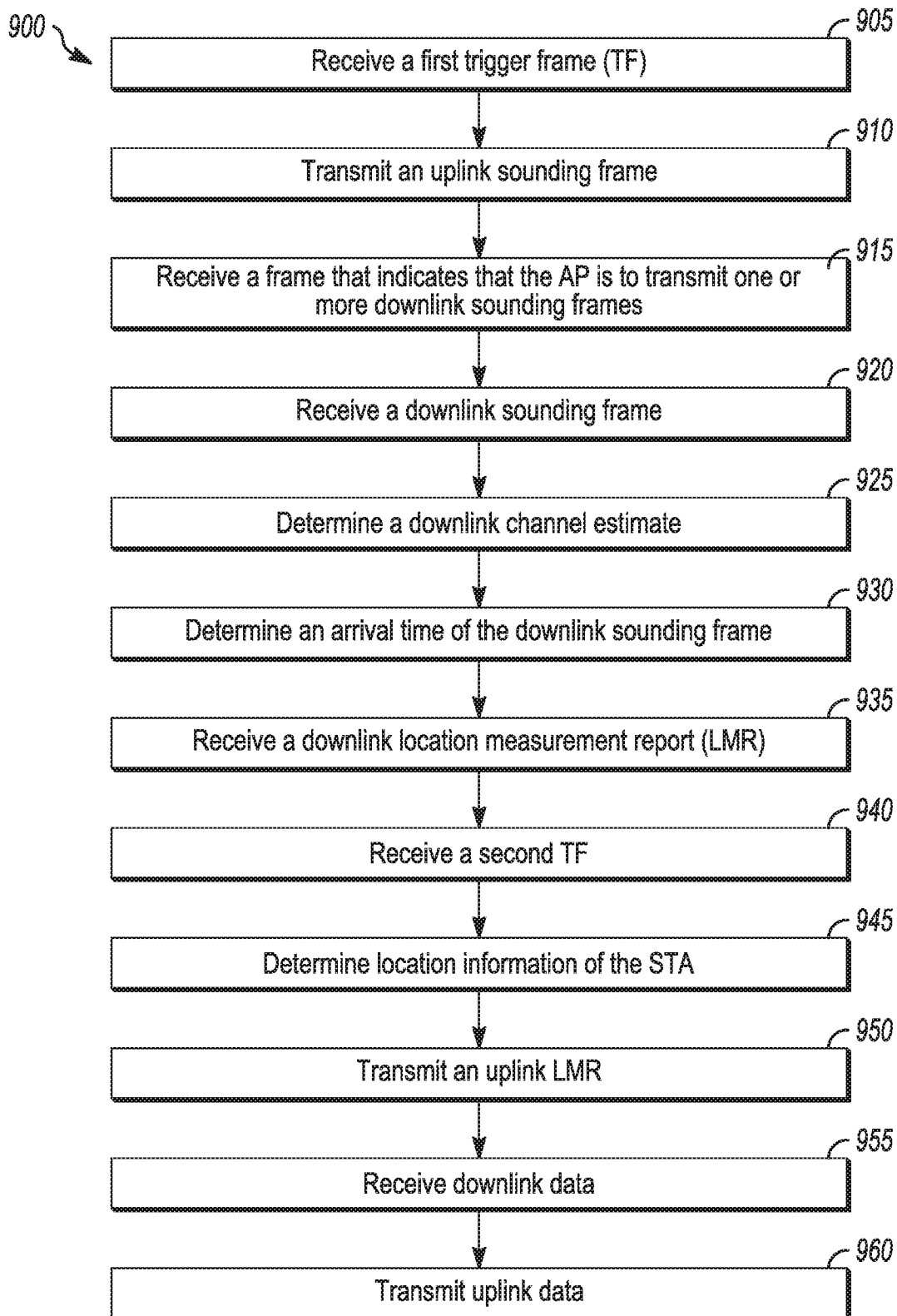


FIG. 9

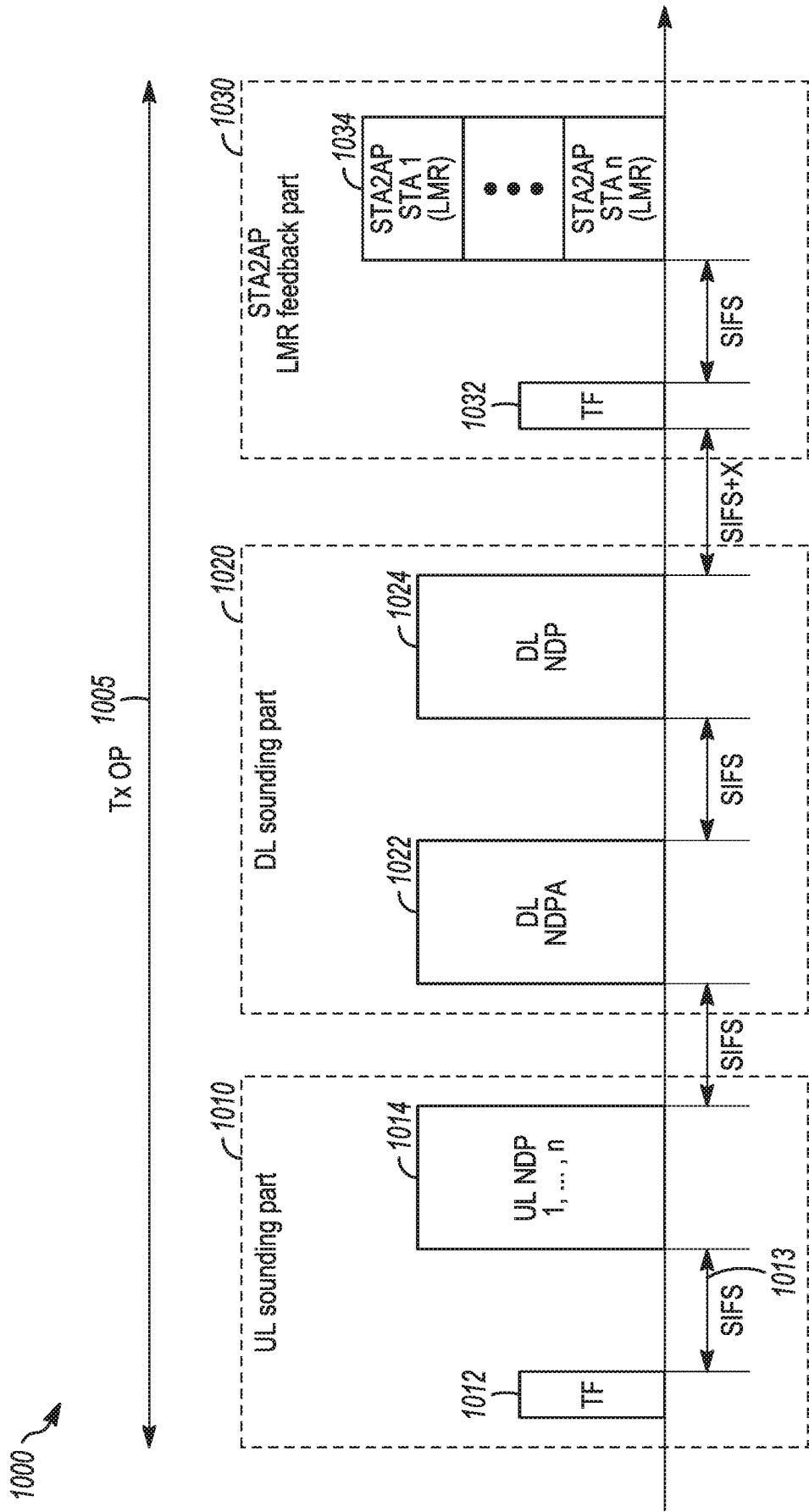


FIG. 10

