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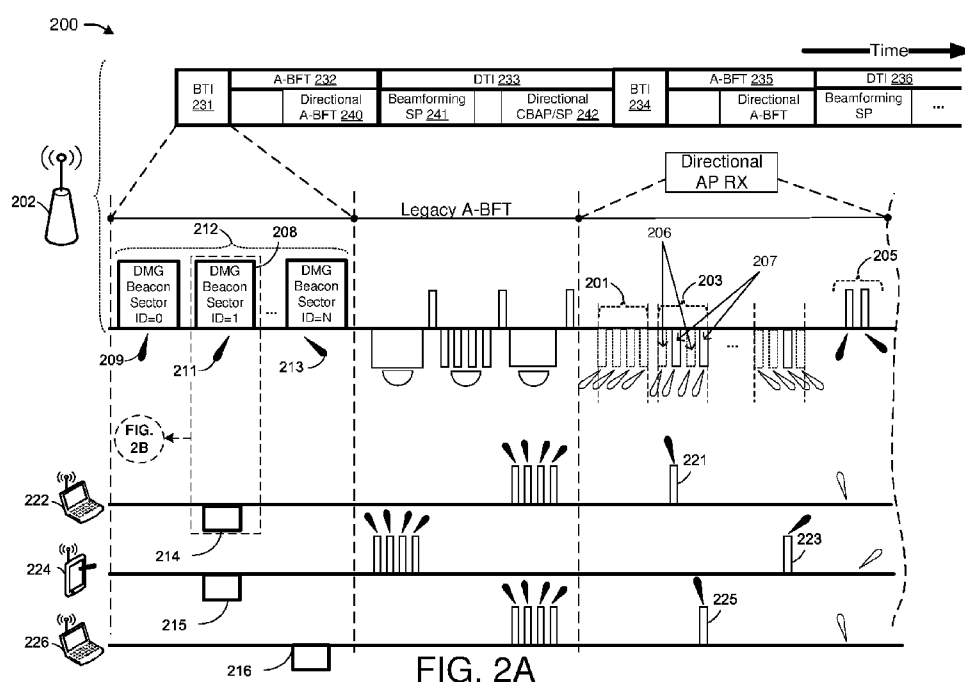
(71) Applicant: **INTEL CORPORATION** [US/US]; 2200
Mission College Boulevard, Santa Clara, California 95054
(US).

(72) Inventors: **MALTSEV, Alexander**; 1-7 Verchne-Pecherskay Str., Nizhny Novgorod, 603163 (RU). **PUDEYEV, Andrey**; ul. Osharskaya 88/217, Nizhny Novgorod, 603950 (RU). **BOLOTIN, Ilya**; Respublikanskaya, 43/5 - 6, Nizhny Novgorod, 603089 (RU). **TRAININ, Solomon**; Respublikanskaya, 43/5 - 6, Nizhny Novgorod, 603089 (RU).

(74) Agent: **GRIFFIN, Malvern U. III** et al.; Eversheds Sutherland (US) LLP, 999 Peachtree Street NE, Suite 2300, Atlanta, Georgia 30309 (US).

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(54) Title: EFFECTIVE COLLISION RESOLUTION IN ENHANCED SECTOR LEVEL SWEEP BEAMFORMING



(57) **Abstract:** This disclosure describes systems, methods, and devices related to effective collision resolution in enhanced sector-level sweep (SLS) beamforming. A device may determine a beacon frame of one or more beacon frames to be sent to one or more station devices during a first beamforming interval of one or more beamforming training intervals, wherein the beacon frame is associated with a first sector of one or more sectors of an antenna. The device may identify a sector frame received from a first station device of the one or more station devices at a first space time slot of one or more space time slots associated with the first sector. The device may determine to adjust a number of space time slots during a second beamforming interval for beamforming training based on the sector frame.

SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
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EFFECTIVE COLLISION RESOLUTION IN ENHANCED SECTOR LEVEL SWEEP BEAMFORMING

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims the benefit of U.S. Provisional Application No. 62/484,162, filed April 11, 2017, the disclosure of which is incorporated herein by reference as if set forth in full.

5 TECHNICAL FIELD

[0002] This disclosure generally relates to systems and methods for wireless communications and, more particularly, to effective collision resolution in enhanced sector level sweep (SLS) beamforming.

BACKGROUND

10 [0003] Wireless devices are becoming widely prevalent and are increasingly requesting access to wireless channels. A wireless communication network in a millimeter-wave band may provide high-speed data access for users of wireless communication devices.

BRIEF DESCRIPTION OF THE DRAWINGS

15 [0004] FIG. 1 depicts a network diagram illustrating an example network environment of an illustrative effective collision resolution in enhanced sector level sweep (SLS) beamforming, according to one or more example embodiments of the present disclosure.

[0005] FIG. 2A depicts an illustrative schematic diagram of an effective collision resolution in enhanced SLS beamforming, in accordance with one or more example embodiments of the present disclosure.

20 [0006] FIG. 2B depicts an illustrative schematic diagram of an effective collision resolution in enhanced SLS beamforming, in accordance with one or more example embodiments of the present disclosure.

[0007] FIG. 3 depicts an illustrative schematic diagram for effective collision resolution in enhanced SLS beamforming, in accordance with one or more example embodiments of the present disclosure.

25 [0008] FIG. 4A depicts a flow diagram of an illustrative process for an illustrative effective collision resolution in enhanced SLS beamforming system, in accordance with one or more embodiments of the present disclosure.

[0009] FIG. 4B depicts a flow diagram of an illustrative process for an illustrative effective collision resolution in enhanced SLS beamforming system, in accordance with one or more embodiments of the present disclosure.

[0010] FIG. 5 depicts a functional diagram of an example communication station that may be suitable for use as a user device, in accordance with one or more example embodiments of the present disclosure.

[0011] FIG. 6 depicts a block diagram of an example machine upon which any of one or more techniques (e.g., methods) may be performed, in accordance with one or more embodiments of the present disclosure.

10 **DETAILED DESCRIPTION**

[0012] Example embodiments described herein provide certain systems, methods, and devices for single user (SU) and multiuser (MU) multiple-input and multiple-output (MIMO) beamforming protocol for Wi-Fi devices in various Wi-Fi networks, including, but not limited to, IEEE 802.11ay.

15 [0013] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.

20 [0014] During communication between two devices, one or more frames may be sent and received. These frames may include one or more fields (or symbols) that may be based on IEEE 802.11 specifications, including, but not limited to, an IEEE 802.11ad specification or an IEEE 802.11ay specification. Devices may operate in multiuser multiple-input and multiple-output (MU-MIMO) technology. It is understood that MIMO facilitates multiplying
25 the capacity of a radio link using multiple transmit and receive antennas to exploit multipath propagation. MIMO provides a practical technique for sending and receiving more than one data signal on the same radio channel at the same time via multipath propagation. MU-MIMO provides a means for wireless devices to communicate with each other using multiple antennas such that the wireless devices may transmit at the same time and frequency and still be
30 separated by their spatial signatures. For example, by using MU-MIMO technology, an access point (AP) may be able to communicate with multiple devices using multiple antennas at the same time to send and receive data. An AP operating in MU-MIMO and in a 60 GHz frequency band may utilize an MU-MIMO frame to communicate with devices serviced by that AP.

[0015] Task Group ay (TGay) is currently developing an amendment that will define modifications to the IEEE 802.11 PHY and MAC to enable stations (STAs) operating in the license-exempt bands above 45 GHz to have a maximum throughput of at least 20 Gbps. Sector level sweep (SLS) procedures enable an STA to find the optimal antenna configuration with its recipient by first using all sectors and determining the optimal sector. However, this is limited to STAs that are in proximity to the personal basic service set (PBSS) control point/access point (PCP/AP). IEEE 802.11ay proposes a variety of new use cases and corresponding channel scenarios to be supported in the future standard. Some new scenarios, such as street canyon and open area, require communications between the access point (AP) and used station (STA) at distances up to 100-200m.

[0016] In the current 11ad SLS, the PCP/AP and the STA perform antenna training alternatively with the receiver's antenna pattern configured to quasi-omni mode. Since the PCP/AP may have large array(s) and transmission power, a distant STA might be able to detect the A directional multi-gigabit (DMG) beacon frame sent in a directional mode from the PCP/AP. However, if the STA is equipped with a much smaller array, it may not be able to send a response that will be detected by the AP/PCP in a quasi-omni mode. This limits the range of the AP-STA communication to the values far below the new IEEE 802.11ay requirements.

[0017] However, in a crowded areas/hotspot scenarios, the STAs can be located closely to each other, covered by the same AP's sector beam, or simply be on the same direction from the AP at different distances. In this case, the collision is possible within a timeslot designated to the specific sector in directional association beamforming training (A-BFT) or beamforming service period (SP) in data transmission interval (DTI).

[0018] Example embodiments of the present disclosure relate to systems, methods, and devices for an effective collision resolution in enhanced SLS beamforming.

[0019] In some demonstrative embodiments, one or more devices may be configured to communicate an SU or an MU-MIMO frame, for example, over a 60 GHz frequency band. The one or more devices may be configured to communicate in a mixed environment such that one or more legacy devices are able to communicate with one or more non-legacy devices. That is, devices following one or more IEEE 802.11 specifications may communicate with each other regardless of which IEEE 802.11 specification is followed.

[0020] A directional multi-gigabit (DMG) communications may involve one or more directional links to communicate at a rate of multiple gigabits per second, for example, at least 1 Gigabit per second, e.g., 7 Gigabits per second, or any other rate. An amendment to a DMG

operation in a 60 GHz band, e.g., according to an IEEE 802.11ad standard, may be defined, for example, by an IEEE 802.11ay project.

[0021] In some demonstrative embodiments, one or more devices may be configured to communicate over a next generation 60 GHz (NG60) network, an extended DMG (EDMG) network, and/or any other network. For example, the one or more devices may be configured to communicate over the NG60 or EDMG networks.

[0022] In some demonstrative embodiments, one or more devices may be configured to support the one or more mechanisms and/or features in a backwards compatible manner, for example, in a manner which may be compatible with one or more devices ("legacy devices"), which may not support these mechanisms and/or features, for example, one or more non-EDMG devices (e.g., devices configured according to an IEEE 802.11ad standard), and the like. In one example, a legacy device, for example, a DMG device, may include, may comply with, and/ or may be configured according to, a first specification, for example, an IEEE 802.11ad specification, while a non-legacy device, for example, an EDMG device, may include, may comply with, and/or may be configured according to, a second specification, for example, an IEEE 802.11ay specification.

[0023] During beamforming training of the devices, there are one or more periods. These one or more periods may include beacon transmission interval (BTI), association beamforming training (A-BFT), and data transmission interval (DTI).

[0024] In one embodiment, an effective collision resolution in an enhanced SLS beamforming system may facilitate that in an enhanced sector-level sweep (SLS) beamforming system there are two important parts. The first part is the BTI, where there are one or more transmit sector sweeps (SSW-TXs), where multiple DMG beacon frames are transmitted in different sectors associated with different directions from the AP to an STA. These multiple DMG beacon frames are the same DMG beacon frames that are transmitted on different sectors. Training fields may be appended to each of these DMG beacon frames at the end of each DMG beacon frame. These training fields are used by the receiving STA. In that sense, after the BTI, the STAs will know the best sector to be used for the station from the point of view of the AP. That is, each STA would know the best AP transmit (TX) sector and would know the best STA receive (RX) sector. The second part is the portion of the DTI referred to as a beamforming service period (SP) or any other name indicating a period where the AP is listening during one or more space time slots in a particular sector or one or more sectors of an antenna on the AP. In this part, the AP will be listening in a directional mode. Further, the STA would know when the AP will be listening in a particular direction. Antenna pattern

reciprocity is also assumed, where if the STA knows the AP's best TX sector, it will also know the AP's listening opportunity in best RX sector. For example during the BTI, if the best AP TX sector for an STA was for sector ID 1, the STA should transmit its response at the time when the AP will be listening on sector ID 1. However, other STAs may also transmit during that sector ID, which may result in collisions. For example, if there are an increased number of STAs in one sector, the probability of collisions may increase. For example, if there are four time slots in one sector, but there are 10 STAs sending their packets during that sector, then the probability of collision may be high.

[0025] In one embodiment, an effective collision resolution in enhanced SLS beamforming system may facilitate that the AP may also allocate additional time slots for directional listening purposes. After transmitting its packets in a certain direction, the STA may then enter into a listening mode in order to receive a sector acknowledgment from the AP in that same direction. The AP would then transmit a sector acknowledgment corresponding to each of the time slots and directions during which the AP received the packets from each of the STAs. The sector acknowledgment contains IDs of all discovered STAs. Therefore, all STAs that were detected by the AP, meaning that they did not have collisions, are included in the sector acknowledgment. All other STAs that were part of the collisions would not find their IDs included in the sector acknowledgment. The AP would not know about the STA process that had collisions, because it only has information about the STAs that did not have collisions.

[0026] In one embodiment, an effective collision resolution in enhanced SLS beamforming system may facilitate that STAs that did not identify their IDs in the sector acknowledgment sent by the AP may determine that collisions have occurred. Therefore, they have not completely completed the beamforming training, and should attempt to perform directional the CBAP/SP in order to contact the AP. Similarly, during that time, the STAs may be listening in the same direction they transmitted their packets to the AP. During the the CBAP/SP of the DTI, the AP may determine one or more allocations for one or more sectors. However, the allocated CBAP/SP may not be in the same sector as the STAs that were involved in collisions. The information of which sector will be allocated in the CBAP/SB may be included in the one or more beacon frames during the BTI interval. If the STA fails to negotiate because the AP allocated a different sector during the CBAP/SP then the sector of the STA would try to negotiate with the AP in the next beamforming SP.

[0027] In one embodiment, an effective collision resolution in enhanced SLS beamforming system may facilitate that an extended schedule element (e.g., EDMG or DMG extended schedule element) may contain one or more allocations if the AP determines that it needs to

add additional allocations during the directional allocations. The extended schedule element may contain information about one or more sector allocations in the directional allocation period of DTI. The AP may determine whether to have directional allocations or not based on implementation.

5 [0028] In one embodiment, the AP may determine to increase the amount of resources in the beamforming SP period of the DTI. For example, the AP may increase the number of space time slots in the next beamforming SP period of a next DTI based on information from the current beamforming SP period of a current DTI. For example, in the case of collisions during a current beamforming SP part of the DTI, the AP may learn from that and tries to prevent
10 additional collisions in the next DTI. For example, if there are many collisions during a current beamforming SP period, the AP may increase the number of space time slots in the next beamforming SP period. For example, if there were four space time slots in sector 0, where collisions occurred in the current beamforming SP, the AP may allocate a larger number than four space time slots in sector 0 in the next beamforming SP. However, this is not limited to
15 collisions. For example, if the AP determines that all space time slots in a sector of a current beamforming SP period are used, the AP may decide and determine to increase the number of space time slots in a next beamforming SP of a next DTI. In that sense, the number of space time slots may be variable for different directions for different sectors based on usage and collisions. This information may be sent in the BTI period in each of the multiple beacon
20 frames. Each of the beacons will have information about the start time for listening on a corresponding sector. There will sector specific fields in each of the beacon frames.

[0029] In one embodiment, an effective collision resolution in enhanced SLS beamforming system may provide an enhanced beamforming flow based on the directional transmission and directional reception both for an access point (AP) and a station device (STA). For such
25 directional STA to AP transmission organization, two options may be possible, one for introducing a directional A-BFT or a beamforming SP in the DTI. This directional transmission solves two important issues, namely, the STA's range extension and synchronization collision avoidance by using spatial (angular) STA separation.

