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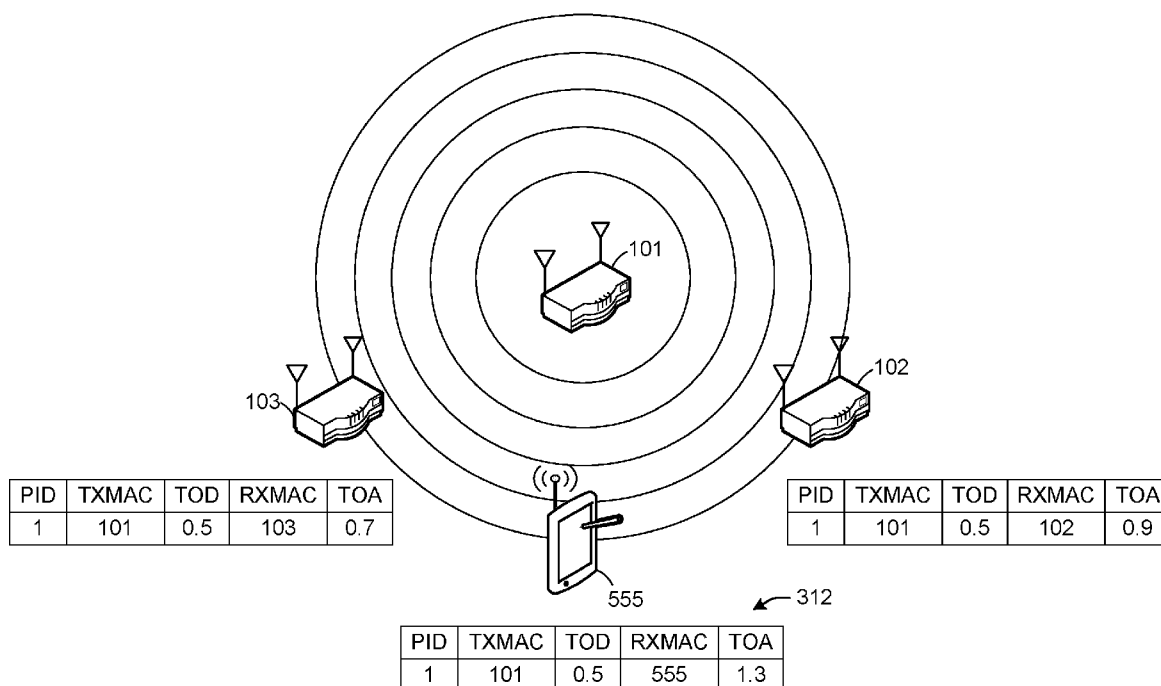
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(57) Abstract: This disclosure describes systems, methods, and devices related to a collaborative time-of-arrival protocol. A device may determine a first location associated with a first responder device of one or more responder devices. The device may determine a second location associated with a second responder device of the one or more responder devices. The device may identify a first CToA measurement frame indicating one or more first location determination parameters, received from the first responder device, the first broadcast measurement frame comprising a first null data packet announcement (NDPA) and a first null data packet (NDP), separated by a short interframe spacing (SIFS). The device may determine a third location associated with the device based on the one or more first location determination parameters, the one or more second location determination parameters, the first location, and the second location.

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## WIRELESS DEVICE POSITIONING AND NAVIGATION

### **CROSS-REFERENCE TO RELATED APPLICATIONS**

[0001] This application claims the benefit of U.S. Provisional Application 62/470,699 filed on March 13, 2017, the disclosure of which is incorporated herein by reference as if set forth in full.

### **TECHNICAL FIELD**

[0002] This disclosure generally relates to systems, methods, and devices for wireless communications and, more particularly, wireless device positioning and navigation.

### **BACKGROUND**

10 [0003] Wireless devices are becoming widely prevalent and are increasingly requesting access to wireless channels. IEEE 802.11 is a specification for implementing wireless local area network (WLAN) communication between the wireless devices. IEEE 802.11 plays an important role in the growing application of indoor and outdoor location of the wireless devices.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0004] FIG. 1 depicts a diagram illustrating an example network environment of an illustrative collaborative time-of-arrival (CToA) system, in accordance with one or more example embodiments of the present disclosure.

20 [0005] FIG. 2 depicts an illustrative schematic diagram for a CToA system, in accordance with one or more example embodiments of the present disclosure.

[0006] FIG. 3 depicts an illustrative schematic diagram for a CToA system, in accordance with one or more example embodiments of the present disclosure.

[0007] FIG. 4 depicts an illustrative schematic diagram for a CToA system, in accordance with one or more example embodiments of the present disclosure.

25 [0008] FIG. 5 depicts an illustrative schematic diagram for a CToA system, in accordance with one or more example embodiments of the present disclosure.

[0009] FIGs. 6A-6B depict illustrative schematic diagrams for a CToA system, in accordance with one or more example embodiments of the present disclosure.

30 [0010] FIG. 7A depicts a flow diagram of an illustrative process for a CToA system, in accordance with one or more example embodiments of the disclosure.

[0011] FIG. 7B depicts a flow diagram of an illustrative process for a CToA system, in accordance with one or more example embodiments of the disclosure.

[0012] FIG. 8 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.

[0013] FIG. 9 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 example  
5 embodiments of the present disclosure.

### **DETAILED DESCRIPTION**

[0014] Example embodiments described herein provide certain systems, methods, and devices, for wireless device positioning and navigation using collaborative time of arrival.