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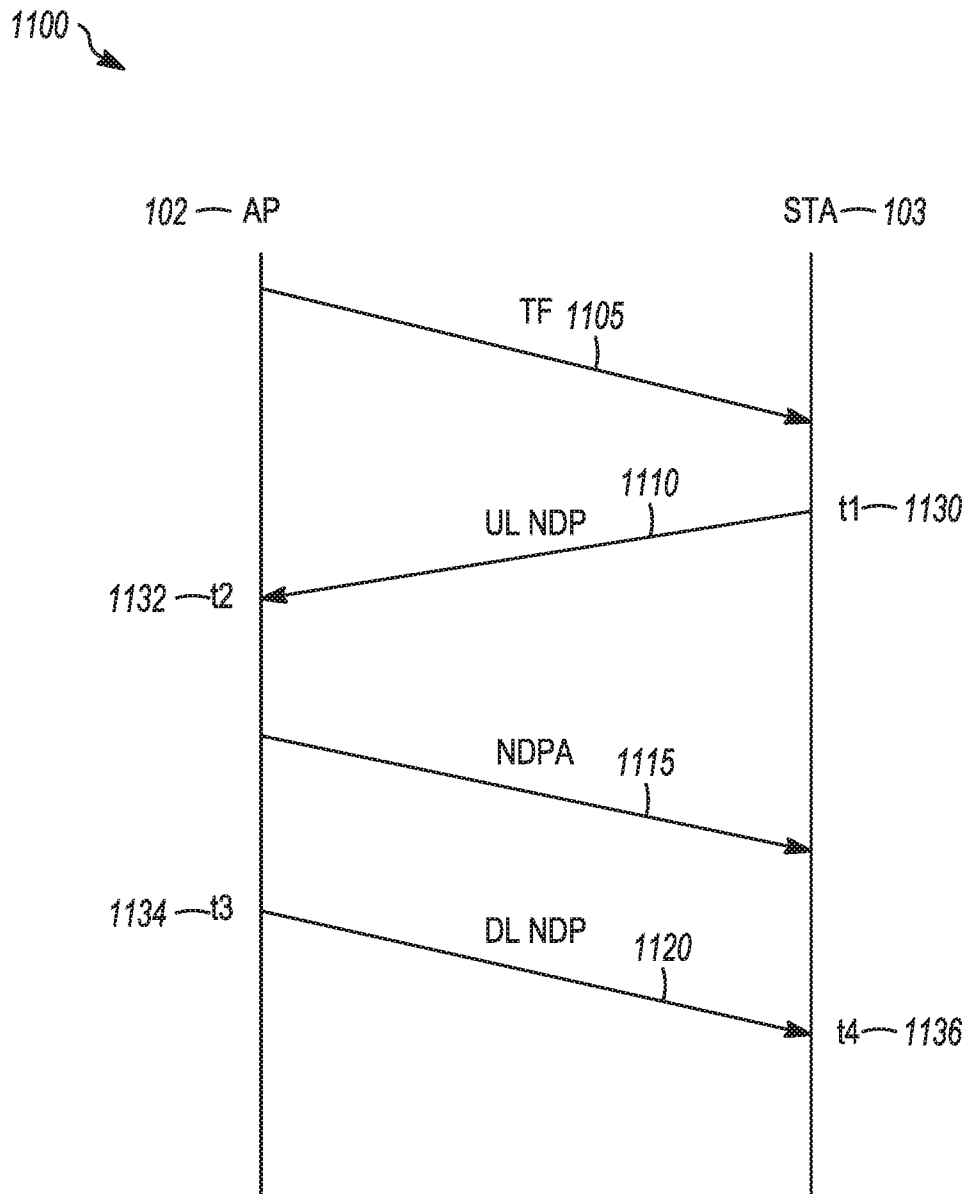