[0030] In one embodiment, an effective collision resolution in enhanced SLS beamforming
30 system may facilitate a new method for EDMG STA collision resolution and avoidance for the enhanced SLS beamforming flow described above. The collision resolution and avoidance may introduce an information element (IE), which is included in the sector acknowledgment frame (broadcasted by the AP to each sector where the STAs were discovered or even energy detection took place), and specifies the IDs of the STAs that were already identified by the AP.

The present invention specifies the behavior of the EDMG STA after the reception of a sector acknowledgment frame. All non-associated STAs in a given sector may continue the negotiation process in the next available period with directional AP RX: the directional CBAP/SP or the next directional A-BFT/beamforming SP.

5 [0031] In one embodiment, an effective collision resolution in enhanced SLS beamforming system may also introduce the solution for the AP to adaptively increase the amount of resources (space time slots) in the crowded sector at the expense of the time slots in the desolate sectors.

10 [0032] The legacy 802.11ad approach to beamforming is based on the omni-directional reception of the STA response (when the STA performs R-TXSS) and the introduction of the multiple time SS (Sector Sweep) slots with random access of all STAs for collision avoidance.

[0033] In one embodiment, the effective collision resolution in enhanced SLS beamforming system may be based on the STA to AP directional transmission and reception in special directional A-BFT or beamforming SP periods, where the STAs are separated at the
15 AP by the angles of arrival (sectors) and, additionally, by the introduction of a few time slots to resolve collisions within each sector. This may allow more efficient STA to AP communication with a range extension of up to hundreds of meters, but the process of collision resolution inside of each sector in crowded hotspots may not be optimized.

[0034] In one embodiment, the effective collision resolution in enhanced SLS
20 beamforming system may introduce additional adaptive capabilities for the EDMG AP and STAs for efficient collision resolution in the case of crowded hotspot scenarios. The process of beamforming and AP-STA negotiation may become faster and less chaotic, allowing the resolution of collisions between many closely spaced STAs even if they are located in a faraway zone and can be reached only through the STA-AP directional transmission and
25 reception.

[0035] The above descriptions are for purposes of illustration and are not meant to be limiting. Numerous other examples, configurations, processes, etc., may exist, some of which are described in greater detail below. Example embodiments will now be described with reference to the accompanying figures.

30 [0036] FIG. 1 is a network diagram illustrating an example network environment, according to some example embodiments of the present disclosure. Wireless network 100 may include one or more user device(s) 120 and one or more access point(s) (AP) 102, which may communicate in accordance with IEEE 802.11 communication standards, such as the IEEE

802.11ad and/or IEEE 802.11ay specifications. The user device(s) 120 may be mobile devices that are non-stationary and do not have fixed locations.

[0037] In some embodiments, the user device(s) 120 and the AP 102 may include one or more computer systems similar to that of the functional diagram of FIG. 5 and/or the example machine/system of FIG. 6.

[0038] One or more illustrative user device(s) 120 and/or AP 102 may be operable by one or more user(s) 110. It should be noted that any addressable unit may be a station (STA). An STA may take on multiple distinct characteristics, each of which shape its function. For example, a single addressable unit might simultaneously be a portable STA, a quality-of-service (QoS) STA, a dependent STA, and a hidden STA. The one or more illustrative user device(s) 120 and the AP(s) 102 may be STAs. The one or more illustrative user device(s) 120 and/or AP 102 may operate as a personal basic service set (PBSS) control point/access point (PCP/AP). The user device(s) 120 (e.g., 124, 126, or 128) and/or AP 102 may include any suitable processor-driven device including, but not limited to, a mobile device or a non-mobile, e.g., a static, device. For example, user device(s) 120 and/or AP 102 may include, for example, a DMG device, an EDMG device, a UE, an MD, a station (STA), an access point (AP), a personal computer (PC), a wearable wireless device (e.g., bracelet, watch, glasses, ring, etc.), a desktop computer, a mobile computer, a laptop computer, an ultrabook™ computer, a notebook computer, a tablet computer, a server computer, a handheld computer, a handheld device, an internet of things (IoT) device, a sensor device, a PDA device, a handheld PDA device, an on-board device, an off-board device, a hybrid device (e.g., combining cellular phone functionalities with PDA device functionalities), a consumer device, a vehicular device, a non-vehicular device, a mobile or portable device, a non-mobile or non-portable device, a mobile phone, a cellular telephone, a PCS device, a PDA device which incorporates a wireless communication device, a mobile or portable GPS device, a DVB device, a relatively small computing device, a non-desktop computer, a “carry small live large” (CSLL) device, an ultra mobile device (UMD), an ultra mobile PC (UMPC), a mobile internet device (MID), an “origami” device or computing device, a device that supports dynamically composable computing (DCC), a context-aware device, a video device, an audio device, an A/V device, a set-top-box (STB), a blu-ray disc (BD) player, a BD recorder, a digital video disc (DVD) player, a high definition (HD) DVD player, a DVD recorder, a HD DVD recorder, a personal video recorder (PVR), a broadcast HD receiver, a video source, an audio source, a video sink, an audio sink, a stereo tuner, a broadcast radio receiver, a flat panel display, a personal media player (PMP), a digital video camera (DVC), a digital audio player, a speaker, an audio

receiver, an audio amplifier, a gaming device, a data source, a data sink, a digital still camera (DSC), a media player, a smartphone, a television, a music player, or the like.

[0039] Any of the user device(s) 120 (e.g., user devices 124, 126, 128), and AP 102 may be configured to communicate with each other via one or more communications networks 130 and/or 135 wirelessly or wired. Any of the communications networks 130 and/or 135 may include, but not limited to, any one of a combination of different types of suitable communications networks such as, for example, broadcasting networks, cable networks, public networks (e.g., the Internet), private networks, wireless networks, cellular networks, or any other suitable private and/or public networks. Further, any of the communications networks 130 and/or 135 may have any suitable communication range associated therewith and may include, for example, global networks (e.g., the Internet), metropolitan area networks (MANs), wide area networks (WANs), local area networks (LANs), or personal area networks (PANs). In addition, any of the communications networks 130 and/or 135 may include any type of medium over which network traffic may be carried including, but not limited to, coaxial cable, twisted-pair wire, optical fiber, a hybrid fiber coaxial (HFC) medium, microwave terrestrial transceivers, radio frequency communication mediums, white space communication mediums, ultra-high frequency communication mediums, satellite communication mediums, or any combination thereof.

[0040] Any of the user device(s) 120 (e.g., user devices 124, 126, 128), and AP 102 may include one or more communications antennae. Communications antenna may be any suitable type of antenna corresponding to the communications protocols used by the user device(s) 120 (e.g., user devices 124, 124 and 128), and AP 102. Some non-limiting examples of suitable communications antennas include Wi-Fi antennas, Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards compatible antennas, directional antennas, non-directional antennas, dipole antennas, folded dipole antennas, patch antennas, multiple-input multiple-output (MIMO) antennas, or the like. The communications antenna may be communicatively coupled to a radio component to transmit and/or receive signals, such as communications signals to and/or from the user device(s) 120.

[0041] Any of the user device(s) 120 (e.g., user devices 124, 126, 128), and/or AP 102 may include any suitable radio and/or transceiver for transmitting and/or receiving radio frequency (RF) signals in the bandwidth and/or channels corresponding to the communications protocols utilized by any of the user device(s) 120 and/or AP 102 to communicate with each other. The radio components may include hardware and/or software to modulate and/or demodulate communications signals according to pre-established transmission protocols. The radio

components may further have hardware and/or software instructions to communicate via one or more Wi-Fi and/or Wi-Fi direct protocols, as standardized by the Institute of Electrical and Electronics Engineers (IEEE) 802.11 standards. In certain example embodiments, the radio component, in cooperation with the communications antennas, may be configured to
5 communicate via 2.4 GHz channels (e.g., 802.11b, 802.11g, 802.11n, 802.11ax), 5 GHz channels (e.g., 802.11n, 802.11ac, 802.11ax), or 60 GHz channels (e.g., 802.11ad). In some embodiments, non-Wi-Fi protocols may be used for communications between devices, such as Bluetooth, dedicated short-range communication (DSRC), Ultra-High Frequency (UHF) (e.g., IEEE 802.11af, IEEE 802.22), white band frequency (e.g., white spaces), or other packetized
10 radio communications. The radio component may include any known receiver and baseband suitable for communicating via the communications protocols. The radio component may further include a low noise amplifier (LNA), additional signal amplifiers, an analog-to-digital (A/D) converter, one or more buffers, and digital baseband.

[0042] Some demonstrative embodiments may be used in conjunction with a wireless
15 communication network communicating over a frequency band of 60 GHz. However, other embodiments may be implemented utilizing any other suitable wireless communication frequency bands, for example, an extremely high frequency (EHF) band (the millimeter wave (mmWave) frequency band), e.g., a frequency band within the frequency band of between 20 GHz and 30 0GHz, a WLAN frequency band, a WPAN frequency band, a frequency band
20 according to the WGA specification, and the like.

[0043] The phrases “directional multi-gigabit” (DMG) and “directional band” (DBand), as used herein, may relate to a frequency band wherein the channel starting frequency is above 45 GHz. In one example, DMG communications may involve one or more directional links to communicate at a rate of multiple gigabits per second, for example, at least 1 gigabit per
25 second, e.g., 7 gigabits per second, or any other rate.

[0044] In some demonstrative embodiments, the user device(s) 120 and/or the AP 102 may be configured to operate in accordance with one or more specifications, for example, including, one or more IEEE 802.11 specifications, e.g., an IEEE 802.11ad specification, an IEEE 802.11ay specification, and/or any other specification and/or protocol. For example, an
30 amendment to a DMG operation in the 60 GHz band, e.g., according to an IEEE 802.11ad standard, may be defined, for example, by an IEEE 802.11ay project.

[0045] Some communications over a wireless communication band, for example, a DMG band, may be performed over a single channel bandwidth (BW). For example, the IEEE

802.11ad specification defines a 60 GHz system with a single channel bandwidth (BW) of 2.16 GHz, which is to be used by all stations (STAs) for both transmission and reception.

[0046] In some demonstrative embodiments, devices 102 and/or 120 may be configured to implement one or more mechanisms, which may, for example, be able to extend a single-channel BW scheme, e.g., according to the IEEE 802.11ad specification, for higher data rates and/or increased capabilities.

[0047] Some specifications, e.g., an IEEE 802.11ad specification, may be configured to support a single user (SU) system, in which an STA cannot transmit frames to more than a single STA at a time. Such specifications may not be able, for example, to support an STA transmitting to multiple STAs simultaneously, for example, using a multi-user (MU) multiple-input multiple-output (MIMO) (MU-MIMO) scheme, e.g., a downlink (DL) MU-MIMO, or any other MU scheme.

[0048] In some demonstrative embodiments, the user device(s) 120 and/or the AP 102 may be configured to implement one or more MU mechanisms. For example, the user device(s) 120 and/or the AP 102 may be configured to implement one or more MU mechanisms, which may be configured to enable MU communication of DL frames using an MIMO) scheme, for example, between a device, e.g., the AP 102, and a plurality of user devices, e.g., including user device(s) 120 and/or one or more other devices.

[0049] In some demonstrative embodiments, the user device(s) 120 and/or the AP 102 may be configured to communicate over a Next Generation 60 GHz (NG60) network, an Extended DMG (EDMG) network, and/or any other network. For example, the user device(s) 120 and/or the AP 102 may be configured to communicate MIMO, e.g., DL MU-MIMO, transmissions and/or use channel bonding for communicating over the NG60 and/or EDMG networks.

[0050] In some demonstrative embodiments, the user device(s) 120 and/or the AP 102 may be configured to support one or more mechanisms and/or features, for example, channel bonding, single user (SU) MIMO, and/or MU-MIMO, in accordance with an EDMG standard, an IEEE 802.11ay standard and/or any other standard and/or protocol.

[0051] In one embodiment, and with reference to FIG. 1, an initiator (e.g., the AP 102) may be configured to communicate using an SU and/or MU-MIMO technique, for example, over a 60 GHz frequency band with one or more responders (e.g., non-AP STAs, such as the user devices 120).

[0052] For example, in order for the AP 102 to establish an MU-MIMO communication with two devices (e.g., user device 124 and user device 128), the AP 102 may need to perform beamforming training with the user device 124 and the user device 128 in order to determine

beams 104 and 106 that the AP 102 and the user device 124 and the user device 128 may use during communication, respectively. It is understood that the above descriptions are for purposes of illustration and are not meant to be limiting.

[0053] FIG. 2A depicts an illustrative schematic diagram 200 of an effective collision resolution in enhanced SLS beamforming, in accordance with one or more example embodiments of the present disclosure.

[0054] Referring to FIG. 2A, there are shown beamforming training intervals using directional TX and RX between an AP 202 (or a PCP) and user devices 222, 224 and 226. In this scenario, user devices 222, 224 and 226 may be EDMG or DMG devices. The beamforming training intervals include a beacon transmission interval (BTI) 231, a legacy association beamforming training (A-BFT), which is included in the A-BFT 232, and a data transmission interval (DTI) 233. Since these are intervals, the next BTI may be BTI 234, the next A-BFT is A-BFT 235 and the next DTI is DTI 236. If a user device failed to train and negotiate with an AP during the BTI 231, the A-BFT 232 and the DTI 233, the user device may attempt to successfully negotiate with the AP during the BTI 234, the A-BFT 235, and the DTI 236.

[0055] The AP 202 may be an initiator device that may perform a transmit and initiator sector sweep (I-TXSS) during the BTI interval by sending one or more directional beacon frames (e.g., DMG beacon frames 212) to one or more responder STAs (e.g., user device 222). These DMG beacon frames 212 may be associated with one or more directions. For example, a DMG beacon with ID = 0 may have a direction 209, while the DMG beacon frame 208, which may have an ID = 1, may have a direction 211, and a DMG beacon frame with ID = N (where N is a positive integer), may have a direction 213 and so on.

[0056] The user devices may receive in at least one of a non-directional mode (e.g., quasi-omni mode) or a directional mode in the BTI interval. The reception may be depicted as frames 214, 215 and 216 at the user devices 222, 224 and 226, respectively. In the directional mode, the user devices may need to listen directionally for signals coming from the initiator device (e.g., the AP/PCP 202). It should be understood that the STAs and the user devices may be non-AP devices and will be used interchangeably.

[0057] In crowded areas/hotspot scenarios the user devices may be close to each other, covered by the same antenna sector of the AP, or may just be on the same direction from the AP 202 at different distances. In this case, collisions may occur within a space time slot designated to the specific sector in the directional A-BFT 240 (in A-BFT 232) or the beamforming SP 241 (in the DTI 233). In case of a collision (e.g., simultaneous transmissions

from different user devices) of the SSW frame transmissions (e.g., SSW frames 221, 223, and 225) during the directional AP RX interval, which could be in the directional A-BFT 240 or the beamforming SP 241, the AP may successfully process only one transmission (or maybe none), probably from the closely spaced user device with the strongest signal. For example, the SSW frames 221 and 225 may be received on sector 203 during space time slots 207. However, space time slots 206 of sector 203 may be empty, meaning that nothing was received from the user devices during those times.

[0058] To avoid further collisions, the AP may inform the user devices in the desired sector, which user devices were discovered and associated, and which should try to perform beamforming in the next possible access period with the directional AP RX. For example, the AP 202 may send a sector feedback 205, which may include sector acknowledgment frames that are acknowledgments to the received SSWs that were received during one of the sectors during the directional AP RX. Since the user device 222 sent the SSW frame 221 that was successfully received by the AP 202 in sector 203, the AP 202 may send a sector acknowledgment frame to the user device 222.