10 [0015] 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.

15 [0016] Fine timing measurement (FTM) protocol is used to determine a client device's location. FTM is typically is a point-to-point protocol. For example, one FTM responder and one FTM receiver can establish a connection to each other and exchange a few messages in order to establish timing measurements that could be translated into a range measurement between the FTM responder and the FTM receiver. This process also has to be repeated with  
20 other FTM responders.

[0017] Currently, no unidirectional packet format exists that enables an unlimited number of client devices to estimate their location – both indoors and outdoors.

[0018] Example embodiments of the present disclosure relate to systems, methods, and devices for wireless device positioning and navigation.

25 [0019] In one embodiment, a wireless device positioning and navigation system may define a unidirectional protocol to enable client-receiver devices, to estimate and track their own geographical position. The suggested protocol and position estimation algorithm enable unlimited system capacity in terms of the number of client receivers that can be supported simultaneously. Aside from the unlimited capacity enabled by the devised system, the  
30 wireless device positioning and navigation system may rely on a network of unsynchronized Wi-Fi/IEEE802.11 responders, which makes the solution efficient and desirable, as well as capable of providing high-accuracy indoor navigation. The wireless device positioning and

navigation system is termed throughout this disclosure as a collaborative time-of-arrival (CToA) system.

[0020] In one embodiment, the transmitter devices (also referred to CToA broadcasting stations or bSTA), which are unsynchronized, independent and stationed at locations known to client devices, periodically broadcast FTM measurement frames, which consist of an announcement packet, containing the format and relevant data for the required measurement, followed by a null data packet (NDP) frame for the actual timing measurement. Transmitter devices may be implemented as an 802.11 access point (AP) or 802.11 FTM responders (in both cases, device firmware should be modified). The receivers are both the client devices, as well as peer responder devices. The bSTAs broadcast their measurements such that the client devices can combine their own time delay measurements with the bSTA reported measurements in order to obtain an estimate of their own location.

[0021] In one embodiment, a CToA system may determine the actual client device position estimation similar to the trilateration location principles, which are used in a global navigation satellite system (GNSS). Aside from its ability to provide location service indoors and in areas where GNSS does not have sufficient coverage, a difference between CToA and GNSS is in the fact that from the client device viewpoint, all GNSS satellites are synchronized (using atomic clocks, which are observed and controlled by the system ground control segment). As a result, the client device has to estimate and track its clock offset with respect to the offset of the system. In CToA, the “satellites” (i.e., the bSTAs) are unsynchronized and independent (i.e., unlike GNSS there is no explicit “control segment” that tracks and controls the bSTA clock and status). Hence, the client device needs to estimate and track the offset (and drift) between its own clock and each responder clock.

[0022] For example, each of the responder devices may be running with its own independent clock sources, which are unsynchronized. The CToA system is established to provide geolocation services to a number of client receivers. The CToA system uses cheap crystals (XTALs) in unsynchronized Wi-Fi FTM responders (referred to as CToA broadcasting stations or bSTA), to build a high-precision geolocation network. These bSTAs are independent of each other, they are not connected to each other, they do not report to a centric server, they are not wire connected to any server, and they are not synchronized with each other. The CToA client receivers are referred to a cSTAs. Each of the bSTA broadcast a CToA measurement frame, which is independent of other bSTAs.

[0023] The CToA system is different from an FTM system because it has fewer frame exchanges, and there are no time constraints as in an FTM system. Typically, FTM is a

point-to-point protocol. For example, one FTM responder and one FTM receiver can establish a connection to each other and exchange at least six messages in order to establish timing measurements that could be translated into a range measurement between the FTM responder and the FTM receiver. This process also has to be repeated with other FTM responders. In a CToA system, multiple bSTAs' help determine the location (or range) of a cSTA.

[0024] In one embodiment, a CToA system may define a CToA broadcast to comprise two packets separated by a short inter-frame space (SIFS) interval of time. These two packets may make a periodic transmission that consists of an IEEE 802.11az null data packet announcement (NDPA) and a null data packet (NDP). The CToA system may send one or more CToA broadcast frames to one or more cSTAs. The NDPA and the NDP may include additional information to support the CToA system, such as time of departure (ToD), and enables time of arrival (ToA) measurement.

[0025] In one embodiment, a CToA system may facilitate that each bSTA broadcasts a CToA measurement frame periodically, and measures the ToD of that measurement frame. In one embodiment, each bSTA receives the CToA measurement frames transmitted by its neighbor bSTA and measures the ToA of the CToA measurement frames. In one embodiment, a bSTA publishes its ToA and ToD measurements of its neighbor bSTAs CToA measurement frames to other devices with the transmission range of the bSTA.

[0026] In one embodiment, a CToA system may facilitate that a cSTA receives and does not have to transmit any messages related to the measurement. In contrast, in FTM and other measurement protocols, the client device must initiate and transmit some messages in order to perform ranging or location determination.

[0027] In one embodiment, a CToA system may facilitate that a cSTA may broadcast a report of what the cSTA has collected from one or more bSTAs (e.g., a neighbors report). For example, a cSTA may use a CToA broadcast announcement frame in order to broadcast the report. The report may be sent periodically or at a predetermined time. For example, it may be sent after a certain number of entries have been added to a memory.