FIG. 11

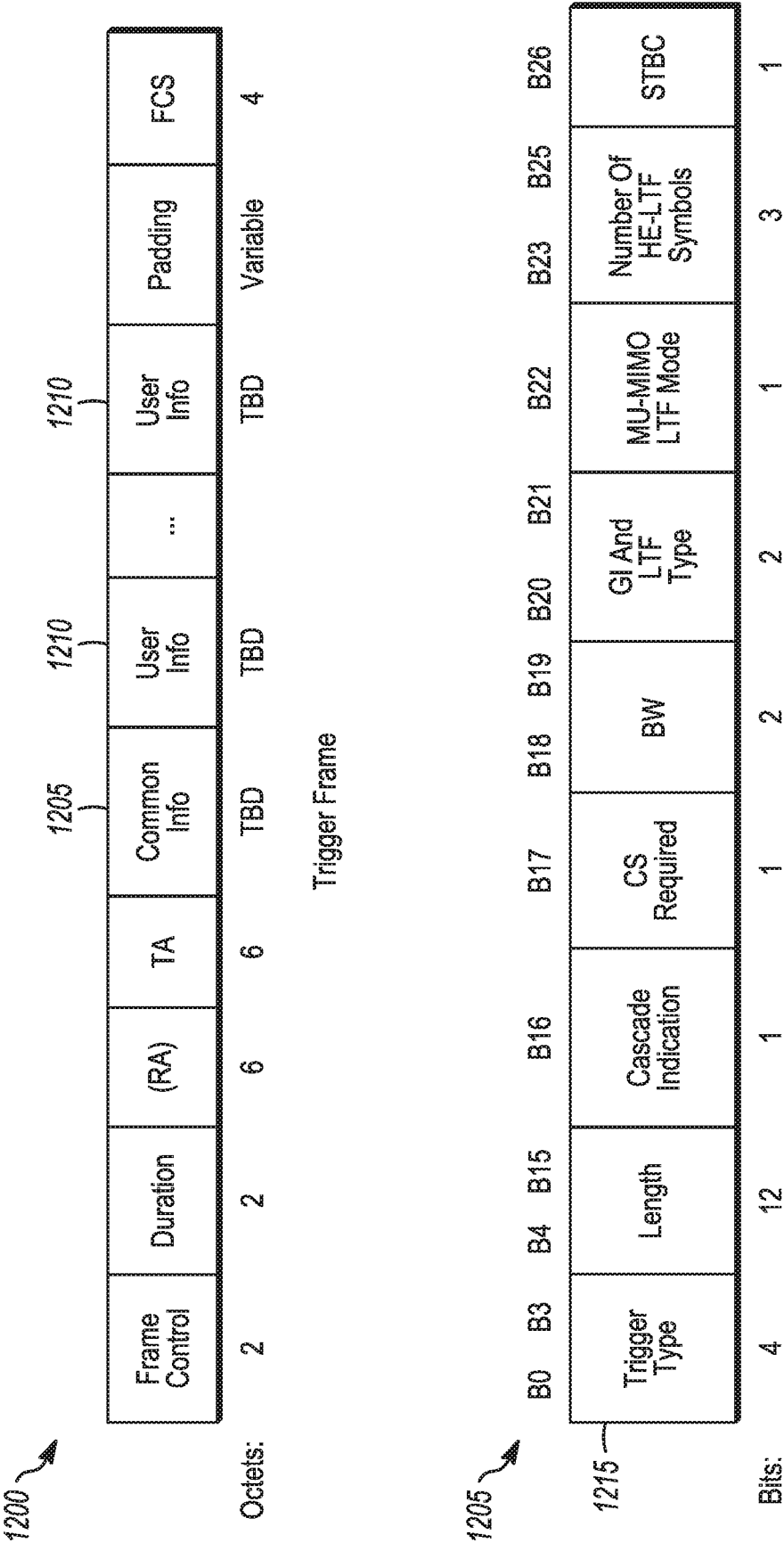


FIG. 12A

1220 ↗

Trigger Type field value	Description
0	Basic Trigger
1	Beamforming Report Poll
2	MU - BAR
3	MU - RTS
4	Buffer Status Report Poll (BSRP)