[0059] In one embodiment, a new information element (IE) may be included in the sector feedback 205 that contains IDs of all discovered user devices (e.g., user devices 222, 224 and 226). The user device behavior after reception of this sector feedback 205 with the new IE may be that if the user device finds its own user device ID in the IE, it assumes that beamforming training is finished, and it may start data transmission in a usual way. If the user device ID is absent in the IE, the user device would continue the negotiation process in the next possible opportunity. The next possible opportunity may be in the directional CBAP/SP 242 of the DTI 233. The user device may check the extended schedule element that would have been included in a beacon frame received by the user device during the BTI 231. The user device may determine whether the extended schedule element includes allocations information during a portion of the DTI 233. That portion of the DTI 233 may be a directional service period (e.g., beamforming SP 241) or a contention-based access period (e.g., directional CBAP/SP 242). If the user device determines that the extended schedule element did not include allocations information for a certain sector, which indicates that a directional CBAP/SP was not allocated, then the user device must perform additional negotiation with the AP.

[0060] Moreover, to avoid collisions during the next directional A-BFT/beamforming SP, the AP 202 may adaptively increase the amount of resources (space time slots) in the crowded sector at the expense of the time slots of the desolate sectors (sectors that were not used, e.g., sector 201). To support the unequal duration of different sector reception, special information

should be sent in a DMG beacon frame (e.g., DMG beacon frame 208). DMG beacon frame 208 transmitted in AP sector i may include the start time of the first space time slot allocated for AP sector i and the end time of the last space time slot allocated for AP sector i. Based on this information, the user device can calculate the exact number of space time slots available in AP sector i. It is understood that the above descriptions are for purposes of illustration and are not meant to be limiting.

[0061] FIG. 2B depicts an illustrative schematic diagram of an effective collision resolution in enhanced SLS beamforming system, in accordance with one or more example embodiments of the present disclosure.

[0062] Referring to FIG. 2B, there is shown the AP/PCP 202 of FIG. 2, as an initiator device, that may perform a transmit and initiator sector sweep (I-TXSS) during the BTI interval by sending one or more directional beacon frames (e.g., DMG beacon frames 212 of FIG. 2A) to one or more responder STAs (e.g., user device 222). These DMG beacon frames 212 may be associated with one or more directions. For example, the DMG beacon with ID = 0 may have a direction 209, while the DMG beacon frame 208, which may have an ID = 1, may have a direction 211, and a DMG beacon frame with ID = N (where N is a positive integer) may have a direction 213 and so on. It should be understood that the STAs and user devices may be non-AP devices and will be used interchangeably.

[0063] In one embodiment, the effective collision resolution in enhanced SLS beamforming system may define a directional beacon frame (e.g., DMG beacon 208) to append a training (TRN-R) field 254 to one or more fields of the directional beacon frame. For example, the DMG beacon frame 208 may include, at least in part, a legacy short training field (L-STF), a legacy channel estimation (L-CE), a legacy header (L-Header), a data field, an automatic gain control (AGC), and an appended TRN-R field 254.

[0064] In one embodiment, the effective collision resolution in enhanced SLS beamforming system may facilitate that a responder device (e.g., user device 222) may receive in at least one of a non-directional mode (e.g., quasi-omni mode) or a directional mode in the BTI interval. For example, the user device 222 may be able to receive in non-directional receive mode 258 and/or a directional mode 256. In the directional mode 256, the responder device (e.g., user device 222) may need to listen directionally for signals coming from the initiator device (e.g., the AP/PCP 202).

[0065] The TRN-R field 254 may facilitate the training of a responder's receive (RX) sectors. As shown in FIG. 2B, a TRN-R field 254 is appended to the DMG beacon frame 208 to allow the training of the user device 222's RX sectors. This may allow the user device 222

to discover its best RX sector. The TRN-R field 254 may include one or more training sequences that may help the user device 222 to identify an operating sector (e.g., best RX sector) to be used when transmitting in later intervals to the AP/PCP 202 in a particular direction.

5 [0066] In one embodiment, the AP/PCP 202 may transmit DMG beacon frames over different antenna sectors. The STAs may listen for the SSW frames in the non-directional mode. In this way, the best TX sector of the AP/PCP 202 may be determined. Due to antenna reciprocity, the best RX sector for the AP/PCP 202 may also be determined. On the other hand, the AP/PCP 202 may append training fields (TRN-Rs) at the end of each beacon frame, and
10 for each training field, an STA may sweep its receiving antenna sectors to determine its best RX sector, then due to antenna reciprocity, the STAs also may determine their best TX sectors.

[0067] The user device 222 may determine its own best RX sector, which may be aligned with the best TX sector of the AP/PCP 202. The same is true for the best TX sector of the user device 222 being aligned with the best RX sector of the AP/PCP 202 because of the antenna
15 reciprocity presumption. Antenna reciprocity means that a best transmit sector is also the best receiving sector. If a transceiver has TX-RX sector alignment, discovering the best RX sector for the transceiver may mean finding the best TX sector (applicable for both APs and STAs) and selecting the corresponding RX sector. It is understood that the above descriptions are for purposes of illustration and are not meant to be limiting.

20 [0068] FIG. 3 depicts an illustrative schematic diagram 300 for effective collision resolution in enhanced SLS beamforming, in accordance with one or more example embodiments of the present disclosure.

[0069] Referring to FIG. 3, there is shown a flowchart 300 that illustrates the behavior of an STA during beamforming training with an AP in a sector i associated with one or more AP
25 antennas, where i is a positive integer. The STA may be an EDMG STA. During beamforming training of the devices, there are one or more periods. These one or more periods may include a beacon transmission interval (BTI), an association beamforming training (A-BFT), and a data transmission interval (DTI).

[0070] At block 301, the AP may have received one or more SSWs from one or more STAs
30 in different space time slots of a sector i . This may occur during a beamforming SP of a DTI or during a directional A-BFT of the A-BFT interval.

[0071] At block 302, the AP may broadcast sector acknowledgment frames to the one or more STAs. The sector acknowledgment frame may contain the IDs of all the STAs which were detected in sector i where the STAs had sent their SSWs to the AP.

[0072] At block 303, since the sector acknowledgment frames are broadcast, the STAs would receive those frames and decode them. For example, an STA may receive a sector acknowledgment frame and determine whether its STA ID is included in the STA ID list included in the sector acknowledgment frame. This is mainly to determine whether the AP has
5 acknowledged a received SSW from that STA. If the STA finds itself in the STA ID list included in the sector acknowledgment frame, then the STA will continue to access the network because beamforming training is established.

[0073] At block 305, however, if the STA determines that it did not find its STA ID in the STA ID list included in the sector acknowledgment frame, this may be an indication that the
10 STA's SSW may not have been successfully received by the AP. This may be due to collisions or other network issues. In that case, in order for the STA to complete its beamforming training, the STA may then perform additional steps.

[0074] At block 306, the STA may then check the extended schedule element that would have been included in a beacon frame received by the STA during the beacon transmission
15 interval (BTI). The STA may determine whether the extended schedule element includes allocations information during a portion of the DTI. That portion of the DTI may be a directional service period or a contention-based access period (CBAP). At block 307, if the STA determines that the extended schedule element did not include allocations information for sector i, which indicates that a directional SP/CBAP was not allocated, then the STA must
20 perform additional negotiation with the AP.

[0075] At block 308, since the STA determined that the extended schedule element did not include allocations information for a sector i, the STA may try to negotiate with the AP in the next beamforming SP/directional A-BFT, which is part of the next DTI.

[0076] At block 310, if negotiation succeeded, the STA's beamforming training is
25 established between the STA and the AP, and the STA is able to access the network (at block 311).

[0077] At block 309, if the negotiation failed, the STA's beamforming training is considered incomplete, and therefore the STA restarts the process at block 301.

[0078] At block 312, after the STA checks the extended schedule element and determines
30 that a directional SP/CBAP allocation was allocated for sector i, the STA may proceed with the beamforming training.

[0079] At block 313, the STA may try to negotiate with the AP in the scheduled directional SP/CBAP allocation.

[0080] At block 314, if the negotiation was successful, the STA made then access the network because beamforming training is established.

[0081] At block 315, if the negotiation failed, the STA may continue to block 308, where the STA may try to negotiate with the AP in the next beamforming SP/directional A-BFT, which is part of the next DTI. If the negotiation is successful, the STA may then access the network because beamforming training is established.

[0082] It is understood that the above descriptions are for purposes of illustration and are not meant to be limiting.

[0083] FIG. 4A illustrates a flow diagram of an illustrative process 400 for an illustrative effective collision resolution in enhanced SLS beamforming system, in accordance with one or more example embodiments of the present disclosure.

[0084] At block 402, a device (e.g., the user device(s) 120 and/or the AP 102 of FIG. 1) may determine a beacon frame of one or more beacon frames to be sent to one or more station devices during a first beamforming interval of one or more beamforming training intervals, wherein the beacon frame is associated with a first sector of one or more sectors of an antenna. For example, during beamforming training for devices, there are one or more periods. These one or more periods may include BTI, A-BFT, and DTI. In an enhanced sector-level sweep (SLS) beamforming system, there are two important parts. The first part is the BTI, where there are one or more transmit sector sweeps (SSW-TXs), where multiple DMG beacon frames are transmitted in different sectors associated with different directions from the AP to an STA. These multiple DMG beacon frames are a same DMG beacon frame that is transmitted on different sectors. Training fields may be appended to each of these DMG beacon frames at the end of each DMG beacon frame. These training fields are used by the receiving STA. In that sense, after the BTI, the STAs will know the best sector to be used for the station from the point of view of the AP. That is, each STA would know the best AP TX sector and would know the best STA RX sector. The second part is the portion of the DTI referred to as the beamforming service period (SP) or any other name indicating a period where the AP is listening during one or more space time slots in a particular sector or one or more sectors of an antenna on the AP. In this part, the AP will be listening in a directional mode. Further, the STA would know when the AP will be listening in a particular direction.

[0085] At block 404, the device may identify a sector frame received from a first station device of the one or more station devices at a first space time slot of one or more space time slots associated with the first sector. The AP may receive one or more SSWs from one or more user devices in different space time slots of a sector i , where i is a positive integer. This may

occur during a beamforming SP of the DTI or during a directional A-BFT of the A-BFT interval. For example, the AP may receive an SSW frame from a user device during a time slot associated with a specific sector. The sector may be the same sector identified in the BTI as the best sector for TX and RX. After transmitting its packets in a certain direction, the user device may then enter into a listening mode in order to receive a sector acknowledgment from the AP in that same direction. The AP would then transmit a sector acknowledgment corresponding to each of the time slots and directions during which the AP received the packets from each of the user devices. The sector acknowledgment contains the IDs of all discovered user devices. Therefore, all user devices that were detected by the AP, meaning that they did not have collisions, are included in the sector acknowledgment. For all other user devices that were part of the collisions, their IDs would not be included in the sector acknowledgment. The AP would not know about the user device process that had collisions; it only has information about the user devices that did not have collisions.

[0086] At block 406, the device may determine to adjust a number of space time slots during a second beamforming interval for beamforming training based on the sector frame. A new IE may be included in the sector feedback 205 that contains the IDs of all discovered user devices (e.g., user devices 222, 224 and 226). The user device's behavior after reception of this sector feedback 205 with the new IE may be that if the user device finds its own user device ID in the IE, it assumes that beamforming training is finished, and it may start data transmission in a usual way. If the user device's ID is absent in the IE, the user device would continue the negotiation process at the next possible opportunity. The next possible opportunity may be in the directional CBAP/SP 242 of the DTI 233. The user device may check the extended schedule element that would have been included in a beacon frame received by the user device during the BTI 231. The user device may determine whether the extended schedule element includes allocations information during a portion of the DTI 233. That portion of the DTI 233 may be a directional service period (e.g., beamforming SP 241) or a contention-based access period (e.g., directional CBAP/SP 242). If the user device determines that the extended schedule element did not include allocations information for a certain sector, which indicates that a directional CBAP/SP was not allocated, then the user device must perform additional negotiation with the AP.

[0087] Moreover, to avoid collisions during the next directional A-BFT/beamforming SP, the AP may adaptively increase the amount of resources (space time slots) in the crowded sector at the expense of the time slots of the desolate sectors (sectors that were not used, e.g., sector 201). To support the unequal duration of different sector receptions, special information

should be sent in the DMG beacon frame (e.g., DMG beacon frame 208). The DMG beacon frame transmitted in AP sector i may include the start time of the first space time slot allocated for AP sector i and the end time of the last space time slot allocated for AP sector i. Based on this information, the user device can calculate the exact number of space time slots available in AP sector i. It is understood that the above descriptions are for purposes of illustration and are not meant to be limiting.

[0088] FIG. 4B illustrates a flow diagram of an illustrative process 450 for an illustrative effective collision resolution in enhanced SLS beamforming system, in accordance with one or more example embodiments of the present disclosure.

10 [0089] At block 452, a device (e.g., the user device(s) 120 and/or the AP 102 of FIG. 1) may identify a beacon frame of one or more beacon frames received from an access point during a first beamforming interval of one or more beamforming training intervals. For example, during beamforming training for devices, there are one or more periods. These one or more periods may include BTI, A-BFT, and DTI. An initiator device (e.g., an AP or PCP) may perform a transmit and initiator sector sweep (I-TXSS) during the BTI interval by sending one or more directional beacon frames (e.g., DMG beacon frames) to one or more responder user devices. The directional beacon frame appends a training (TRN-R) field to one or more fields of the directional beacon frame.

20 [0090] At block 454, the device may determine a first extended schedule element included in the beacon frame, wherein the first extended schedule element comprises one or more allocations for one or more space time slots in a second beamforming training interval. The directional beacon frame may include an extended schedule element. This element may be used by the user device to determine if additional allocations were allocated by the AP during the DTI in case collisions occurred.

25 [0091] At block 456, the device may determine an operational direction to be used when transmitting a sector frame during a first space time slot of the one or more space time slots in a first sector of one or more sectors of an antenna. Training fields may be appended to each of these directional beacon frames at the end of each directional beacon frame. These training fields are used by the user device. In that sense, after BTI, the user devices will know the best sector to be used for the station from the point of view of the AP. That is, each user device would know the best AP TX sector and would know the best user device RX sector. The second part is the portion of the DTI referred to as beamforming SP or any other name indicating a period where the AP is listening during one or more space time slots in a particular sector or one or more sectors of an antenna on the AP. In this part, the AP will be listening in

a directional mode. Further, the user device would know when the AP will be listening in a particular direction.