[0028] In one embodiment, similar to bSTA, each cSTA also receives the CToA measurement frame broadcast coming from other bSTAs and measures their ToA. The cSTA would store that information in memory. Further, the cSTA collects the ToA and ToD measured and published by the bSTAs. The cSTA may use all of the information to calculate its own position.

[0029] 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 detail below. Example embodiments will now be described with reference to the accompanying figures.

5 [0030] FIG. 1 is a diagram illustrating an example network environment of a cooperative time-of-arrival (CTOA) system, in accordance with one or more example embodiments of the present disclosure. Wireless network 100 may include one or more user devices 120 and one or more access point(s) (AP) 102, which may communicate in accordance with IEEE 802.11 communication standards, including IEEE 802.11ax. The user device(s) 120 may be mobile  
10 devices that are non-stationary (e.g., not having fixed locations) or may be stationary devices.

[0031] In some embodiments, the user devices 120 and the AP 102 may include one or more computer systems similar to that of the functional diagram of FIG. 8 and/or the example machine/system of FIG. 9.

[0032] One or more illustrative user device(s) 120 and/or AP(s) 102 may be operable by  
15 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)  
20 120 and/or AP(s) 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(s) 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(s) 102 may include, a user equipment (UE), a station (STA), an access point (AP), a software enabled AP  
25 (SoftAP), 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  
30 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. Other devices, including smart devices such as lamps, climate control, car components, household components, appliances, etc. may also be included in this list.

[0033] As used herein, the term “Internet of Things (IoT) device” is used to refer to any object (e.g., an appliance, a sensor, etc.) that has an addressable interface (e.g., an Internet protocol (IP) address, a Bluetooth identifier (ID), a near-field communication (NFC) ID, etc.) and can transmit information to one or more other devices over a wired or wireless connection. An IoT device may have a passive communication interface, such as a quick response (QR) code, a radio-frequency identification (RFID) tag, an NFC tag, or the like, or an active communication interface, such as a modem, a transceiver, a transmitter-receiver, or the like. An IoT device can have a particular set of attributes (e.g., a device state or status, such as whether the IoT device is on or off, open or closed, idle or active, available for task execution or busy, and so on, a cooling or heating function, an environmental monitoring or recording function, a light-emitting function, a sound-emitting function, etc.) that can be embedded in and/or controlled/monitored by a central processing unit (CPU), microprocessor, ASIC, or the like, and configured for connection to an IoT network such as a local ad-hoc network or the Internet. For example, IoT devices may include, but are not limited to, refrigerators, toasters, ovens, microwaves, freezers, dishwashers, dishes, hand tools, clothes washers, clothes dryers, furnaces, air conditioners, thermostats, televisions, light fixtures, vacuum cleaners, sprinklers, electricity meters, gas meters, etc., so long as the devices are equipped with an addressable communications interface for communicating with the IoT network. IoT devices may also include cell phones, desktop computers, laptop computers, tablet computers, personal digital assistants (PDAs), etc. Accordingly, the IoT network may be comprised of a combination of “legacy” Internet-accessible devices (e.g.,

laptop or desktop computers, cell phones, etc.) in addition to devices that do not typically have Internet-connectivity (e.g., dishwashers, etc.).

[0034] The user device(s) 120 and/or AP(s) 102 may also include mesh stations in, for example, a mesh network, in accordance with one or more IEEE 802.11 standards and/or 3GPP standards.

[0035] Any of the user device(s) 120 (e.g., user devices 124, 126, 128), and AP(s) 102 may be configured to communicate with each other via one or more communications networks 130 and/or 135 wirelessly or wired. The user device(s) 120 may also communicate peer-to-peer or directly with each other with or without the AP(s) 102. 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.

[0036] Any of the user device(s) 120 (e.g., user devices 124, 126, 128) and AP(s) 102 may include one or more communications antennas. The one or more communications antennas may be any suitable type of antennas corresponding to the communications protocols used by the user device(s) 120 (e.g., user devices 124, 126 and 128), and AP(s) 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, omnidirectional antennas, quasi-omnidirectional antennas, or the like. The one or more communications antennas may be communicatively coupled to a radio component to transmit

and/or receive signals, such as communications signals to and/or from the user devices 120 and/or AP(s) 102.

[0037] Any of the user device(s) 120 (e.g., user devices 124, 126, 128), and AP(s) 102 may be configured to perform directional transmission and/or directional reception in conjunction with wirelessly communicating in a wireless network. Any of the user device(s) 120 (e.g., user devices 124, 126, 128), and AP(s) 102 may be configured to perform such directional transmission and/or reception using a set of multiple antenna arrays (e.g., DMG antenna arrays or the like). Each of the multiple antenna arrays may be used for transmission and/or reception in a particular respective direction or range of directions. Any of the user device(s) 120 (e.g., user devices 124, 126, 128), and AP(s) 102 may be configured to perform any given directional transmission towards one or more defined transmit sectors. Any of the user device(s) 120 (e.g., user devices 124, 126, 128), and AP(s) 102 may be configured to perform any given directional reception from one or more defined receive sectors.

[0038] MIMO beamforming in a wireless network may be accomplished using radio frequency (RF) beamforming and/or digital beamforming. In some embodiments, in performing a given MIMO transmission, the user devices 120 and/or the AP(s) 102 may be configured to use all or a subset of its one or more communications antennas to perform MIMO beamforming.