5	GCR MU - BAR
6	Bandwidth Query Report Poll (BQRP)
7 - 15	Reserved

FIG. 12B

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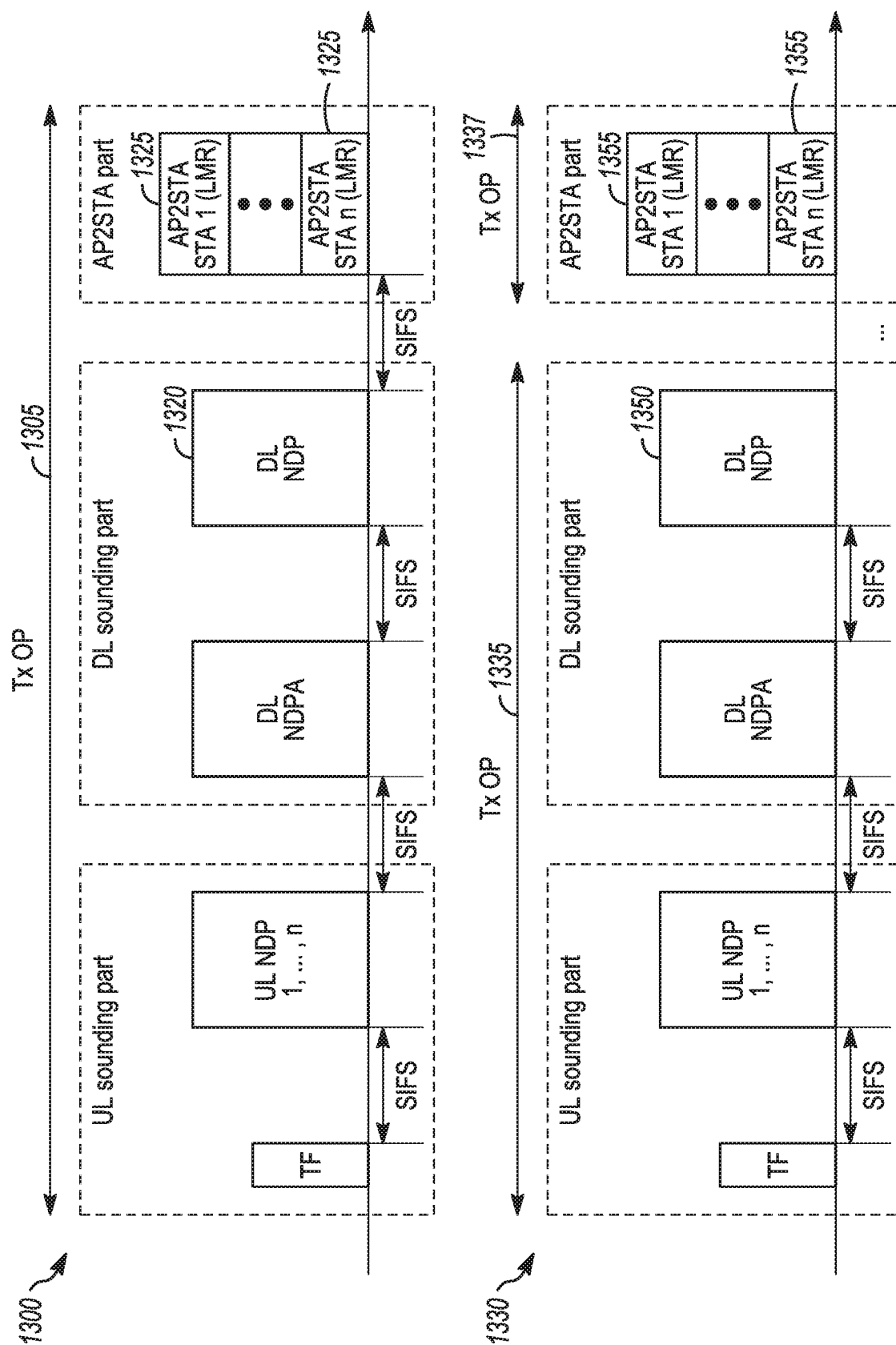