[0092] At block 458, the device may cause to send the sector frame during the first space time slot to the access point. In crowded areas/hotspot scenarios the user devices may be close
5 to each other, covered by the same antenna sector of the AP, or just be on the same direction from the AP at different distances. In this case, collisions may occur within a space time slot designated to the specific sector in the directional A-BFT (in A-BFT) or the beamforming SP (in DTI). In case of the collision (e.g., simultaneous transmissions from different user devices) of the SSW frame transmissions during the directional AP RX interval, which could be in the
10 directional A-BFT or the beamforming SP, the AP may successfully process only one transmission (or maybe none), probably from the closely spaced user device with the strongest signal. In case of collisions, the user device may check an extended schedule element that may be included in a directional beacon frame received from an AP during the BTI. The user device may determine whether the extended schedule element includes allocations information during
15 a portion of the DTI. That portion of the DTI may be a directional service period (e.g., beamforming SP) or a contention-based access period (e.g., directional CBAP/SP). If the user device determines that the extended schedule element did not include allocations information for a certain sector, which indicates that a directional CBAP/SP was not allocated, then the user device must perform additional negotiation with the AP. After the user device checks the
20 extended schedule element and determines that a directional SP/CBAP allocation was allocated for sector i, the user device may proceed with the beamforming training. To avoid further collisions, the AP may inform the user devices in the desired sector, which user devices were discovered and associated, and which should try to perform beamforming in the next possible access period with the directional AP RX. For example, the AP may send a sector feedback,
25 which may include sector acknowledgment frames that are acknowledgments to the received SSWs that were received from one of the sectors during the directional AP RX. If a user device send an SSW that is successfully received by the AP in sector i, the AP may send a sector acknowledgment frame to that user device. A new IE may be included in the sector feedback that contains the IDs of all discovered user devices. The user device behavior after reception
30 of this sector feedback with the new IE may be that if the user device finds its own user device ID in the IE, it assumes that beamforming training is finished, and it may start data transmission in a usual way. If the user device's ID is absent in the IE, the user device would continue the negotiation process at the next possible opportunity. The next possible opportunity may be in the directional CBAP/SP of the DTI. The user device may check the extended schedule

element that would have been included in a beacon frame received by the user device during the BTI. The user device may determine whether the extended schedule element includes allocations information during a portion of the DTI. That portion of the DTI may be a directional service period (e.g., beamforming SP) or a contention-based access period (e.g., directional CBAP/SP). If the user device determines that the extended schedule element did not include allocations information for a certain sector, which indicates that a directional CBAP/SP was not allocated, then the user device must perform additional negotiation with the AP. It is understood that the above descriptions are for purposes of illustration and are not meant to be limiting.

[0001] FIG. 5 shows a functional diagram of an exemplary communication station 500 in accordance with some embodiments. In one embodiment, FIG. 5 illustrates a functional block diagram of a communication station that may be suitable for use as an AP 102 (FIG. 1) or user device 120 (FIG. 1) in accordance with some embodiments. The communication station 500 may also be suitable for use as a handheld device, a mobile device, a cellular telephone, a smartphone, a tablet, a netbook, a wireless terminal, a laptop computer, a wearable computer device, a femtocell, a high data rate (HDR) subscriber station, an access point, an access terminal, or other personal communication system (PCS) device.

[0093] The communication station 500 may include communications circuitry 502 and a transceiver 510 for transmitting and receiving signals to and from other communication stations using one or more antennas 501. The transceiver 510 may be a device comprising both a transmitter and a receiver that are combined and share common circuitry (e.g., communications circuitry 502). The communications circuitry 502 may include amplifiers, filters, mixers, analog to digital and/or digital to analog converters. The transceiver 510 may transmit and receive analog or digital signals. The transceiver 510 may allow reception of signals during transmission periods. This mode is known as full-duplex, and may require the transmitter and receiver to operate on different frequencies to minimize interference between the transmitted signal and the received signal. The transceiver 510 may operate in a half-duplex mode, where the transceiver 510 may transmit or receive signals in one direction at a time.

[0094] The communications circuitry 502 may include circuitry that can operate the physical layer (PHY) communications and/or media access control (MAC) communications for controlling access to the wireless medium, and/or any other communications layers for transmitting and receiving signals. The communication station 500 may also include processing circuitry 506 and memory 508 arranged to perform the operations described herein.

In some embodiments, the communications circuitry 502 and the processing circuitry 506 may be configured to perform operations detailed in detailed in FIGs. 1, 2A, 2B, 3, 4A and 4B.

[0095] In accordance with some embodiments, the communications circuitry 502 may be arranged to contend for a wireless medium and configure frames or packets for communicating over the wireless medium. The communications circuitry 502 may be arranged to transmit and receive signals. The communications circuitry 502 may also include circuitry for modulation/demodulation, upconversion/downconversion, filtering, amplification, etc. In some embodiments, the processing circuitry 506 of the communication station 500 may include one or more processors. In other embodiments, two or more antennas 501 may be coupled to the communications circuitry 502 arranged for sending and receiving signals. The memory 508 may store information for configuring the processing circuitry 506 to perform operations for configuring and transmitting message frames and performing the various operations described herein. The memory 508 may include any type of memory, including non-transitory memory, for storing information in a form readable by a machine (e.g., a computer). For example, the memory 508 may include a computer-readable storage device, read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices and other storage devices and media.

[0096] In some embodiments, the communication station 500 may be part of a portable wireless communication device, such as a personal digital assistant (PDA), a laptop or portable computer with wireless communication capability, a web tablet, a wireless telephone, a smartphone, a wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, a medical device (e.g., a heart rate monitor, a blood pressure monitor, etc.), a wearable computer device, or another device that may receive and/or transmit information wirelessly.

[0097] In some embodiments, the communication station 500 may include one or more antennas 501. The antennas 501 may include 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 embodiments, instead of two or more antennas, a single antenna with multiple apertures may be used. In these embodiments, each aperture may be considered a separate antenna. In some multiple-input multiple-output (MIMO) embodiments, the antennas may be effectively separated for spatial diversity and the different channel characteristics that may result between each of the antennas and the antennas of a transmitting station.

[0098] In some embodiments, the communication station 500 may include one or more of

a keyboard, a display, a non-volatile memory port, multiple antennas, a graphics processor, an application processor, speakers, and other mobile device elements. The display may be an LCD screen including a touch screen.

[0099] Although the communication station 500 is illustrated as having several separate
5 functional elements, two 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 include one or more microprocessors, DSPs, field-programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), radio-frequency integrated circuits
10 (RFICs) and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements of the communication station 500 may refer to one or more processes operating on one or more processing elements.

[00100] Certain embodiments may be implemented in one or a combination of hardware,
15 firmware, and software. Other 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 memory mechanism for storing information in a form readable by a machine (e.g., a computer). For example, a computer-readable storage device may include
20 read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and other storage devices and media. In some embodiments, the communication station 500 may include one or more processors and may be configured with instructions stored on a computer-readable storage device memory.

[00101] FIG. 6 illustrates a block diagram of an example of a machine 600 or system upon
25 which any one or more of the techniques (e.g., methodologies) discussed herein may be performed. In other embodiments, the machine 600 may operate as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine 600 may operate in the capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine 600 may act as a peer machine in peer-to-
30 peer (P2P) (or other distributed) network environments. The machine 600 may be a personal computer (PC), a tablet PC, a set-top box (STB), a personal digital assistant (PDA), a mobile telephone, a wearable computer device, a web appliance, a network router, a switch or bridge, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine, such as a base station. 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), or other computer cluster configurations.

5 [00102] 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 when operating. A module includes hardware. In an example, the hardware may be specifically configured to carry out a specific operation (e.g., hardwired). In another example, the hardware may include configurable execution units (e.g.,
10 transistors, circuits, etc.) and a computer readable medium containing instructions where the instructions configure the execution units to carry out a specific operation when in operation. The configuring may occur under the direction of the executions units or a loading mechanism. Accordingly, the execution units are communicatively coupled to the computer-readable medium when the device is operating. In this example, the execution units may be a member
15 of more than one module. For example, under operation, the execution units may be configured by a first set of instructions to implement a first module at one point in time and reconfigured by a second set of instructions to implement a second module at a second point in time.

[00103] The machine (e.g., computer system) 600 may include a hardware processor 602 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor
20 core, or any combination thereof), a main memory 604 and a static memory 606, some or all of which may communicate with each other via an interlink (e.g., bus) 608. The machine 600 may further include a power management device 632, a graphics display device 610, an alphanumeric input device 612 (e.g., a keyboard), and a user interface (UI) navigation device 614 (e.g., a mouse). In an example, the graphics display device 610, alphanumeric input device
25 612, and UI navigation device 614 may be a touch screen display. The machine 600 may additionally include a storage device (i.e., drive unit) 616, a signal generation device 618 (e.g., a speaker), an effective collision resolution in enhanced SLS beamforming device 619, a network interface device/transceiver 620 coupled to antenna(s) 630, and one or more sensors 628, such as a global positioning system (GPS) sensor, a compass, an accelerometer, or other
30 sensor. The machine 600 may include an output controller 634, 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 with or control one or more peripheral devices (e.g., a printer, a card reader, etc.)).

[00104] The storage device 616 may include a machine readable medium 622 on which is

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

[00105] The effective collision resolution in enhanced SLS beamforming device 619 may carry out or perform any of the operations and processes (e.g., processes 400 and 450) described and shown above. For example, the effective collision resolution in enhanced SLS beamforming device 619 may facilitate that in an enhanced sector-level sweep (SLS) beamforming system there are two important parts. The first part is the BTI, where there are one or more transmit sector sweeps (SSW-TXs), where multiple DMG beacon frames are transmitted in different sectors associated with different directions from the AP to an STA. These multiple DMG beacon frames are a same DMG beacon frame that is transmitted on different sectors. Training fields may be appended to each of these DMG beacon frames at the end of each DMG beacon frame. These training fields are used by the receiving STA. In that sense, after BTI, the STAs will know the best sector to be used for the station from the point of view of the AP. That is, each STA would know the best AP transmit (TX) sector and would know the best STA receive (RX) sector. The second part is the portion of the DTI referred to as the beamforming service period (SP) or any other name indicating a period where the AP is listening during one or more space time slots in a particular sector or one or more sectors of an antenna on the AP. In this part, the AP will be listening in a directional mode. Further, the STA would know when the AP will be listening in a particular direction. Antenna pattern reciprocity is also assumed, where if the STA knows the AP's best TX sector, it will also know the AP's listening opportunity in the best RX sector. For example, during BTI, if the best AP TX sector for an STA was for sector ID 1, the STA should transmit its response at the time when the AP will be listening on sector ID 1. However, other STAs may also transmit during that sector ID, which may result in collisions. For example, if there are an increased number of STAs in one sector, the probability of collisions may increase. For example, if there are four time slots in one sector, but there are 10 STAs sending their packets during that sector, then the probability of collision may be high.

[00106] The effective collision resolution in enhanced SLS beamforming device 619 may facilitate that the AP may also allocate additional time slots for directional listening purposes.

After transmitting its packets in a certain direction, the STA may then enter into a listening mode in order to receive a sector acknowledgment from the AP in that same direction. The AP would then transmit a sector acknowledgment corresponding to each of the time slots and directions during which the AP received the packets from each of the STAs. The sector acknowledgment contains the IDs of all discovered STAs. Therefore, all STAs that were
5 detected by the AP, meaning that they did not have collisions, are included in the sector acknowledgment. For all other STAs that were part of the collisions, their IDs would not be included in the sector acknowledgment. The AP would not know about the STA process that had collisions; it only has information about the STAs that did not have collisions.

[00107] The effective collision resolution in enhanced SLS beamforming device 619 may facilitate that the STAs that did not identify their IDs in the sector acknowledgment sent by the AP may determine that collisions have occurred. Therefore, they have not completely completed the beamforming training, and should attempt to perform directional CBAP/SP in order to contact the AP. Similarly, during that time, the STAs may be listening in the same
15 direction that they transmitted their packets to the AP. During the CBAP/SP of the DTI, the AP may determine one or more allocations for one or more sectors. However, the allocated CBAP/SP may not be in the same sector as the STAs that were involved in collisions. The information of which sector will be allocated in the CBAP/SP may be included in the one or more beacon frames during the BTI interval. If the STA fails to negotiate because the AP
20 allocated a different sector during the CBAP/SP than the sector of the STA, the STA would try to negotiate with the AP in the next beamforming SP.

[00108] The effective collision resolution in enhanced SLS beamforming device 619 may facilitate that an extended schedule element (e.g., EDMG or DMG extended schedule element) may contain one or more allocations if the AP determines that it needs to add additional
25 allocations during the directional allocations. The extended schedule element may contain information about one or more sector allocations in the directional allocation period of the DTI. The AP may determine whether to have directional allocations or not based on implementation.

[00109] The effective collision resolution in enhanced SLS beamforming device 619 may facilitate that the AP may determine to increase the amount of resources in the beamforming
30 SP period of the DTI. For example, the AP may increase the number of space time slots in the next beamforming SP period of a next DTI based on information from the current beamforming SP period of a current DTI. For example, in the case of collisions during a current beamforming SP part of the DTI, the AP may learn from that and may try to prevent additional collisions in the next DTI. For example, if there are many collisions during a current beamforming SP

period, the AP may increase the number of space time slots in the next beamforming SP period. For example, if there were four space time slots in sector 0, where collisions occurred in the current beamforming SP, the AP may allocate a larger number than four space time slots in sector 0 in the next beamforming SP. However, this is not limited to collisions. For example, 5 if the AP determines that all space time slots in a sector of a current beamforming SP period are used, the AP may decide and determine to increase the number of space time slots in a next beamforming SP of a next DTI. In that sense, the number of space time slots may be variable and non-constant for different directions for different sectors based on usage and collisions. This information may be sent in the BTI period in each of the multiple beacon frames. Each 10 of the beacons will have information about the start time for listening on a corresponding sector. There will be sector specific fields in each of the beacon frames.

[00110] The effective collision resolution in enhanced SLS beamforming device 619 may provide an enhanced beamforming flow based on the directional transmission and the directional reception for both the access point (AP) and the station device (STA). For such 15 directional STA to AP transmission organization, two options may be possible: one for introducing a directional A-BFT or a beamforming SP in the DTI. This directional transmission solves two important issues, namely, the STA's range extension and synchronization collision avoidance by using spatial (angular) STA separation.

[00111] The effective collision resolution in enhanced SLS beamforming device 619 may 20 facilitate a new method for EDMG STA collision resolution and avoidance for the enhanced SLS beamforming flow described above. The collision resolution and avoidance may introduce an information element (IE), which is included in the sector acknowledgment frame (broadcasted by the AP to each sector where the STAs were discovered or even energy detection took place), and specifies the IDs of the STAs that were already identified by the AP. 25 The present disclosure specifies the behavior of the EDMG STA after the reception of a sector acknowledgment frame. All non-associated STAs in a given sector may continue the negotiation process in the next available period with directional AP RX: the directional CBAP/SP or the next directional A-BFT/beamforming SP.

[00112] The effective collision resolution in enhanced SLS beamforming device 619 may 30 also introduce the solution for the AP to adaptively increase the amount of resources (space timeslots) in the crowded sector at the expense of the time slots of the desolate sectors.

[00113] The effective collision resolution in enhanced SLS beamforming device 619 may be based on the STA to AP directional transmission and reception in special directional A-BFT or beamforming SP periods, where the STAs are separated at the AP by the angles of arrival

(sectors) and, additionally, by the introduction of a few time slots to resolve collisions within each sector. This may allow more efficient STA to AP communication with a range extension of up to hundreds of meters, but the process of collision resolution inside of each sector in crowded hotspots may not be optimized.

5 [00114] It is understood that the above are only a subset of what the effective collision resolution in enhanced SLS beamforming device 619 may be configured to perform and that other functions included throughout this disclosure may also be performed by the effective collision resolution in enhanced SLS beamforming device 619.

[00115] While the machine-readable medium 622 is illustrated as a single medium, the term
10 “machine-readable medium” may include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) configured to store the one or more instructions 624.