[0039] Any of the user devices 120 (e.g., user devices 124, 126, 128), and the AP(s) 102 may include any suitable radio and/or transceiver for transmitting and/or receiving RF signals in the bandwidth and/or channels corresponding to the communications protocols utilized by any of the user device(s) 120 and the AP(s) 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 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 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 a digital baseband.

[0040] In one embodiment, and with reference to FIG. 1, a collaborative time-of-arrival  
5 protocol 140 may be implemented between one or more AP(s) 102 and the user device(s) 120, in accordance with one or more example embodiments of the present disclosure. It is understood that the above descriptions are for purposes of illustration and are not meant to be limiting.

[0041] In one embodiment, a CToA system may determine a user device 120 position  
10 estimation similar to the trilateration location principles, which are used in GNSS. Aside from its ability to provide location service indoors and in areas where GNSS does not have sufficient coverage, a difference between CToA and GNSS is in the fact that from the client viewpoint, all GNSS satellites are synchronized (using atomic clocks, which are observed and controlled by the system ground control segment). As a result, the client has to estimate and  
15 track its clock offset with respect to the offset of the system. In CToA, the responder devices (e.g., the APs 102) are unsynchronized and independent. Hence, a user device 120 needs to estimate and track the offset (and drift) between its own clock and each AP 102 clock.

[0042] For example, each of the APs 102 may be running with its own independent clock  
20 sources, which are unsynchronized. The CToA system is established to provide geolocation services to a number of user devices 120. The CToA system uses cheap, unsynchronized, Wi-Fi responders (referred to as CToA broadcasting stations or bSTA), to build a high-precision geolocation network. These bSTAs (e.g., APs 102) are independent of each other, they do not need to be connected to each other, they do not report to a centric server, they are not wire connected to any server, and they are not synchronized with each other. The CToA  
25 user devices 120 are referred to as cSTAs. Each of the bSTA broadcast a CToA measurement frame, which is independent of other bSTAs' CToA measurement frames.

[0043] FIG. 2 depicts an illustrative schematic diagram for a CToA system, in accordance with one or more example embodiments of the present disclosure.

[0044] Referring to FIG. 2, there is shown one or more responder devices (e.g., responder  
30 devices 202 and 204) that may communicate with one or more receiver devices (e.g., user devices 222, 224, and/or 226).

[0045] In one embodiment, the one or more responder devices may each transmit a CToA measurement frame (e.g., CToA measurement frames 230 and 232) that may be transmitted

periodically in the CToA network, and may be received by the one or more receiver devices that are located within the coverage area of the CToA network.

[0046] Each responder device (e.g., responder devices 202 and 204) periodically transmits a CToA measurement frame (e.g., CToA measurement frames 230 and 232). The CToA measurement frame may be comprised of two frames, separated by a short inter-frame space (SIFS) period 236 (about 16  $\mu$ sec). The first frame may be a positioning NDP announcement frame (PNDP-A) 234, which can also be referred to as NDPA. The second frame may be an NDP 238. The PNDP-A 234 may be used for one or more purposes. A purpose may be to convey positioning-related information, such as packet ID number, time of departure (ToD) of the NDP, the media access control (MAC) address of the transmitter, location configuration information (LCI), neighbor responders' event report, etc. Another purpose may be to announce the transmission of the NDP frame. The second frame may be an NDP. The NDP may be used by a receiver device to estimate the time delay between the transmitter (e.g., responder device) and the receiver device, by measuring the time of arrival (ToA).

[0047] In one embodiment, a CToA system may define the two packets PNDP-A 234, and NDP 238 may be periodic transmissions that may be IEEE 802.11az NDPA and NDP. The CToA system may send one or more CToA measurement frame frames to one or more cSTAs. The PNDP-A 234 and the NDP 238 may include additional information to support the CToA system, such as time of departure (ToD), and enables time of arrival (ToA) measurement. Other information may include the LCI. In some examples, a bSTA may send the LCI associated with other bSTAs or may only send its own LCI.

[0048] In one embodiment, a CToA system may facilitate that each bSTA broadcasts CToA measurement frame periodically, and measures the ToD of that CToA measurement frame. In one embodiment, each bSTA receives the CToA measurement frames transmitted by its neighbor bSTA and measures the ToA of the CToA measurement frames. In one embodiment, a bSTA publishes its ToA and ToD measurements of its neighbor bSTAs CToA measurement frames to other devices with the transmission range of the bSTA.

[0049] It is understood that the above descriptions are for purposes of illustration and are not meant to be limiting.

[0050] FIG. 3 depicts an illustrative schematic diagram for a CToA system, in accordance with one or more example embodiments of the present disclosure.

[0051] Referring to FIG. 3, there is shown an example where the CToA system consists of three Wi-Fi responder devices (e.g., responder devices 101, 102, and 103) that are capable

of measuring time delays (e.g., FTM). The responder devices 101, 102, and 103 have MAC addresses 101, 102, and 103, respectively. Within the coverage area of each responder device, there may be a single client mobile device (e.g., user device 555), with MAC address 555. The user device 555 may use the three responder device transmissions to estimate its  
5 location.