FIG. 13A

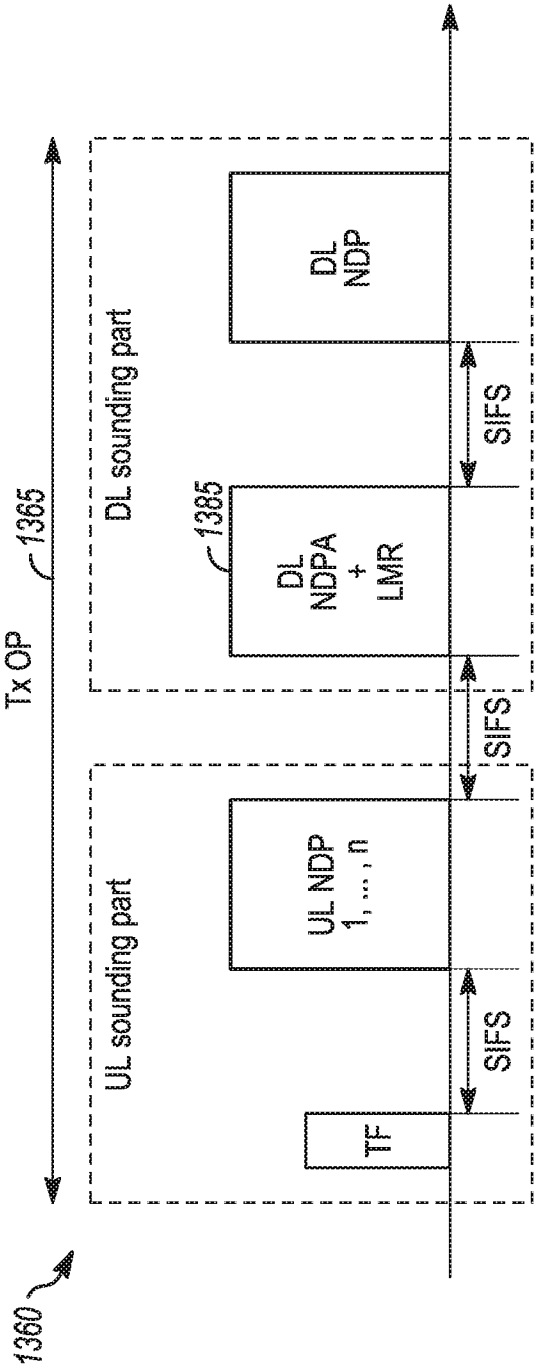


FIG. 13B

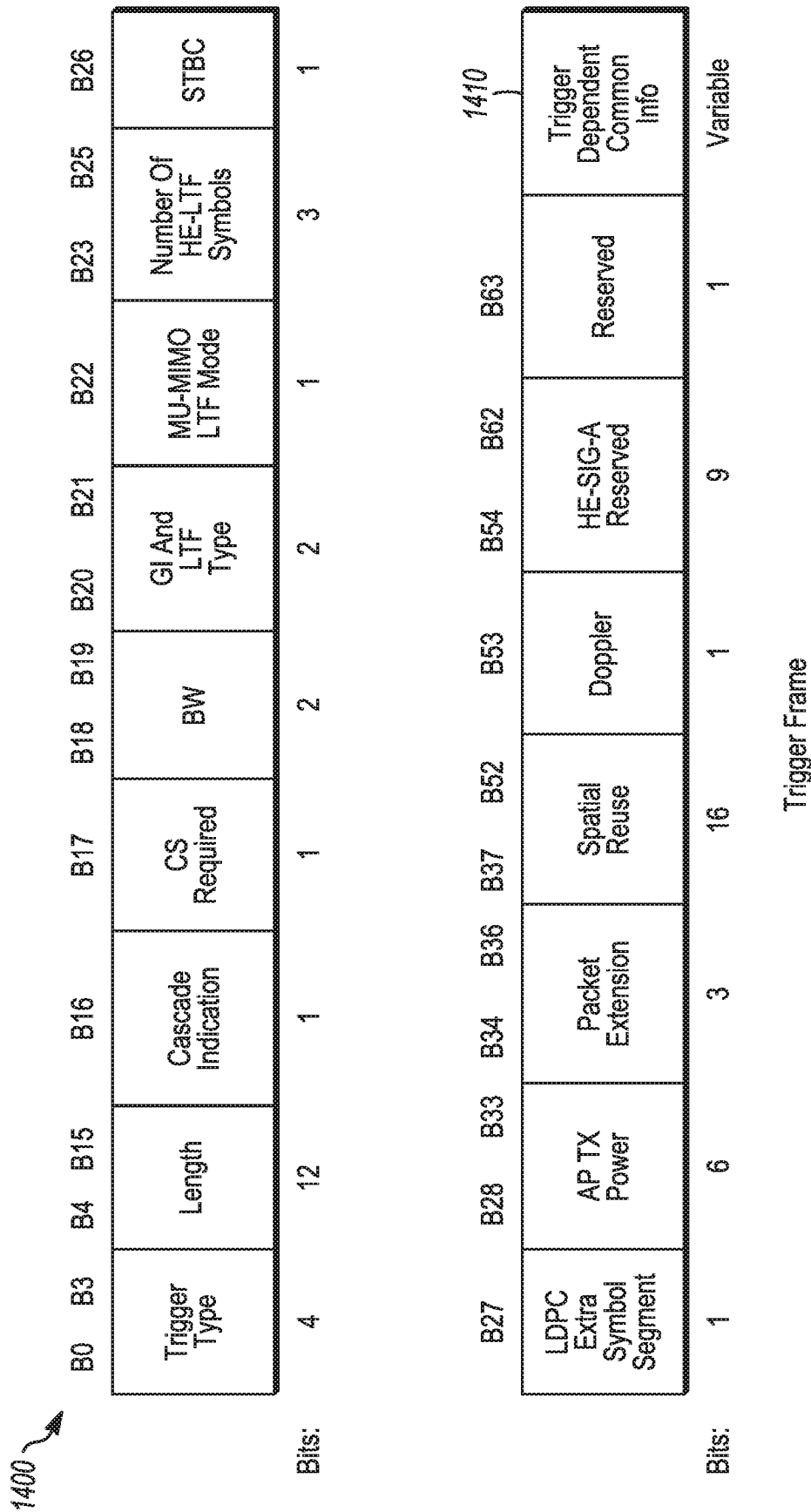


FIG. 14A

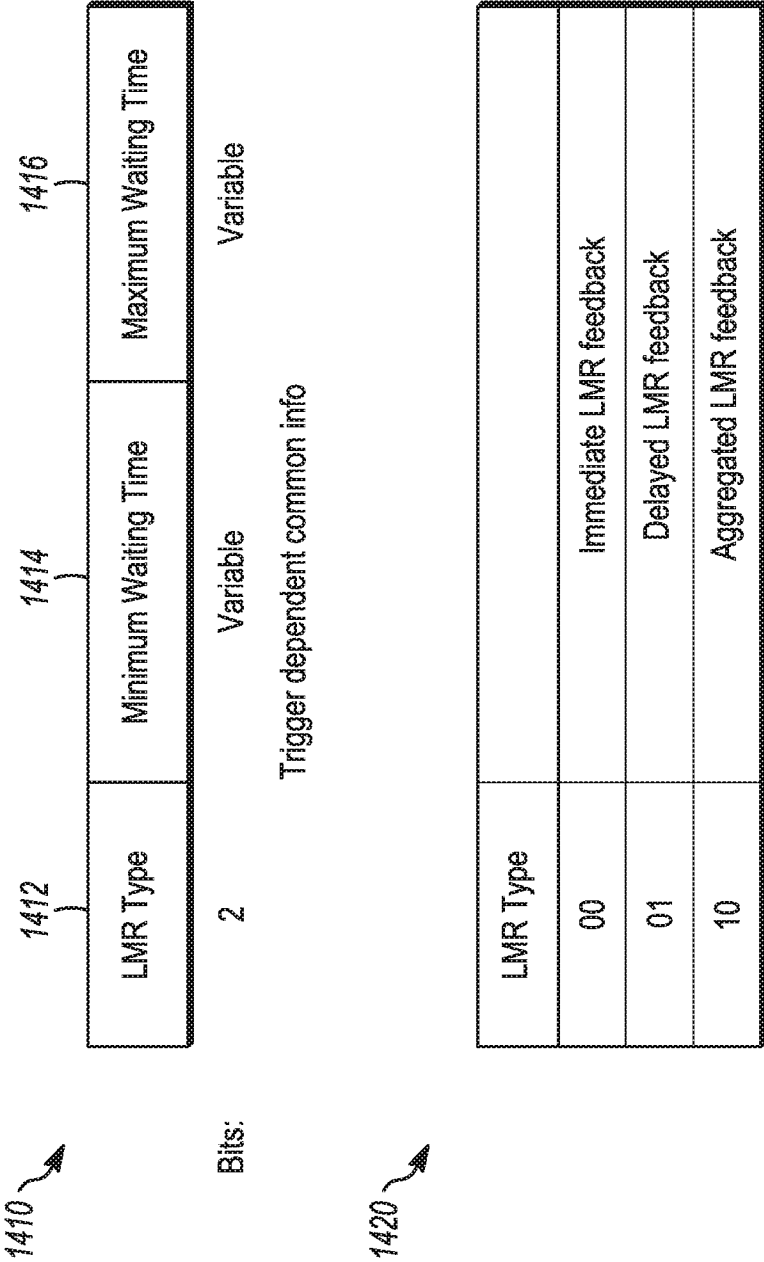


FIG. 14B

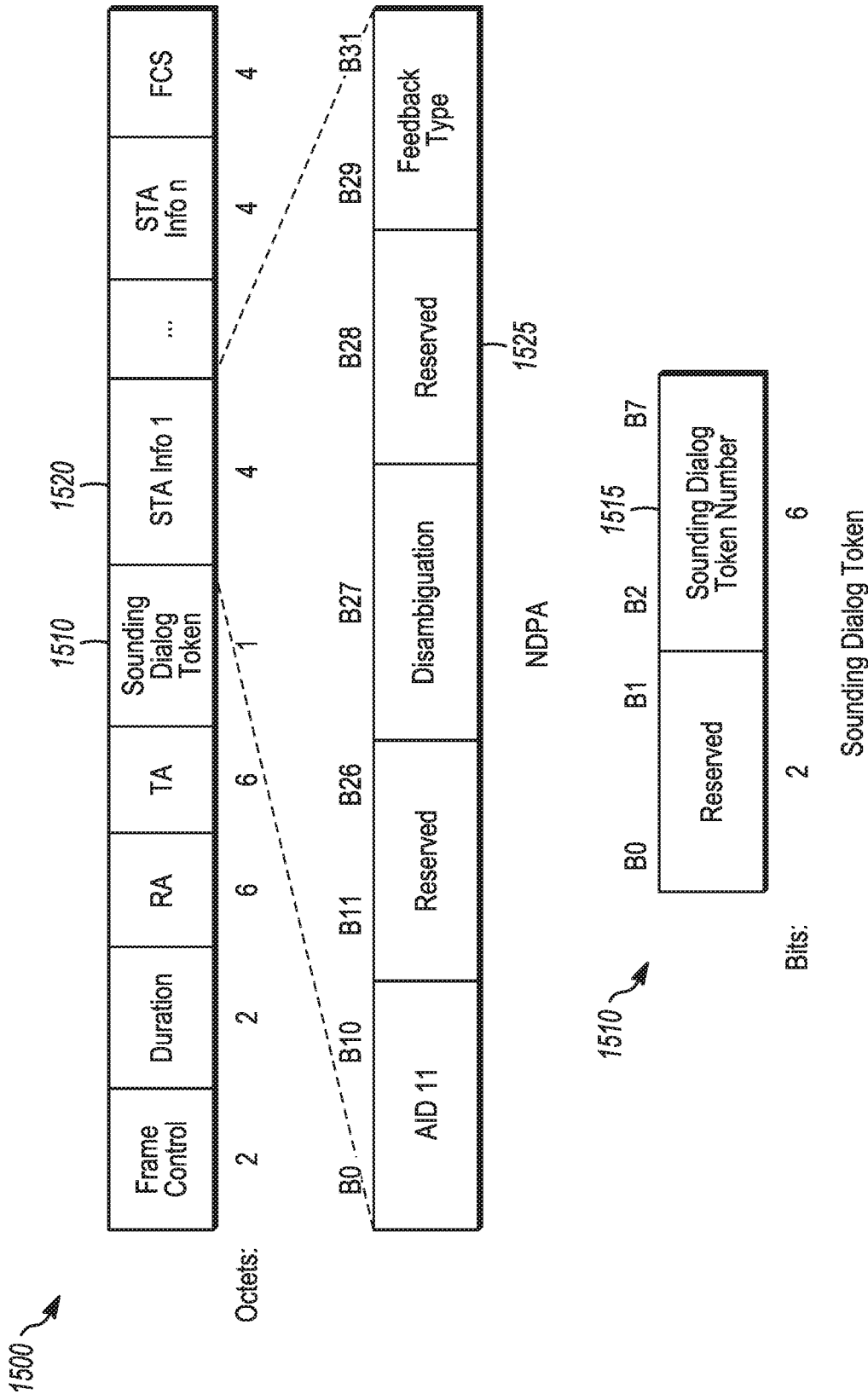


FIG. 15

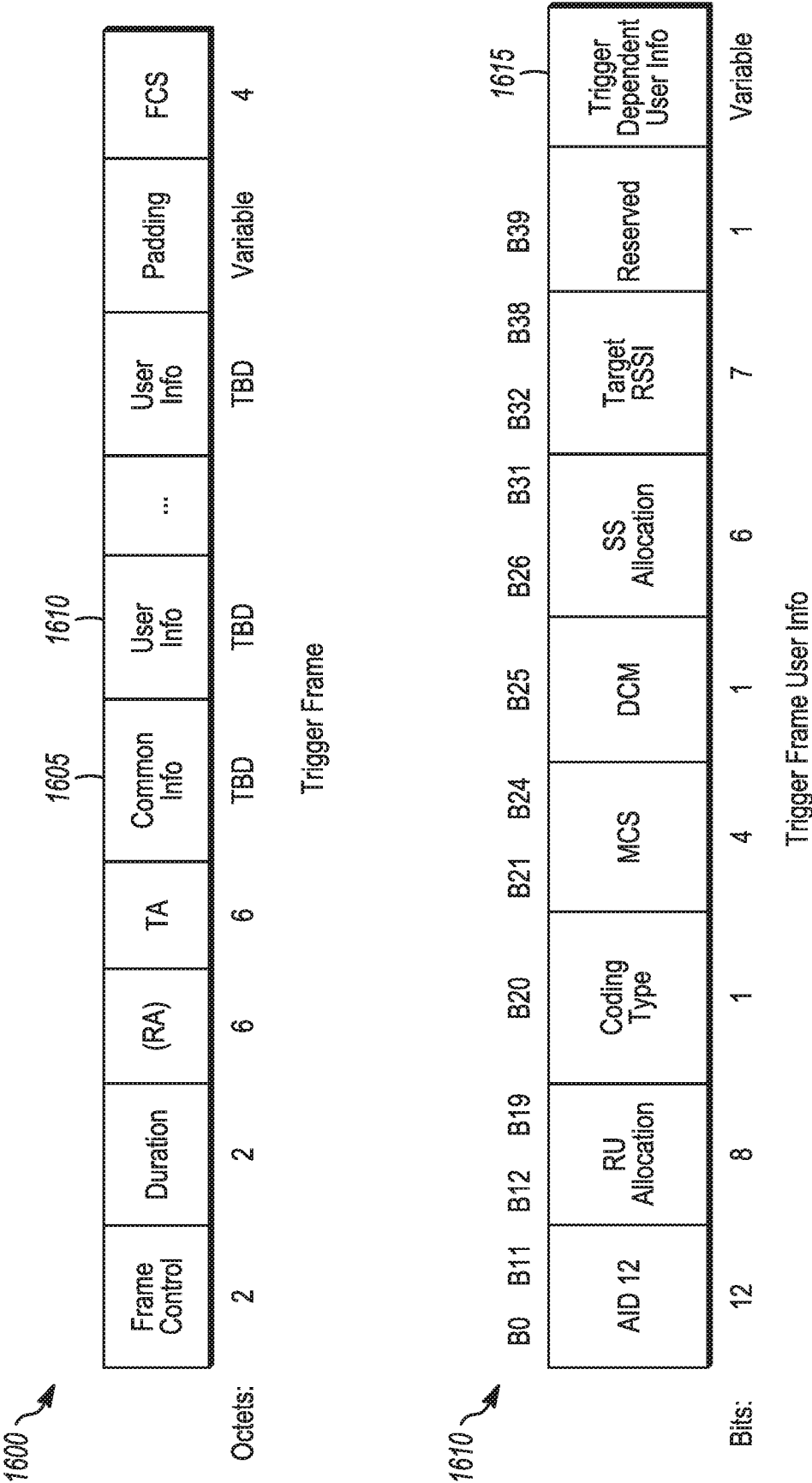


FIG. 16

A. CLASSIFICATION OF SUBJECT MATTER**H04W 64/00(2009.01)i, H04W 56/00(2009.01)i, H04L 27/26(2006.01)i, H04W 84/12(2009.01)i**

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

B. FIELDS SEARCHEDMinimum documentation searched (classification system followed by classification symbols)