[00116] Various embodiments may be implemented fully or partially in software and/or
firmware. This software and/or firmware may take the form of instructions contained in or on
15 a non-transitory computer-readable storage medium. Those instructions may then be read and executed by one or more processors to enable performance of the operations described herein. The instructions may be in any suitable form, such as but not limited to source code, compiled code, interpreted code, executable code, static code, dynamic code, and the like. Such a computer-readable medium may include any tangible non-transitory medium for storing
20 information in a form readable by one or more computers, such as but not limited to read only memory (ROM); random access memory (RAM); magnetic disk storage media; optical storage media; a flash memory, etc.

[00117] The term “machine-readable medium” may include any medium that is capable of
storing, encoding, or carrying instructions for execution by the machine 600 and that cause the
25 machine 600 to perform any one or more of the techniques of the present disclosure, or that is capable of storing, encoding, or carrying data structures used by or associated with such instructions. Non-limiting machine-readable medium examples may include solid-state memories and optical and magnetic media. In an example, a massed machine-readable medium includes a machine-readable medium with a plurality of particles having resting mass. Specific
30 examples of massed machine-readable media may include non-volatile memory, such as semiconductor memory devices (e.g., electrically programmable read-only memory (EPROM), or electrically erasable programmable read-only memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; and CD-ROM and DVD- ROM disks.

[00118] The instructions 624 may further be transmitted or received over a communications network 626 using a transmission medium via the network interface device/transceiver 620 utilizing any one of a number of transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communications 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, 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, and peer-to-peer (P2P) networks, among others. In an example, the network interface device/transceiver 620 may include one or more physical jacks (e.g., Ethernet, coaxial, or phone jacks) or one or more antennas to connect to the communications network 626. In an example, the network interface device/transceiver 620 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. The term “transmission medium” shall be taken to include any intangible medium that is capable of storing, encoding, or carrying instructions for execution by the machine 600 and includes digital or analog communications signals or other intangible media to facilitate communication of such software. The operations and processes described and shown above may be carried out or performed in any suitable order as desired in various implementations. Additionally, in certain implementations, at least a portion of the operations may be carried out in parallel. Furthermore, in certain implementations, less than or more than the operations described may be performed.

[00119] The word “exemplary” is used herein to mean “serving as an example, instance, or illustration.” Any embodiment described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other embodiments. The terms “computing device,” “user device,” “communication station,” “station,” “handheld device,” “mobile device,” “wireless device” and “user equipment” (UE) as used herein refers to a wireless communication device such as a cellular telephone, a smartphone, a tablet, a netbook, a wireless terminal, a laptop computer, a femtocell, a high data rate (HDR) subscriber station, an access point, a printer, a point of sale device, an access terminal, or other personal communication system (PCS) device. The device may be either mobile or stationary.

[00120] As used within this document, the term “communicate” is intended to include transmitting, or receiving, or both transmitting and receiving. This may be particularly useful

in claims when describing the organization of data that is being transmitted by one device and received by another, but only the functionality of one of those devices is required to infringe the claim. Similarly, the bidirectional exchange of data between two devices (both devices transmit and receive during the exchange) may be described as “communicating,” when only
5 the functionality of one of those devices is being claimed. The term “communicating” as used herein with respect to a wireless communication signal includes transmitting the wireless communication signal and/or receiving the wireless communication signal. For example, a wireless communication unit, which is capable of communicating a wireless communication signal, may include a wireless transmitter to transmit the wireless communication signal to at
10 least one other wireless communication unit, and/or a wireless communication receiver to receive the wireless communication signal from at least one other wireless communication unit.

[00121] As used herein, unless otherwise specified, the use of the ordinal adjectives “first,” “second,” “third,” etc., to describe a common object, merely indicates that different instances of like objects are being referred to and are not intended to imply that the objects so described
15 must be in a given sequence, either temporally, spatially, in ranking, or in any other manner.

[00122] The term “access point” (AP) as used herein may be a fixed station. An access point may also be referred to as an access node, a base station, an evolved node B (eNodeB), an evolved node B (eNodeB), or some other similar terminology known in the art. An access terminal may also be called a mobile station, user equipment (UE), a wireless communication
20 device, or some other similar terminology known in the art. Embodiments disclosed herein generally pertain to wireless networks. Some embodiments may relate to wireless networks that operate in accordance with one of the IEEE 802.11 standards.

[00123] Some embodiments may be used in conjunction with various devices and systems, for example, a personal computer (PC), a desktop computer, a mobile computer, a laptop computer, a notebook computer, a tablet computer, a server computer, a handheld computer, a
25 handheld device, a personal digital assistant (PDA) device, a handheld PDA device, an on-board device, an off-board device, a hybrid device, a vehicular device, a non-vehicular device, a mobile or portable device, a consumer device, a non-mobile or non-portable device, a wireless communication station, a wireless communication device, a wireless access point (AP), a wired
30 or wireless router, a wired or wireless modem, a video device, an audio device, an audio-video (A/V) device, a wired or wireless network, a wireless area network, a wireless video area network (WVAN), a local area network (LAN), a wireless LAN (WLAN), a personal area network (PAN), a wireless PAN (WPAN), and the like.

[00124] Some embodiments may be used in conjunction with one way and/or two-way radio communication systems, cellular radio-telephone communication systems, a mobile phone, a cellular telephone, a wireless telephone, a personal communication system (PCS) device, a PDA device which incorporates a wireless communication device, a mobile or portable global positioning system (GPS) device, a device which incorporates a GPS receiver or transceiver or chip, a device which incorporates an RFID element or chip, a multiple-input multiple-output (MIMO) transceiver or device, a single input multiple output (SIMO) transceiver or device, a multiple input single output (MISO) transceiver or device, a device having one or more internal antennas and/or external antennas, digital video broadcast (DVB) devices or systems, multi-standard radio devices or systems, a wired or wireless handheld device, e.g., a smartphone, a wireless application protocol (WAP) device, or the like.

[00125] Some embodiments may be used in conjunction with one or more types of wireless communication signals and/or systems following one or more wireless communication protocols, for example, radio frequency (RF), infrared (IR), frequency-division multiplexing (FDM), orthogonal FDM (OFDM), time-division multiplexing (TDM), time-division multiple access (TDMA), extended TDMA (E-TDMA), general packet radio service (GPRS), extended GPRS, code-division multiple access (CDMA), wideband CDMA (WCDMA), CDMA 2000, single-carrier CDMA, multi-carrier CDMA, multi-carrier modulation (MDM), discrete multi-tone (DMT), Bluetooth®, global positioning system (GPS), Wi-Fi, Wi-Max, ZigBee, ultra-wideband (UWB), global system for mobile communications (GSM), 2G, 2.5G, 3G, 3.5G, 4G, fifth generation (5G) mobile networks, 3GPP, long term evolution (LTE), LTE advanced, enhanced data rates for GSM Evolution (EDGE), or the like. Other embodiments may be used in various other devices, systems, and/or networks.

[00126] Example 1 may include a device comprising memory and processing circuitry configured to: determine a beacon frame to be sent to one or more station devices during a first beamforming interval of one or more beamforming training intervals, wherein the beacon frame may be associated with a first sector of one or more sectors of an antenna; identify a sector frame received from a first station device of the one or more station devices at a first space time slot of one or more space time slots associated with the first sector; and determine to adjust a number of space time slots during a second beamforming interval for beamforming training based on the sector frame.

[00127] Example 2 may include the device of example 1 and/or some other example herein, wherein the beacon frame may include a first extended schedule element.

[00128] Example 3 may include the device of example 2 and/or some other example herein, wherein the first extended schedule element may include one or more allocations for one or more space time slots in a first data transmission interval.

5 [00129] Example 4 may include the device of example 1 and/or some other example herein, wherein the first beamforming interval may be a first beacon transmission interval.

[00130] Example 5 may include the device of example 1 and/or some other example herein, wherein to determine to adjust the number of space time slots comprises the memory and the processing circuitry being further configured to: determine one or more collisions during the first sector; and determine to increase the number of the space time slots during the second
10 beamforming interval.

[00131] Example 6 may include the device of example 1 and/or some other example herein, wherein to determine to adjust the number of space time slots comprises the memory and the processing circuitry being further configured to: identify two or more sector frames received during the first sector; and determine to increase the number of the space time slots in the
15 second beamforming interval.

[00132] Example 7 may include the device of example 1 and/or some other example herein, wherein the second interval may be a second beamforming service period interval.

[00133] Example 8 may include the device of example 7 and/or some other example herein, wherein the second beamforming service period interval may be in a second data transmission
20 interval.

[00134] Example 9 may include the device of example 1 and/or some other example herein, wherein the memory and the processing circuitry are further configured to determine a sector acknowledgment frame acknowledging the sector frame received from the first device during the first beamforming interval.

25 [00135] Example 10 may include the device of example 9 and/or some other example herein, wherein the memory and the processing circuitry are further configured to determine an information element included in the sector acknowledgment frame, wherein the sector acknowledgment frame identifies a first station device received the sector frame

[00136] Example 11 may include the device of example 1 and/or some other example herein,
30 further comprising a transceiver configured to transmit and receive wireless signals.

[00137] Example 12 may include the device of example 11 and/or some other example herein, further comprising one or more antennas coupled to the transceiver.

[00138] Example 13 may include a non-transitory computer-readable medium storing computer-executable instructions which when executed by one or more processors result in

performing operations comprising: identifying a beacon frame of one or more beacon frames received from an access point during a first beamforming interval of one or more beamforming training intervals; determining a first extended schedule element included in the beacon frame, wherein the first extended schedule element comprises one or more allocations for one or more space time slots in a second beamforming training interval; determining an operational direction to be used when transmitting a sector frame during a first space time slot of the one or more space time slots in a first sector of one or more sectors of an antenna; and causing to send the sector frame during the first space time slot to the access point.

[00139] Example 14 may include the non-transitory computer-readable medium of example 13 and/or some other example herein, wherein the first beamforming interval may be a first beacon transmission interval (BTI).

[00140] Example 15 may include the non-transitory computer-readable medium of example 13 and/or some other example herein, wherein the second beamforming interval may be a first beamforming service period (SP) in a first data transmission interval (DTI).

[00141] Example 16 may include the non-transitory computer-readable medium of example 15 and/or some other example herein, wherein the operations further comprise: identifying a sector acknowledgment frame received from the access point; determining an absence of a device identification; and determining an allocation of the first sector in an extended schedule element included in the beacon frame; and causing to send a second sector frame during a directional allocation portion of the first data transmission interval or during a second beamforming service period of a second data transmission interval.

[00142] Example 17 may include the non-transitory computer-readable medium of example 16 and/or some other example herein, wherein the directional allocation portion may be a service period or a contention-based access period (CBAP).

[00143] Example 18 may include the non-transitory computer-readable medium of example 16 and/or some other example herein, wherein the operations for causing to send the second sector frame further comprise: determining that no allocations exists in the extended schedule element associated with the first sector; and causing to send the second sector frame during the second beamforming service period (SP).

[00144] Example 19 may include a method comprising: determining, by one or more processors, a beacon frame to be sent to one or more station devices during a first beamforming interval of one or more beamforming training intervals, wherein the beacon frame may be associated with a first sector of one or more sectors of an antenna; identifying a sector frame received from a first station device of the one or more station devices at a first space time slot

of one or more space time slots associated with the first sector; and determining to adjust a number of space time slots during a second beamforming interval for beamforming training based on the sector frame.

5 [00145] Example 20 may include the method of example 19 and/or some other example herein, wherein the beacon frame may include a first extended schedule element.

[00146] Example 21 may include the method of example 20 and/or some other example herein, wherein the first extended schedule element may include one or more allocations for one or more space time slots in a first data transmission interval.

10 [00147] Example 22 may include the method of example 19 and/or some other example herein, wherein the first beamforming interval may be a first beacon transmission interval.

[00148] Example 23 may include the method of example 19 and/or some other example herein, further comprising: determining one or more collisions during the first sector; and determining to increase the number of the space time slots during the second beamforming interval.

15 [00149] Example 24 may include the method of example 19 and/or some other example herein, wherein determining to adjust the number of space time slots further comprises: identifying two or more sector frames received during the first sector; and determining to increase the number of the space time slots in the second beamforming interval.

20 [00150] Example 25 may include the method of example 19 and/or some other example herein, wherein the second interval may be a second beamforming service period interval.

[00151] Example 26 may include the method of example 25 and/or some other example herein, wherein the second beamforming service period interval may be in a second data transmission interval.

25 [00152] Example 27 may include the method of example 19 and/or some other example herein, further comprising determining a sector acknowledgment frame acknowledging the sector frame received from the first device during the first beamforming interval.

[00153] Example 28 may include the method of example 27 and/or some other example herein, further comprising determining an information element included in the sector acknowledgment frame, wherein the sector acknowledgment frame identifies a first station
30 device received the sector frame.

[00154] Example 29 may include an apparatus comprising means for performing a method as claimed in any one of examples 19-28.

[00155] Example 30 may include a system comprising at least one memory device having programmed instruction that, in response to execution cause at least one processor to perform the method of any one of examples 19-28.

5 [00156] Example 31 may include a machine readable medium including code, when executed, to cause a machine to perform the method of any one of examples 19-28.

[00157] Example 32 may include a non-transitory computer-readable medium storing computer-executable instructions which when executed by one or more processors result in performing operations comprising: determining, by one or more processors, a beacon frame to be sent to one or more station devices during a first beamforming interval of one or more
10 beamforming training intervals, wherein the beacon frame may be associated with a first sector of one or more sectors of an antenna; identifying a sector frame received from a first station device of the one or more station devices at a first space time slot of one or more space time slots associated with the first sector; and determining to adjust a number of space time slots during a second beamforming interval for beamforming training based on the sector frame.

15 [00158] Example 33 may include the non-transitory computer-readable medium of example 32 and/or some other example herein, wherein the beacon frame may include a first extended schedule element.

[00159] Example 34 may include the non-transitory computer-readable medium of example 33 and/or some other example herein, wherein the first extended schedule element may include
20 one or more allocations for one or more space time slots in a first data transmission interval.

[00160] Example 35 may include the non-transitory computer-readable medium of example 32 and/or some other example herein, wherein the first beamforming interval may be a first beacon transmission interval.

[00161] Example 36 may include the non-transitory computer-readable medium of example
25 32 and/or some other example herein, wherein the operations further comprise: determining one or more collisions during the first sector; and determining to increase the number of the space time slots during the second beamforming interval.

[00162] Example 37 may include the non-transitory computer-readable medium of example
30 32 and/or some other example herein, wherein determining to adjust the number of space time slots further comprises: identifying two or more sector frames received during the first sector; and determining to increase the number of the space time slots in the second beamforming interval.

[00163] Example 38 may include the non-transitory computer-readable medium of example 32 and/or some other example herein, wherein the second interval may be a second beamforming service period interval.

5 [00164] Example 39 may include the non-transitory computer-readable medium of example 38 and/or some other example herein, wherein the second beamforming service period interval may be in a second data transmission interval.

[00165] Example 40 may include the non-transitory computer-readable medium of example 32 and/or some other example herein, wherein the operations further comprise determining a sector acknowledgment frame acknowledging the sector frame received from the first device
10 during the first beamforming interval.

[00166] Example 41 may include the non-transitory computer-readable medium of example 40 and/or some other example herein, wherein the operations further comprise determining an information element included in the sector acknowledgment frame, wherein the sector acknowledgment frame identifies a first station device received the sector frame.

15 [00167] Example 42 may include an apparatus comprising means for determining, by one or more processors, a beacon frame to be sent to one or more station devices during a first beamforming interval of one or more beamforming training intervals, wherein the beacon frame may be associated with a first sector of one or more sectors of an antenna; means for identifying a sector frame received from a first station device of the one or more station devices
20 at a first space time slot of one or more space time slots associated with the first sector; and means for determining to adjust a number of space time slots during a second beamforming interval for beamforming training based on the sector frame.