[0052] In this example, the first responder device 101 is shown to transmit a CToA measurement frame (comprised of a P-NDPA announcement frame, followed by an NDP frame after an SIFS time). The CToA measurement frame may be received by the two other responder devices 102 and 103, as well as the user device 555. Upon the CToA measurement  
10 frame's reception, each of the receiving devices (e.g., responder devices 102 and 103, and user device 555) that receive the CToA measurement frame may update a database stored in memory that may contain parameters such as packet ID (PID), MAC address of the transmitting device (e.g., the responder device 101), the time of departure (ToD) (as reported by the responder device 101), the MAC address of the receiving device, and the measured  
15 time of arrival (ToA) at the receiving device. Additionally and/or alternatively, the CToA measurement frame may also contain the known location of the transmitting device.

[0053] For example, at the user device 555, entry 312 that may be used to update the database in the memory of the user device 555 may contain a packet ID of 1, the MAC address of the responder device 101, the ToD of the CToA measurement frame of 0.5 units in  
20 time, the MAC address of the user device 555, and the ToA of 1.3 units in time. Similar table entries (e.g., table entries 313 and 315) would be maintained at each of the devices that receive the CToA measurement frame sent by the responder device 101. It is understood that the above descriptions are for purposes of illustration and are not meant to be limiting.

[0054] FIG. 4 depicts an illustrative schematic diagram for a CToA system, in accordance  
25 with one or more example embodiments of the present disclosure.

[0055] Referring to FIG. 4 and still referring to FIG. 3, there is shown that the responder device 102 now transmits its own CToA measurement frame. The CToA measurement frame is received by the user device 555 and by the responder device 101. It should be noted here that the responder device 103 is shown to be outside of the coverage area of the responder  
30 device 102 and therefore does not receive the CToA measurement frame from the responder device 102. Upon reception of the CToA measurement frame of the responder device 102, the user device 555, and the responder device 101 may update the database stored in memory that may contain previous entries that were captured during reception of other CToA measurement frames as was shown in FIG. 3 with the additional table entry for PID 5. The

resulting table entries at each device may be shown as table entry 413 at the responder device 101 and as table entry 415 at the user device 555.

[0056] In this example, the responder device 101 may capture information that was part of the CToA measurement frame sent by the responder device 102. Similarly, the user device 555 may identify information that was part of the CToA measurement frame sent by the responder device 102. In this case, the user device 555 now has two entries to reflect the data collected from the first CToA measurement frame received from responder device 101 as was done in FIG. 3 and from the second CToA measurement frame received from the responder device 102.

[0057] It is understood that the above descriptions are for purposes of illustration and are not meant to be limiting.

[0058] FIG. 5 depicts an illustrative schematic diagram for a CToA system, in accordance with one or more example embodiments of the present disclosure.

[0059] Referring to FIG. 5 and still referring to FIGs. 3 and 4, there is shown that the responder device 103 transmits a CToA measurement frame, which is received by responder device 101 and the user device 555. In this example, the responder device 102 does not receive the CToA measurement frame, for example, due to being out of reception range.

[0060] In one embodiment, a CToA system may facilitate that each responder device may broadcast a measurement announcement frame (NDPA) containing a “neighbors report,” every X seconds, where X is a positive integer. The neighbors report may consist of all of the TX/RX events it has logged during the past X seconds. The value of X may be a positive integer that may be configurable. It may be configured by a system administrator, by a network administrator, by a user, etc. For example, the responder device 101 will have two entries in its database based on FIG. 4 and FIG. 5 CToA measurement frames. These two entries are shown to have PIDs 5 and 17. These PIDs are received from the responder devices 102 (as shown in FIG. 4) and 103 (as shown in FIG. 5), respectively. The responder device 101 may then generate a neighbors report 513 that comprises these entries for the respective PIDs and broadcast those to other devices within its range. Similarly, the user device 555 had entries 415 from FIG. 4, and by receiving the CToA measurement frame from responder device 103, it now has three entries as shown in table 515.

[0061] It is understood that the above descriptions are for purposes of illustration and are not meant to be limiting.

[0062] FIGs. 6A-6B depicts illustrative schematic diagrams for a CToA system, in accordance with one or more example embodiments of the present disclosure.

[0063] FIG. 6A depicts a neighbors report broadcast by the responder device 101, and FIG. 6B depicts the neighbors report broadcast by responder device 102.

[0064] Referring to FIG. 6A, and still referring to FIGs. 3-5, the responder device 101 may have in its database one or more entries that may be used to form the neighbors report  
5 600. The responder device 101 may broadcast the neighbors report 600 to devices within its range. For example, the responder device 101 may broadcast the neighbors report 600 to responder devices 102 and 103 and user device 555. The neighbors report 600 may be received by these devices, which may then be added to their respective databases or tables.

[0065] Referring to FIG. 6B, and still referring to FIGs. 3-6A, the responder device 102  
10 may transmit its neighbors report 650, where the neighbors report 650 contains one or more entries in a database or a table that reflects one or more measurements taken or received from one or more CToA measurement frames during a predetermined period. In this example, the neighbors report 650 contains three entries at the responder device 102. These entries may be tagged by all referenced by a PID. For example, the PID 1 entry contains information about  
15 the transmitting device MAC address, the time of departure of the CToA measurement frame transmitted by the transmitting device, the receiving device MAC address, and the time of arrival. It should be noted that the time of departure is measured at the transmitting device (e.g., responder device 101) and the time of arrival is measured at the receiving device (e.g., responder device 102). It should also be noted that the database or table that is maintained on  
20 the responder device 102 contains the neighbors report 600 that was received by the responder device 102 from the responder device 101 (FIG. 6A). The neighbors report 650 may be received by the one or more responder devices and by the user device 555. The user device 555 may have already included in its table information received in the neighbors report 600 of FIG. 6A. When the user device 555 receives the neighbors report 650, the user  
25 device 555 may add the entries retrieved from the neighbors report 650 into a cumulative table or database that may be an aggregation of all of the CToA measurement frames. In this example of FIG. 6B, the user device 555 may add the neighbors report 650 to an existing table or database that may have been maintained by the user device 555.