H04W 64/00; H04L 5/00; H04W 24/00; G01S 5/02; H04W 56/00; H04L 27/26; H04W 84/12Documentation 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 modelsElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: location measurement reports, uplink sounding frames, downlink sounding frames, arrival times, departure times**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CHITTABRATA GHOSH et al., INTEL, 'Location Measurement Protocol for Unassociated STAs', IEEE 802.11-16/1260r0, 13 September 2016 See pages 13-14	1-30
A	CHITTABRATA GHOSH et al., INTEL, 'Location Measurement Protocol for 11ax', IEEE 802.11-16/1015r0, 26 July 2016 See pages 4, 9-10.	1-30
A	US 2014-0016485 A1 (FLOREAN CURTICAPEAN) 16 January 2014 See paragraphs [0009]-[0012]; and figure 5A.	1-30
A	WO 2013-165582 A1 (INTERDIGITAL PATENT HOLDINGS, INC.) 07 November 2013 See paragraphs [0084], [0141]-[0144], [0151]-[0153]; and figure 4.	1-30
A	KR 10-2011-0133741 A (SK TELECOM CO., LTD. et al.) 14 December 2011 See paragraphs [0058]-[0084]; and figures 7-8.	1-30

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

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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

29 March 2018 (29.03.2018)

Date of mailing of the international search report

29 March 2018 (29.03.2018)

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/063005

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014-0016485 A1	16/01/2014	CN 104429137 A EP 2873281 A1 US 8848565 B2 WO 2014-011381 A1	18/03/2015 20/05/2015 30/09/2014 16/01/2014
WO 2013-165582 A1	07/11/2013	CN 104321998 A EP 2845342 A1 JP 05898376 B2 JP 06251762 B2 JP 2015-520973 A JP 2016-154340 A KR 10-2015-0013640 A KR 10-2017-0001730 A TW 201352039 A US 2013-0286959 A1	28/01/2015 11/03/2015 06/04/2016 20/12/2017 23/07/2015 25/08/2016 05/02/2015 04/01/2017 16/12/2013 31/10/2013
KR 10-2011-0133741 A	14/12/2011	KR 10-1642266 B1	26/07/2016