[00168] Example 43 may include the apparatus of example 42 and/or some other example herein, wherein the beacon frame may include a first extended schedule element.

25 [00169] Example 44 may include the apparatus of example 43 and/or some other example herein, wherein the first extended schedule element may include one or more allocations for one or more space time slots in a first data transmission interval.

[00170] Example 45 may include the apparatus of example 42 and/or some other example herein, wherein the first beamforming interval may be a first beacon transmission interval.

30 [00171] Example 46 may include the apparatus of example 42 and/or some other example herein, further comprising: means for determining one or more collisions during the first sector; and means for determining to increase the number of the space time slots during the second beamforming interval.

[00172] Example 47 may include the apparatus of example 42 and/or some other example herein, wherein determining to adjust the number of space time slots further comprises: means for identifying two or more sector frames received during the first sector; and means for determining to increase the number of the space time slots in the second beamforming interval.

5 [00173] Example 48 may include the apparatus of example 42 and/or some other example herein, wherein the second interval may be a second beamforming service period interval.

[00174] Example 49 may include the apparatus of example 48 and/or some other example herein, wherein the second beamforming service period interval may be in a second data transmission interval.

10 [00175] Example 50 may include the apparatus of example 42 and/or some other example herein, further comprising means for determining a sector acknowledgment frame acknowledging the sector frame received from the first device during the first beamforming interval.

[00176] Example 51 may include the apparatus of example 50 and/or some other example
15 herein, further comprising means for determining an information element included in the sector acknowledgment frame, wherein the sector acknowledgment frame identifies a first station device received the sector frame.

[00177] Example 52 may include a device comprising memory and processing circuitry configured to: identify a beacon frame of one or more beacon frames received from an access
20 point during a first beamforming interval of one or more beamforming training intervals; determine a first extended schedule element included in the beacon frame, wherein the first extended schedule element comprises one or more allocations for one or more space time slots in a second beamforming training interval; determine an operational direction to be used when transmitting a sector frame during a first space time slot of the one or more space time slots in
25 a first sector of one or more sectors of an antenna; and cause to send the sector frame during the first space time slot to the access point.

[00178] Example 53 may include the device of example 52 and/or some other example herein, wherein the first beamforming interval may be a first beacon transmission interval (BTI).

30 [00179] Example 54 may include the device of example 52 and/or some other example herein, wherein the second beamforming interval may be a first beamforming service period (SP) in a first data transmission interval (DTI).

[00180] Example 55 may include the device of example 54 and/or some other example herein, wherein the memory and the processing circuitry are further configured to: identify a

sector acknowledgment frame received from the access point; determine an absence of a device identification; and determine an allocation of the first sector in an extended schedule element included in the beacon frame; and cause to send a second sector frame during a directional allocation portion of the first data transmission interval or during a second beamforming service
5 period of a second data transmission interval.

[00181] Example 56 may include the device of example 55 and/or some other example herein, wherein the directional allocation portion may be a service period or a contention-based access period (CBAP).

[00182] Example 57 may include the device of example 55 and/or some other example
10 herein, wherein the memory and the processing circuitry for causing to send the second sector frame may be further configured to: determine that no allocations exists in the extended schedule element associated with the first sector; and cause to send the second sector frame during the second beamforming service period (SP).

[00183] Example 58 may include the device of example 52 and/or some other example
15 herein, further comprising a transceiver configured to transmit and receive wireless signals.

[00184] Example 59 may include the device of example 58 and/or some other example herein, further comprising one or more antennas coupled to the transceiver.

[00185] Example 60 may include a method comprising: identifying a beacon frame of one or more beacon frames received from an access point during a first beamforming interval of
20 one or more beamforming training intervals; determining a first extended schedule element included in the beacon frame, wherein the first extended schedule element comprises one or more allocations for one or more space time slots in a second beamforming training interval; determining an operational direction to be used when transmitting a sector frame during a first space time slot of the one or more space time slots in a first sector of one or more sectors of an
25 antenna; and causing to send the sector frame during the first space time slot to the access point.

[00186] Example 61 may include the method of example 60 and/or some other example herein, wherein the first beamforming interval may be a first beacon transmission interval (BTI).

[00187] Example 62 may include the method of example 60 and/or some other example
30 herein, wherein the second beamforming interval may be a first beamforming service period (SP) in a first data transmission interval (DTI).

[00188] Example 63 may include the method of example 62 and/or some other example herein, further comprising: identifying a sector acknowledgment frame received from the

access point; determining an absence of a device identification; and determining an allocation of the first sector in an extended schedule element included in the beacon frame; and causing to send a second sector frame during a directional allocation portion of the first data transmission interval or during a second beamforming service period of a second data transmission interval.

[00189] Example 64 may include the method of example 63 and/or some other example herein, wherein the directional allocation portion may be a service period or a contention-based access period (CBAP).

[00190] Example 65 may include the method of example 63 and/or some other example herein, further comprising: determining that no allocations exists in the extended schedule element associated with the first sector; and causing to send the second sector frame during the second beamforming service period (SP).

[00191] Example 66 may include an apparatus comprising means for performing a method as claimed in any one of examples 60-65.

[00192] Example 67 may include a system comprising at least one memory device having programmed instruction that, in response to execution cause at least one processor to perform the method of any one of examples 60-65.

[00193] Example 68 may include a machine readable medium including code, when executed, to cause a machine to perform the method of any one of examples 60-65.

[00194] Example 69 may include an apparatus comprising means for identifying a beacon frame of one or more beacon frames received from an access point during a first beamforming interval of one or more beamforming training intervals; means for determining a first extended schedule element included in the beacon frame, wherein the first extended schedule element comprises one or more allocations for one or more space time slots in a second beamforming training interval; means for determining an operational direction to be used when transmitting a sector frame during a first space time slot of the one or more space time slots in a first sector of one or more sectors of an antenna; and means for causing to send the sector frame during the first space time slot to the access point.

[00195] Example 70 may include the apparatus of example 69 and/or some other example herein, wherein the first beamforming interval may be a first beacon transmission interval (BTI).

[00196] Example 71 may include the apparatus of example 69 and/or some other example herein, wherein the second beamforming interval may be a first beamforming service period (SP) in a first data transmission interval (DTI).

[00197] Example 72 may include the apparatus of example 71 and/or some other example herein, wherein the operations further comprise: means for identifying a sector acknowledgment frame received from the access point; means for determining an absence of a device identification; and means for determining an allocation of the first sector in an extended
5 schedule element included in the beacon frame; and means for causing to send a second sector frame during a directional allocation portion of the first data transmission interval or during a second beamforming service period of a second data transmission interval.

[00198] Example 73 may include the apparatus of example 72 and/or some other example herein, wherein the directional allocation portion may be a service period or a contention-based
10 access period (CBAP).

[00199] Example 74 may include the apparatus of example 72 and/or some other example herein, further comprising: means for determining that no allocations exists in the extended schedule element associated with the first sector; and means for causing to send the second sector frame during the second beamforming service period (SP).

15 [00200] Example 75 may include an apparatus comprising means for performing a method as claimed in any of the preceding examples.

[00201] Example 76 may include a machine-readable storage including machine-readable instructions, when executed, to implement a method as claimed in any preceding example.

[00202] Example 77 may include a machine-readable storage including machine-readable
20 instructions, when executed, to implement a method or realize an apparatus as claimed in any preceding example.

[00203] Example 78 may include one or more non-transitory computer-readable media comprising instructions to cause an electronic device, upon execution of the instructions by one or more processors of the electronic device, to perform one or more elements of a method
25 described in or related to any of examples 1-77, or any other method or process described herein

[00204] Example 79 may include an apparatus comprising logic, modules, and/or circuitry to perform one or more elements of a method described in or related to any of examples 1-77, or any other method or process described herein.

30 [00205] Example 80 may include a method, technique, or process as described in or related to any of examples 1-77, or portions or parts thereof.

[00206] Example 81 may include an apparatus comprising: one or more processors and one or more computer readable media comprising instructions that, when executed by the one or

more processors, cause the one or more processors to perform the method, techniques, or process as described in or related to any of examples 1-77, or portions thereof.

[00207] Example 82 may include a method of communicating in a wireless network as shown and described herein.

5 [00208] Example 83 may include a system for providing wireless communication as shown and described herein.

[00209] Example 84 may include a device for providing wireless communication as shown and described herein.

[00210] Embodiments according to the disclosure are in particular disclosed in the
10 attached claims directed to a method, a storage medium, a device and a computer program product, wherein any feature mentioned in one claim category, e.g., method, can be claimed in another claim category, e.g., system, as well. The dependencies or references back in the attached claims are chosen for formal reasons only. However, any subject matter resulting from a deliberate reference back to any previous claims (in particular multiple dependencies)
15 can be claimed as well, so that any combination of claims and the features thereof are disclosed and can be claimed regardless of the dependencies chosen in the attached claims. The subject-matter which can be claimed comprises not only the combinations of features as set out in the attached claims but also any other combination of features in the claims, wherein each feature mentioned in the claims can be combined with any other feature or combination of other
20 features in the claims. Furthermore, any of the embodiments and features described or depicted herein can be claimed in a separate claim and/or in any combination with any embodiment or feature described or depicted herein or with any of the features of the attached claims.

[00211] The foregoing description of one or more implementations provides illustration and description, but is not intended to be exhaustive or to limit the scope of embodiments to the
25 precise form disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from practice of various embodiments.

[00212] Certain aspects of the disclosure are described above with reference to block and flow diagrams of systems, methods, apparatuses, and/or computer program products according to various implementations. It will be understood that one or more blocks of the block diagrams
30 and flow diagrams, and combinations of blocks in the block diagrams and the flow diagrams, respectively, may be implemented by computer-executable program instructions. Likewise, some blocks of the block diagrams and flow diagrams may not necessarily need to be performed in the order presented, or may not necessarily need to be performed at all, according to some implementations.

[00213] These computer-executable program instructions may be loaded onto a special-purpose computer or other particular machine, a processor, or other programmable data processing apparatus to produce a particular machine, such that the instructions that execute on the computer, processor, or other programmable data processing apparatus create means for
5 implementing one or more functions specified in the flow diagram block or blocks. These computer program instructions may also be stored in a computer-readable storage media or memory that may direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer-readable storage media produce an article of manufacture including instruction means that implement
10 one or more functions specified in the flow diagram block or blocks. As an example, certain implementations may provide for a computer program product, comprising a computer-readable storage medium having a computer-readable program code or program instructions implemented therein, said computer-readable program code adapted to be executed to implement one or more functions specified in the flow diagram block or blocks. The computer
15 program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational elements or steps to be performed on the computer or other programmable apparatus to produce a computer-implemented process such that the instructions that execute on the computer or other programmable apparatus provide elements or steps for implementing the functions specified in the flow diagram block or blocks.

[00214] Accordingly, blocks of the block diagrams and flow diagrams support combinations of means for performing the specified functions, combinations of elements or steps for performing the specified functions and program instruction means for performing the specified functions. It will also be understood that each block of the block diagrams and flow diagrams, and combinations of blocks in the block diagrams and flow diagrams, may be implemented by
25 special-purpose, hardware-based computer systems that perform the specified functions, elements or steps, or combinations of special-purpose hardware and computer instructions.

[00215] Conditional language, such as, among others, “can,” “could,” “might,” or “may,” unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain implementations could include, while other
30 implementations do not include, certain features, elements, and/or operations. Thus, such conditional language is not generally intended to imply that features, elements, and/or operations are in any way required for one or more implementations or that one or more implementations necessarily include logic for deciding, with or without user input or

prompting, whether these features, elements, and/or operations are included or are to be performed in any particular implementation.

[00216] Many modifications and other implementations of the disclosure set forth herein will be apparent having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the disclosure is not to be limited 5 to the specific implementations disclosed and that modifications and other implementations are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

CLAIMS

What is claimed is:

1. A device, the device comprising memory and processing circuitry configured to:
 - determine a beacon frame to be sent to one or more station devices during a first beamforming interval of one or more beamforming training intervals, wherein the beacon frame is associated with a first sector of one or more sectors of an antenna;
 - identify a sector frame received from a first station device of the one or more station devices at a first space time slot of one or more space time slots associated with the first sector;
 - and
 - determine to adjust a number of space time slots during a second beamforming interval for beamforming training based on the sector frame.
2. The device of claim 1, wherein the beacon frame includes a first extended schedule element.
3. The device of claim 2, wherein the first extended schedule element includes one or more allocations for one or more space time slots in a first data transmission interval.
4. The device of claim 1, wherein the first beamforming interval is a beacon transmission interval.
5. The device of claim 1, wherein to determine to adjust the number of space time slots comprises the memory and the processing circuitry being further configured to:
 - determine one or more collisions during the first sector; and
 - determine to increase the number of the space time slots during the second beamforming interval.
6. The device of claim 1, wherein to determine to adjust the number of space time slots comprises the memory and the processing circuitry being further configured to:
 - identify two or more sector frames received during the first sector; and

determine to increase the number of the space time slots in the second beamforming interval.

7. The device of claim 1, wherein the second interval is a second beamforming service period interval.

8. The device of claim 7, wherein the second beamforming service period interval is in a second data transmission interval.

9. The device of any one of claims 1 to 8, wherein the memory and the processing circuitry are further configured to determine a sector acknowledgment frame acknowledging the sector frame received from the first device during the first beamforming interval.

10. The device of claim 9, wherein the memory and the processing circuitry are further configured to determine an information element included in the sector acknowledgment frame, wherein the sector acknowledgment frame identifies a first station device received the sector frame

11. The device of claim 1, further comprising a transceiver configured to transmit and receive wireless signals.

12. The device of claim 11, further comprising one or more antennas coupled to the transceiver.

13. A non-transitory computer-readable medium storing computer-executable instructions which when executed by one or more processors result in performing operations comprising:

identifying a beacon frame of one or more beacon frames received from an access point during a first beamforming interval of one or more beamforming training intervals;

determining a first extended schedule element included in the beacon frame, wherein the first extended schedule element comprises one or more allocations for one or more space time slots in a second beamforming training interval;

determining an operational direction to be used when transmitting a sector frame during a first space time slot of the one or more space time slots in a first sector of one or more sectors of an antenna; and

causing to send the sector frame during the first space time slot to the access point.

14. The non-transitory computer-readable medium of claim 13, wherein the first beamforming interval is a first beacon transmission interval (BTI).

15. The non-transitory computer-readable medium of any one of claims 13 to 14, wherein the second beamforming interval is a first beamforming service period (SP) in a first data transmission interval (DTI).

16. The non-transitory computer-readable medium of claim 15, wherein the operations further comprise:

identifying a sector acknowledgment frame received from the access point;

determining an absence of a device identification; and

determining an allocation of the first sector in an extended schedule element included in the beacon frame; and

causing to send a second sector frame during a directional allocation portion of the first data transmission interval or during a second beamforming service period of a second data transmission interval.

17. The non-transitory computer-readable medium of claim 16, wherein the directional allocation portion is a service period or a contention-based access period (CBAP).

18. The non-transitory computer-readable medium of claim 16, wherein the operations for causing to send the second sector frame further comprise:

determining that no allocations exists in the extended schedule element associated with the first sector; and

causing to send the second sector frame during the second beamforming service period (SP).