[0066] In one embodiment, a CToA system may facilitate that a client device (e.g., user  
30 device 555) may perform calculations to determine its fix or location whenever a certain criteria is met. The criteria may be based on the number of entries associated with a specific PID that may be found in the table or database maintained by the user device 555. In this example, after the user device 555 received the neighbors report 650, the user device 555 now has two sets of entries that are associated with a same PID. For example, the client

device initiates the determination of its location after determining that its table or database contains two sets of entries that have the same PID value. For example, PID 1 has two associated entries in the table or database of the user device 555.

[0067] In one embodiment, once the user device 555 receives this report, it may have  
5 sufficient information to estimate its initial fix using, for example, a Kalman filter algorithm. Further, the user device 555 may continue tracking and updating this estimate with every new measurement it receives, (where “measurement” in this context means any new broadcast measurement frames or report it receives from that point and onward).

[0068] In one embodiment, a CToA system may also be used for locating (legacy) Wi-Fi  
10 client devices that transmit any kind of Wi-Fi packet, which can be received by multiple responders.

[0069] In one embodiment, the CToA system may facilitate that the positioning algorithm that is executed by the user device 555 to determine its fix or location may be executed at a server entity within the network. The server entity may estimate and track the position of  
15 multiple devices within the network coverage area. The server entity may accomplish this task using the CToA measurement frame reports (e.g., neighbors reports) and the received client device packet information that can be delivered to it by the responders. For example, the server entity may collect the various neighbors reports every X seconds and may use, for example, a Kalman filter algorithm, or it may forward the neighbors reports to a device in  
20 order for the device to perform the Kalman filter algorithm in order to determine the devices fix or location. The Kalman filter may be used for estimating and tracking the cSTA position and the time-dependent clock offsets.

[0070] In one embodiment, the announcement packet (e.g., the P-NDPA and/or the NDP of the CToA measurement frame) may be sent as an OFDM broadcast frame according to the  
25 IEEE 802.11 standard, using any of the possible legacy, high throughput (HT), very high throughput (VHT) or high-efficiency (HE) packet formats. As part of the data field, the transmission should include the following fields: announcement packet structure – responder Neighbors Timing measurements as shown in Table 1.

[0071] Table 1: P-NDPA Mandatory Data

| Name                     | Description                                                                                                                                                                                                                                                                                                            |
|--------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Packet ID                | Mandatory field. The ID (TBD-bit field) of the CToA measurement packet. Can be used by the client receiver to associate the measurement with a similar measurement as observed by another responder.                                                                                                                   |
| TX Responder MAC address | Mandatory field per each transmitted packet. The MAC address of the responder that transmitted the CToA measurement frame.                                                                                                                                                                                             |
| ToD                      | Mandatory field per each transmitted packet. The time of transmission of the NDP packet. Could also be traced back to the P-NDPA time of transmission (through the counting of samples included in the P-NDPA – assuming that due to the short time, the clocks did not drift).<br>Resolution TBD (better than 1 nsec) |
| RX Responder MAC address | Mandatory field per each received NDP packet. The time of reception of the NDP packet. Could also be traced back to the P-NDPA time of reception (through the counting of samples included in the P-NDPA – assuming that due to the short time, the clocks did not drift).                                             |
| ToA                      | Mandatory field per each received packet. The time of arrival measured by the receiving responder.<br>Resolution TBD (better than 1 nsec)                                                                                                                                                                              |

[0072] Optionally, the P-NDPA frame may also include an event table aggregating and merging similar event tables broadcast by neighbor responders. Per each NDP transmit-receive event (i.e., PID), the table may contain multiple entries including the entries in Table

5 2:

[0073] Table 2: P-NDPA Data

| Name                                     | Description                                                                                                                                                                                                                                                                                                                |
|------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Packet ID                                | Mandatory field. The ID (TBD-bit field) of the CToA measurement packet. Can be used by the client receiver to associate the measurement with a similar measurement as observed by another responder.                                                                                                                       |
| TX Responder MAC address                 | Mandatory field per each transmitted packet. The MAC address of the responder that transmitted the CToA measurement frame/packet (the packet source).                                                                                                                                                                      |
| ToD                                      | Mandatory field per each transmitted packet. The time of transmission of the NDP packet. Could also be traced back to the P-NDPA time of transmission (through the counting of samples included in the P-NDPA – assuming that due to the short time, the clocks did not drift).<br><br>Resolution TBD (better than 1 nsec) |
| RX Responder MAC address                 | Mandatory field per each received NDP packet. The time of reception of the NDP packet. Could also be traced back to the P-NDPA time of reception (through the counting of samples included in the P-NDPA – assuming that due to the short time, the clocks did not drift).                                                 |
| ToA                                      | Mandatory field per each received packet. The time of arrival measured by the receiving responder.<br><br>Resolution TBD (better than 1 nsec)                                                                                                                                                                              |
| CToA measurement frame/packet Scheduling | Information regarding the next expected CToA measurement frame/packet transmission (to enable what clients do in-between, and enable other responders to target their next CToA measurement frame/packet accordingly).                                                                                                     |

[0074] Optionally, the location of all of the responders in the network (in LCI format) may be announced in a periodical frame broadcast by every responder in a pre-defined periodicity.