19. A method comprising:

determining, by one or more processors, a beacon frame to be sent to one or more station devices during a first beamforming interval of one or more beamforming training intervals, wherein the beacon frame is associated with a first sector of one or more sectors of an antenna;

identifying a sector frame received from a first station device of the one or more station devices at a first space time slot of one or more space time slots associated with the first sector; and

determining to adjust a number of space time slots during a second beamforming interval for beamforming training based on the sector frame.

20. The method of claim 19, wherein the beacon frame includes a first extended schedule element.

21. The method of claim 20, wherein the first extended schedule element includes one or more allocations for one or more space time slots in a first data transmission interval.

22. The method of claim 19, wherein the first beamforming interval is a first beacon transmission interval.

23. The method of claim 19, further comprising:
determining one or more collisions during the first sector; and
determining to increase the number of the space time slots during the second beamforming interval.

24. The method of claim 19, wherein determining to adjust the number of space time slots further comprises:

identifying two or more sector frames received during the first sector ; and
determining to increase the number of the space time slots in the second beamforming interval.

25. The method of any one of claims 19 to 24, wherein the second interval is a second beamforming service period interval.

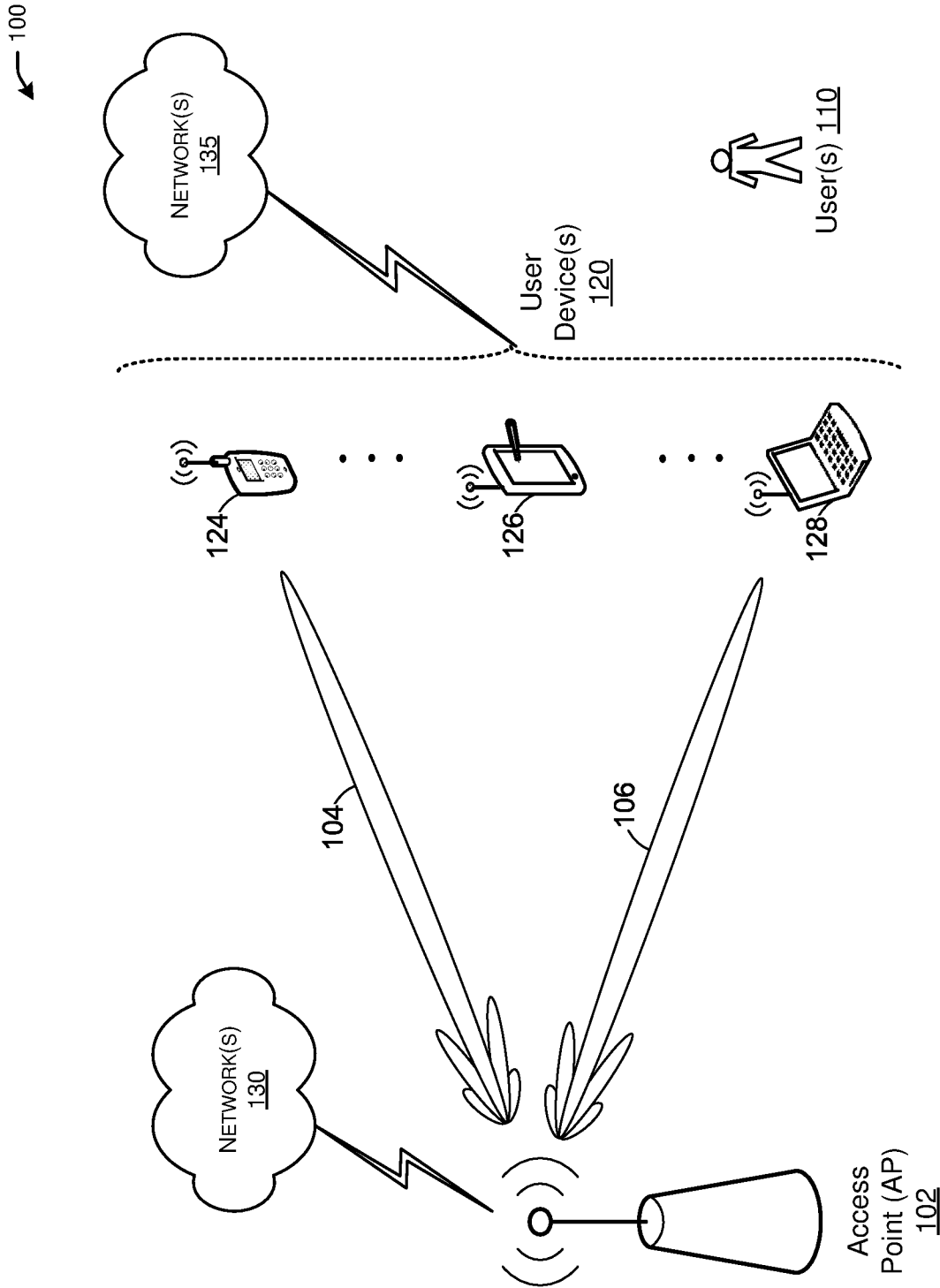
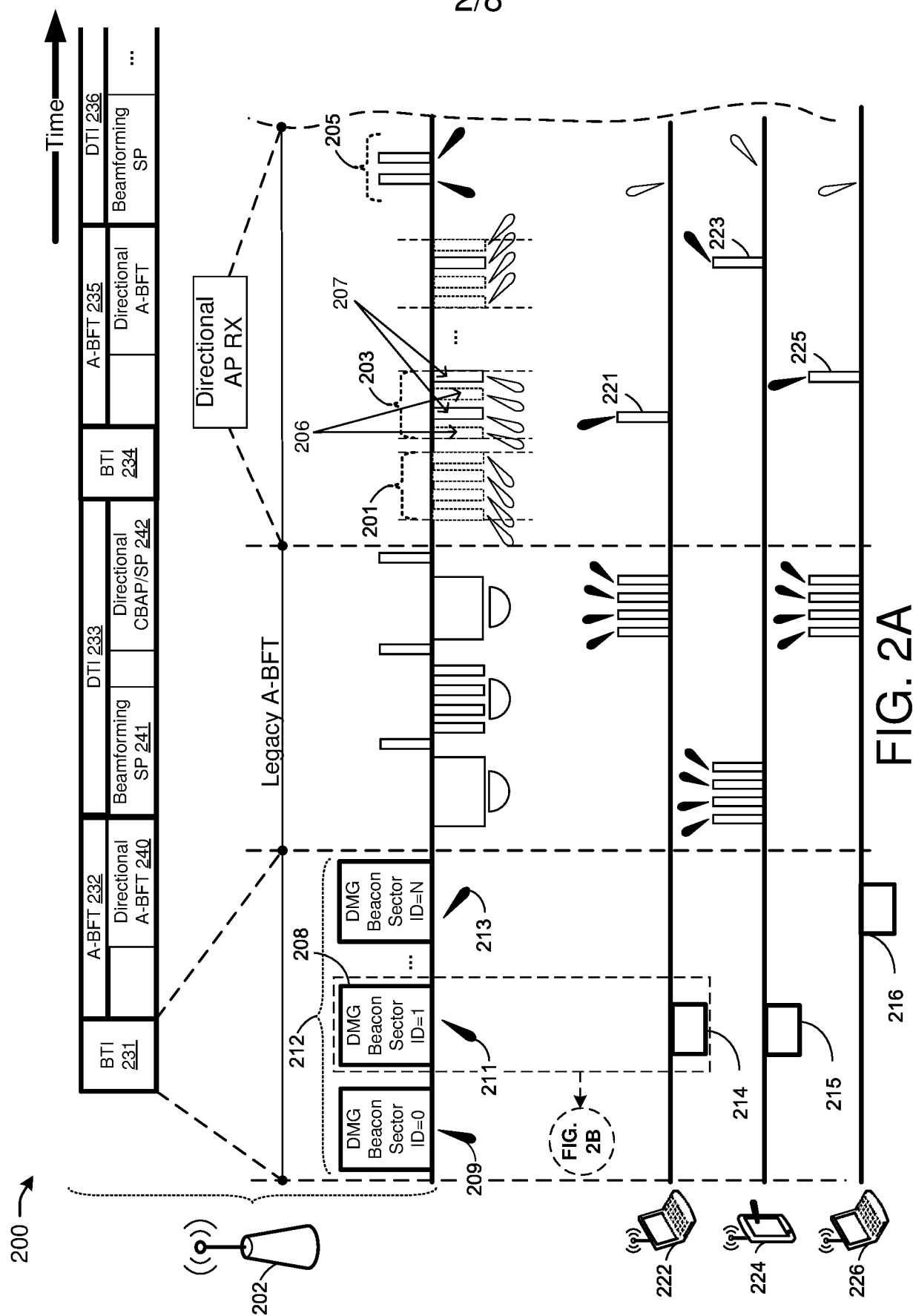