[0075] Additional fields related to, for example, angular estimation may optionally be included in order to enable a combined time-delay and angular location.

[0076] Following the announcement frame, an NDP is sent for the actual measurement. For only a timing estimation, the NDP is sent normally. It can be expected that the preambles  
5 use a special precoding and not the usual Hadamard precoding, which is used in 802.11 for data channel estimation.

[0077] Note that the receiver is not required to transmit back to the transmitter. In addition, a receiver that needs only angle/ranging information can ignore the redundant data. However, it is always required that the receivers defer their transmission during the  
10 announcement and NDP frames. It is understood that the above descriptions are for purposes of illustration and are not meant to be limiting.

[0078] In one embodiment, a CToA system may use the extended Kalman filter (EKF), which is the nonlinear version of the Kalman filter. The EKF linearizes an estimate of the current mean and covariance. The EKF may be assumed to be executed by the client  
15 receiver. A purpose of this algorithm is to estimate and track the following states (parameters): (1) the client receiver's position coordinates; and (2) per each transmitting responder, the responder's clock offset (with regard to receiving the client clock), the responder's clock drift (measured in [ppm]), and the responder's clock drift first and second derivatives.

[0079] Kalman filtering is an algorithm that uses a series of measurements observed over time, containing statistical noise and other inaccuracies, and produces estimates of unknown  
20 variables that tend to be more accurate than those based on a single measurement alone, by using Bayesian inference and estimating a joint probability distribution over the variables for each timeframe.

[0080] In one embodiment, each cSTA will have up to M clock offsets, where M is the number of bSTAs in the CToA network. Therefore, there are M unknown clock offsets that each cSTA must estimate in order to determine its location. This process is different from GNSS, because in GNSS there is only one clock offset since all of the "satellites" in the GPS  
25 system are synchronized. However, in the CToA system, the bSTAs are independent and unsynchronized.  
30

[0081] The cSTA needs the following data for estimating its location:

[0082] For every CToA measurement frame/packet broadcast by the bSTA, there is:

[0083]  $1 \times$  ToD measurement, because the time of departure is specific to each bSTA. This is measured at the broadcaster's side (bSTA).

[0084] Up to  $(M-1) \times \text{ToA}$  by each bSTA, because each bSTA may receive CToA measurement frames from all of the bSTAs that are part of the CToA system, except for itself. Hence, if M is the number of all of the bSTAs in the CToA system, then M - 1 is the number of possible ToAs that may be captured by each bSTA.

5 [0085] At the receiver device (e.g., cSTA), there may be up to  $1 \times \text{ToA}$  by each cSTA.

[0086] In some embodiments, the bSTA LCI is broadcast periodically by all bSTAs. Further, the cSTA collects multiple sets of CToA measurement frame timing measurements ( $1 \times \text{ToD}$  &  $M \times \text{ToA}$ ).

[0087] Each measurement is provided in local timing of either the bSTA or the cSTA.

10 [0088] Using this data and the Kalman filter, the cSTA may calculate its position. The Kalman filter may estimate and track the cSTA's position. The Kalman filter also has to take into consideration that there may be a clock drift or frequency drift of the crystal in each device (cSTA and bSTA). In practice, since bSTAs use cheap XTALs, there is a substantial clock drift between the measurement events. For example, 1 ppm translates to a clock drift of  
15 1 ns every 1 ms. Two CToA measurement frames, which were transmitted by the same bSTA, 3 ms apart, will introduce an accumulated error of 1 m or ~30 m if transmitted @ 10 Hz periodicity. To solve this, the cSTA also tracks the clock drift of each bSTA using a Kalman filter. The cSTA may use the Kalman filter to take into consideration, for each bSTA, the clock offset as well as the clock drift.

20 [0089] The Kalman filter may track and estimate various states. These states may consist of the position coordinates of the cSTA (x, y, and z coordinates), plus for each bSTA, the Kalman filter clock model parameters, the clock offset, the clock offset first derivative, and the clock offset second derivative. Each state vector will consist of all of this information. It is understood that the above descriptions are for purposes of illustration and are not meant to  
25 be limiting.

[0090] FIG. 7A illustrates a flow diagram of an illustrative process 700 for a CToA system, in accordance with one or more example embodiments of the present disclosure.

[0091] At block 702, a device (e.g., the user device(s) 120 and/or the APs 102 of FIG. 1) may determine a first location associated with a first responder device of the one or more  
30 responder devices. For example, the device may be user device 120 that may be aware of one or more locations of one or more responder devices (e.g., APs 102 of FIG. 1). A CToA measurement frame sent from a transmitting device may also contain the known location of the transmitting device. Other means of determining the locations of the responder devices

may be implemented. For example, a server may maintain a database of known locations of the various responder devices that are deployed.