FIG. 1



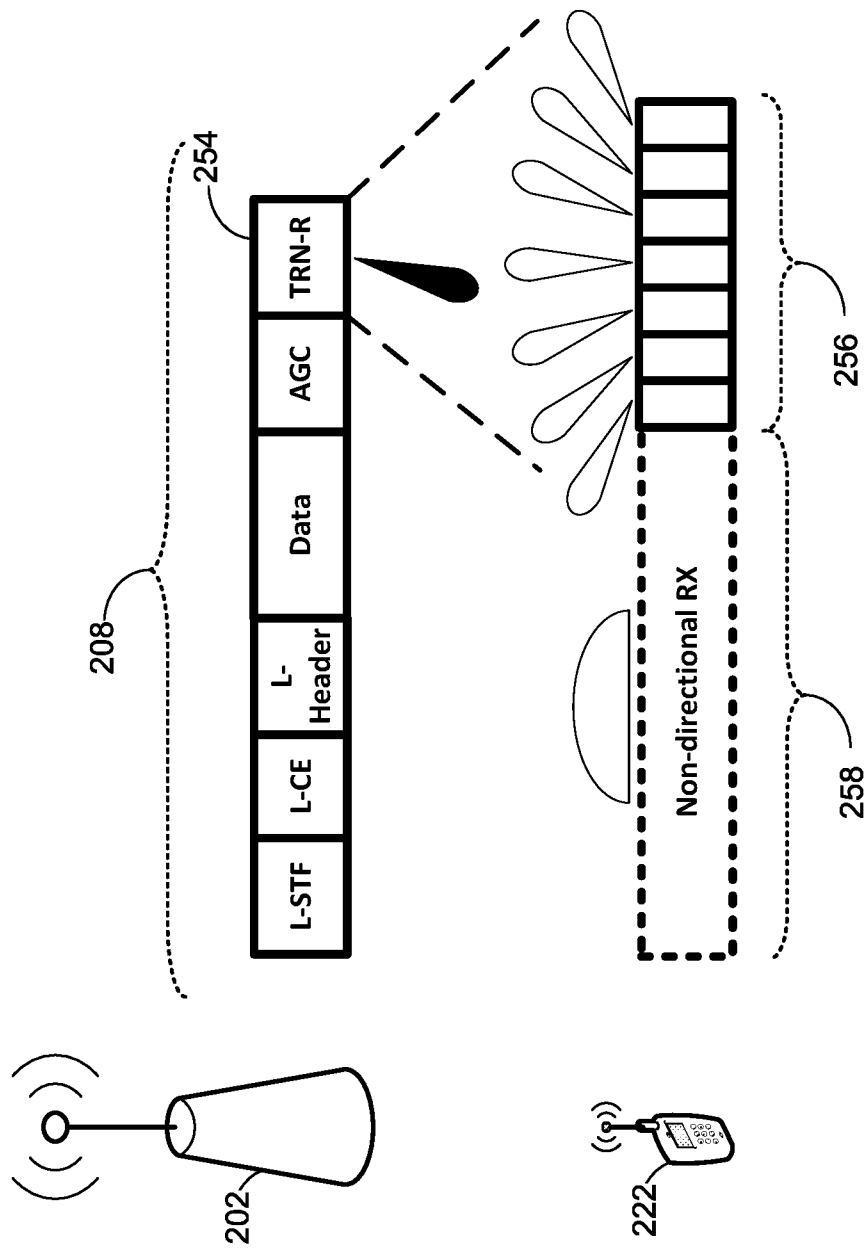


FIG. 2B

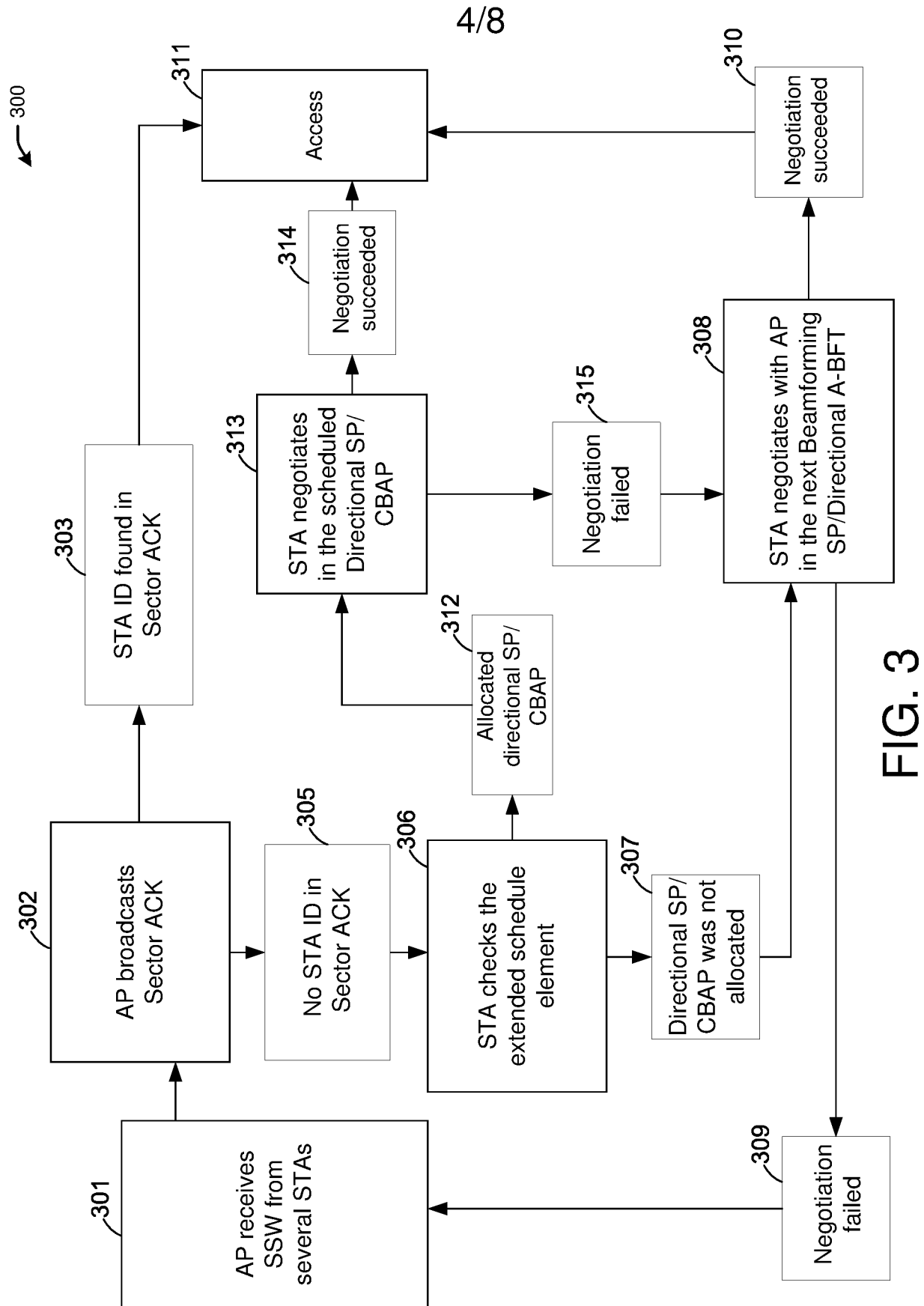


FIG. 3

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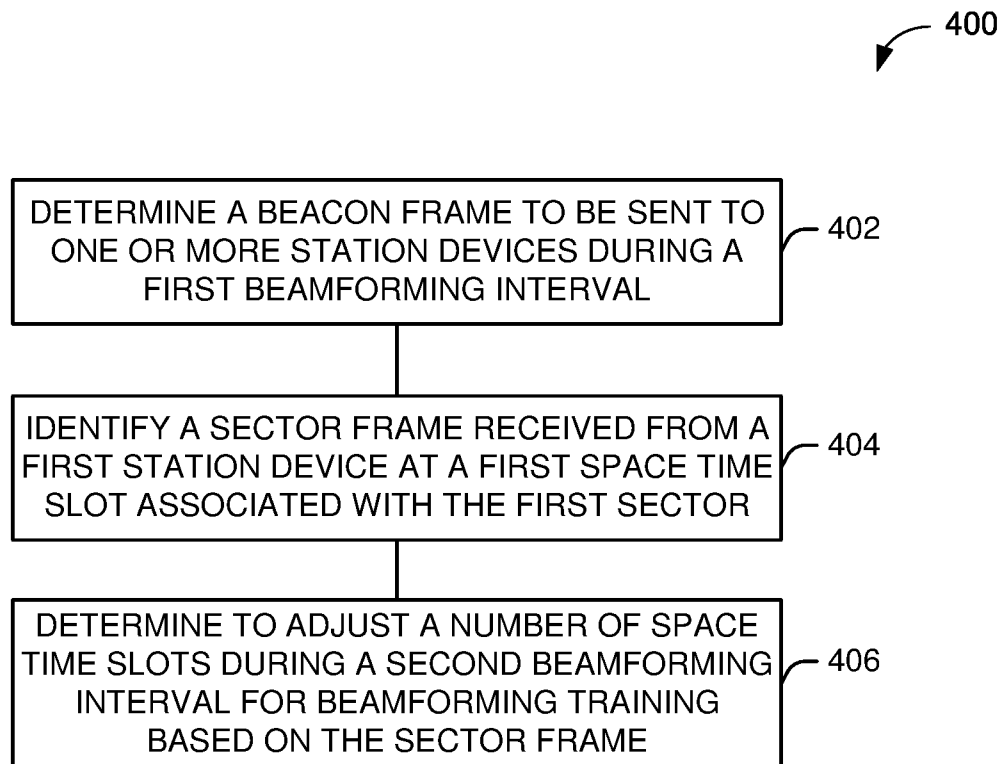


FIG. 4A

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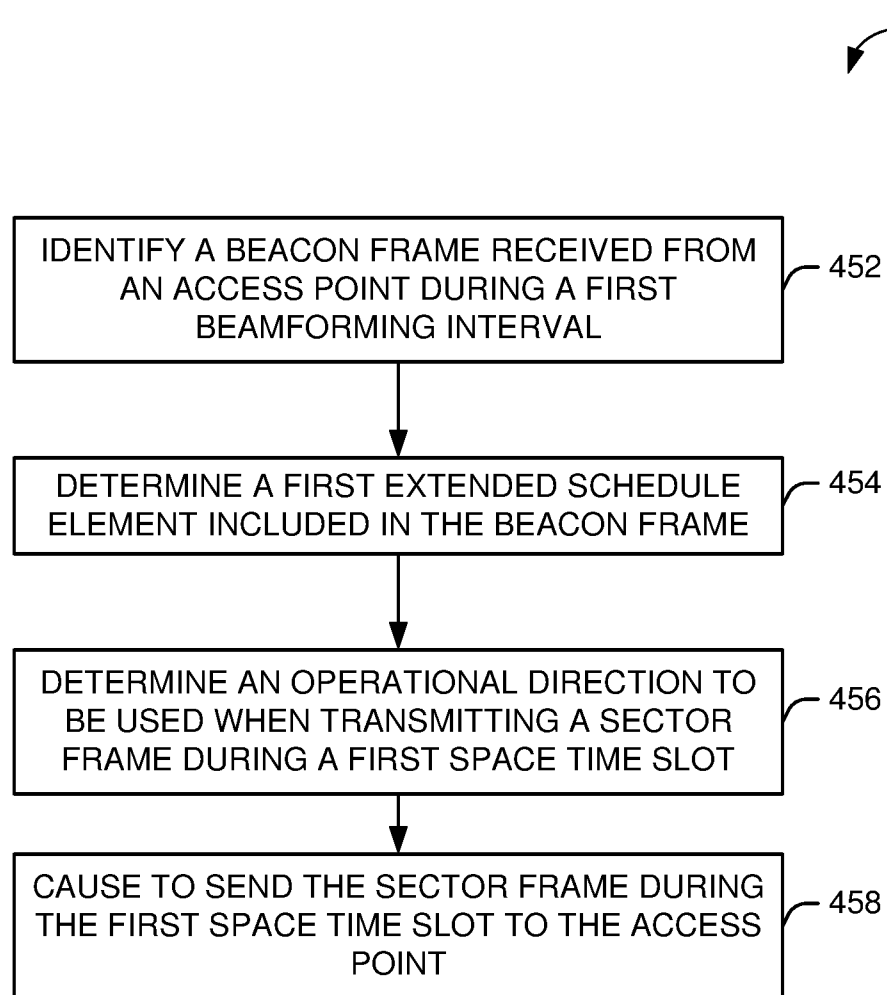


FIG. 4B

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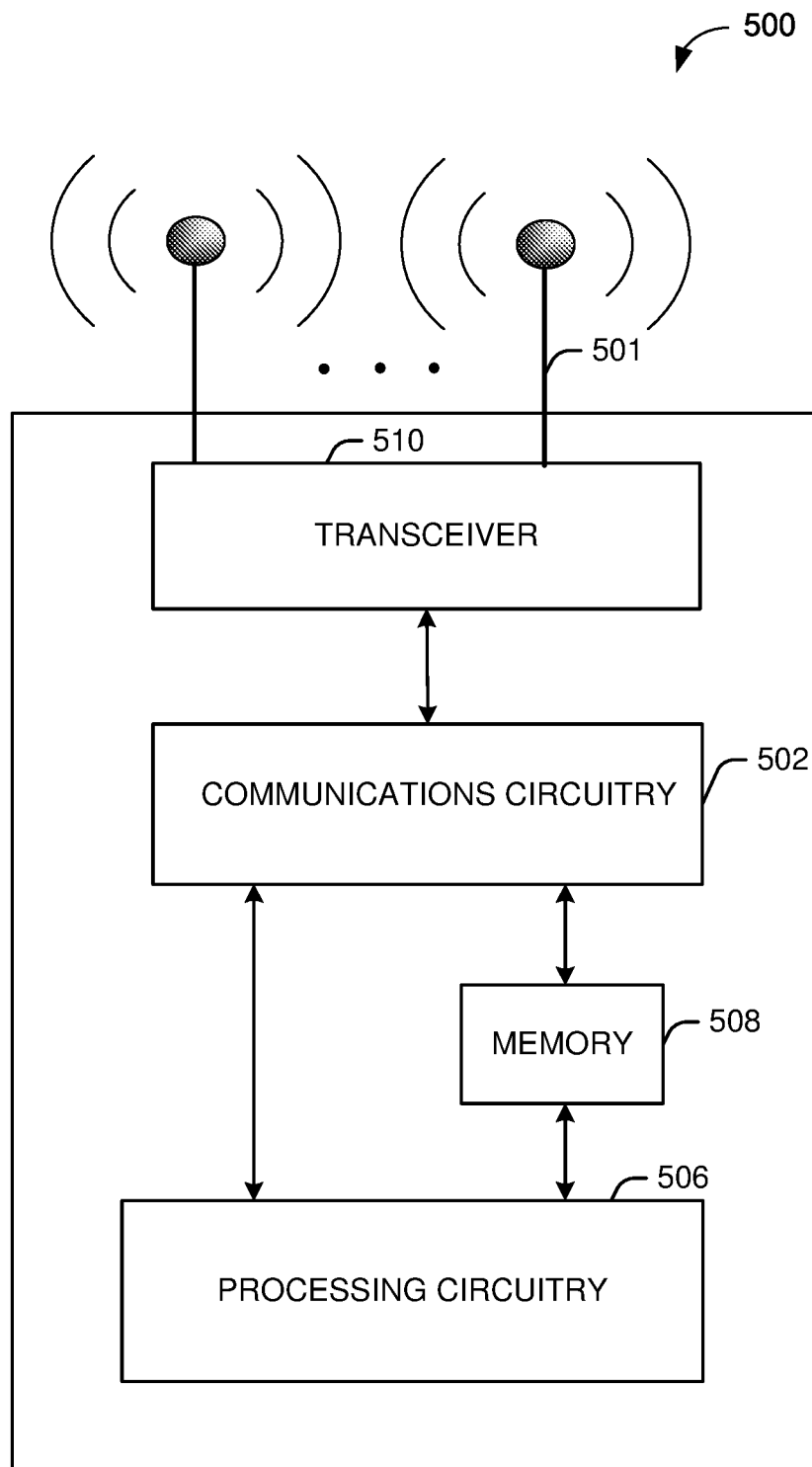


FIG. 5

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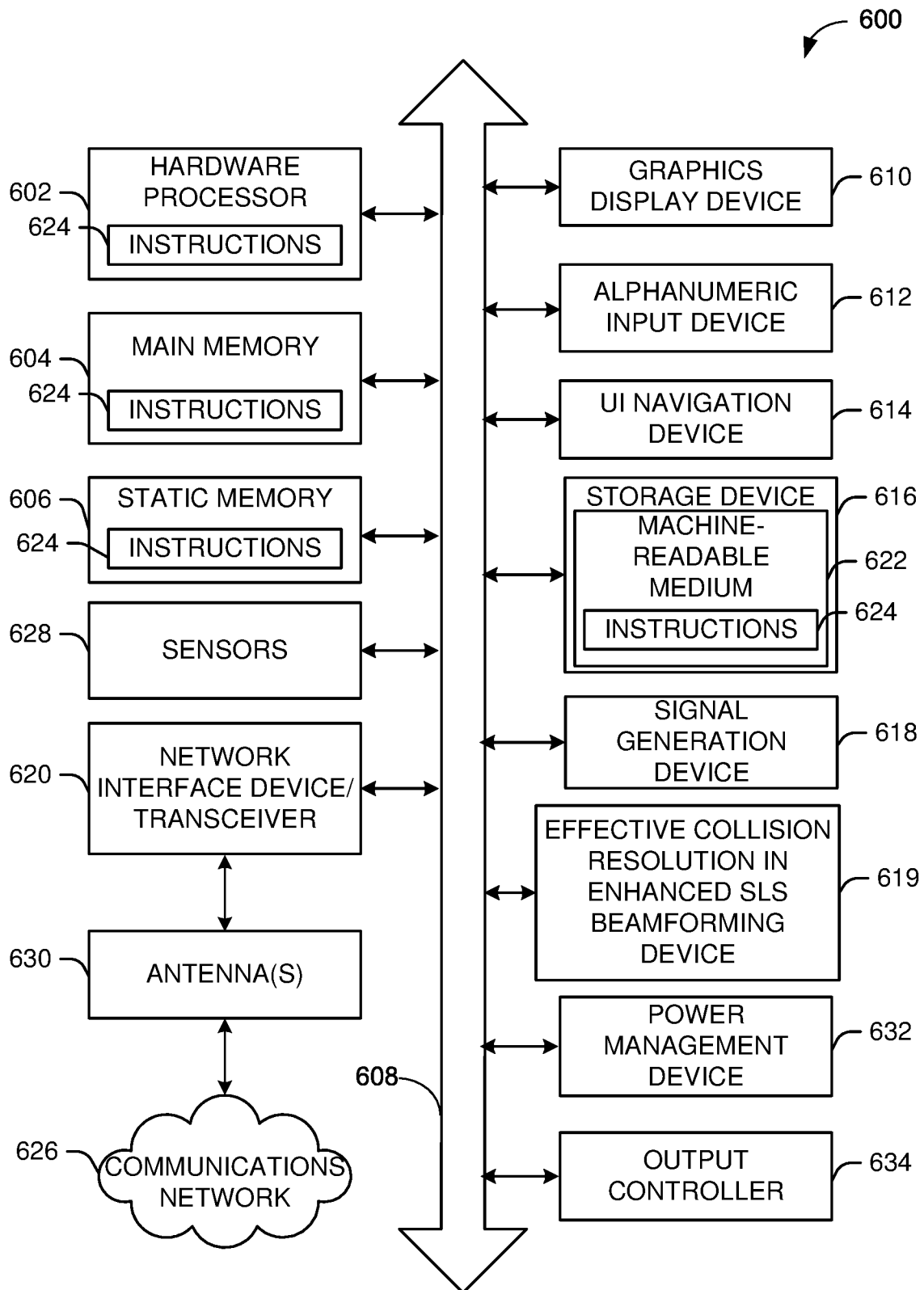


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/068321**A. CLASSIFICATION OF SUBJECT MATTER****H04W 16/28(2009.01)i, H04W 72/04(2009.01)i, H04W 74/08(2009.01)i, H04B 7/0491(2017.01)i**

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W 16/28; H01Q 3/40; H04W 4/00; H04W 72/04; H04W 72/08; H04W 72/00; H04B 7/04; H04W 74/08; H04B 7/0491

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: beamforming training interval, beacon frame, sector frame, space time slot, adjust

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2015-0103756 A1 (BROADCOM CORPORATION) 16 April 2015 See paragraphs [0025]-[0032], [0048]-[0049]; claim 1; and figures 1, 6.	1-25
A	US 8743838 B2 (MICHELLE X. GONG et al.) 03 June 2014 See column 5, lines 1-4; column 8, lines 17-59; and claim 1.	1-25
A	US 2017-0079031 A1 (ALEXANDER ALEXANDROVICH MALTSEV, JR. et al.) 16 March 2017 See paragraphs [0047]-[0057]; and figure 3.	1-25
A	US 2011-0080898 A1 (CARLOS CORDEIRO et al.) 07 April 2011 See paragraphs [0048]-[0051]; and claim 1.	1-25
A	US 2016-0329938 A1 (LG ELECTRONICS INC.) 10 November 2016 See paragraphs [0036]-[0038]; and figure 3.	1-25



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

17 April 2018 (17.04.2018)

Date of mailing of the international search report

18 April 2018 (18.04.2018)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea

Facsimile No. +82-42-481-8578

Authorized officer

KANG, Hee Gok

Telephone No. +82-42-481-8264



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/068321

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US 2011-0080898 A1	07/04/2011	CN 102036258 A CN 102036258 B CN 104079334 A EP 2486669 A2 EP 2824982 A1 IN 2859DEN2012 A JP 05-390711 B2 JP 2013-507088 A RU 2496231 C1 US 2014-0161105 A1 US 8625565 B2 US 9414380 B2 WO 2011-043901 A2 WO 2011-043901 A3	27/04/2011 30/07/2014 01/10/2014 15/08/2012 14/01/2015 24/07/2015 15/01/2014 28/02/2013 20/10/2013 12/06/2014 07/01/2014 09/08/2016 14/04/2011 21/07/2011
US 2016-0329938 A1	10/11/2016	None	