[0092] At block 704, the device may determine a second location associated with a second responder device of the one or more responder devices. These locations may be predetermined or may be determined by the user device 120, when it is associating with an AP 102 and its proximity. There may be more than one responder device in proximity to a client device. The responder devices may be unsynchronized, independent and stationed at locations known to the client devices, and periodically transmit CToA measurement frames, which consist of an announcement packet, containing the format and relevant data for the required measurement, followed by an NDP frame for the actual timing measurement. The receivers are both the client devices, as well as peer responder devices. The responder devices broadcast their measurements such that the client devices can combine their own time delay measurements with the responders' reported measurements in order to obtain an estimate of their own location

[0093] At block 706, the device may identify a first CToA measurement frame indicating one or more first location determination parameters, received from the first responder device, the first CToA measurement frame comprising a first null data packet announcement (NDPA) and a first null data packet (NDP). For example, a CToA measurement frame may comprise two packets separated by a short inter-frame space (SIFS) interval of time. These two packets may make a periodic transmission that consists of an IEEE 802.11az NDPA and an NDP. One or more responder devices may send one or more CToA measurement frame frames to one or more cSTAs (e.g., user device 120). The NDPA and the NDP may include additional information to support the CToA system, such as the time of departure (ToD), and enables a time of arrival (ToA) measurement.

[0094] At block 708, the device may identify a second CToA measurement frame indicating one or more second location determination parameters, received from the second responder device, the second CToA measurement frame comprising a second NDPA and a second NDP. For example, the device may receive multiple CToA measurement frame frames from multiple responder devices. These CToA measurement frame frames may be used to determine the location or fix of the device. In fact, the CToA measurement frame frames may be received by the device without having to solicit them from the responder devices. That is, the device is capable of unidirectional estimation and tracking of its own geographical position without having to initiate a ranging request or a location determination request to one or more responder devices.

[0095] Upon the CToA measurement frame's reception, the device may update a database or a table stored in memory that may contain parameters such as the packet ID (PID), the MAC address of the responder device that transmitted the CToA measurement frame, the time of departure (ToD) (as reported by the responder device), the MAC address of the receiving device, and the measured time of arrival (ToA) at the receiving device. The table may contain entries that may be grouped by the PIDs of the CToA measurement frame frames received. Each device that receives the CToA measurement frame frames may also maintain in a database or memory the information conveyed by the CToA measurement frame frames. At one point, the responder devices may broadcast at a predetermined interval or at a specific occurrence of an event a report of their respective table entries. This report may be received by other devices that may update their respective tables with that information. Consequently, multiple PID entries may be captured and maintained by the devices.

[0096] At block 710, the device may determine a location associated with the device based on the one or more first location determination parameters, the one or more second location determination parameters, the first location, and the second location. The device (e.g., a user device 120) may perform calculations to determine its fix or location whenever a certain criterion is met. The criteria may be based on the number of entries associated with a specific PID that may be found in the table or database maintained by the device. Once the device receives the reports and the CToA measurement frame frames from the responder devices in its proximity, it may have sufficient information to estimate its initial fix using, for example, a Kalman filter algorithm. Further, the device may continue tracking and updating this estimate with every new measurement it receives (where "measurement" in this context means any new CToA measurement frame or report it receives from that point and onward). A purpose of using a Kalman filter algorithm is to estimate and track the following states (parameters): (1) the client receiver's position coordinates; and (2) per each transmitting responder, the responder's clock offset (with regard to receiving the client clock), the responder clock drift (measured in [ppm]), and the responder clock drift first and second derivatives.

[0097] It is understood that the above descriptions are for purposes of illustration and are not meant to be limiting.

[0098] FIG. 7B illustrates a flow diagram of an illustrative process 750 for a CToA system, in accordance with one or more example embodiments of the present disclosure.

[0099] At block 752, a device (e.g., the user device(s) 120 and/or the AP 102 of FIG. 1)

may determine a first broadcast measurement frame comprising a null data packet announcement (NDPA) and a first null data packet (NDP), the NDPA comprising positioning related information, and the NDP is for estimating a time delay. For example, the CToA measurement frame may be comprised of two frames, separated by a short inter-frame space (SIFS) period (about 16  $\mu$ sec). The first frame may be a positioning NDP announcement frame (PNDP-A), which can also be referred to as an NDPA. The second frame may be an NDP. The PNDP-A may be used for one or more purposes. A purpose may be to convey positioning-related information, such as the packet ID number, the time of departure (ToD) of the NDP, the MAC address of the transmitter, the LCI, the neighbor responders' event report, etc. Another purpose may be to announce the transmission of the NDP frame. The second frame may be the NDP. The NDP may be used by a receiver device to estimate the time delay between the transmitter (e.g., the responder device) and the receiver device, by measuring the time of arrival (ToA).

[00100] At block 754, the device may cause to broadcast the first broadcast measurement frame at a first interval to one or more devices within a collaborative time of arrival network, wherein the first broadcast measurement frame further comprises a neighbors report. For example, one or more responder devices may each transmit a CToA measurement frame that may be transmitted periodically in the CToA network, and may be received by the one or more receiver devices that are located within the coverage area of the CToA network. Each responder device periodically transmits a CToA measurement frame.

[00101] At block 756, the device may identify a second broadcast measurement frame from a device of the one or more devices, wherein the second broadcast measurement frame comprises a second neighbors report accumulated at the device. It is understood that the above descriptions are for purposes of illustration and are not meant to be limiting.

[00102] FIG. 8 shows a functional diagram of an exemplary communication station 800 in accordance with some embodiments. In one embodiment, FIG. 8 illustrates a functional block diagram of a communication station that may be suitable for use as an AP 102 (FIG. 1) or a user device 120 (FIG. 1) in accordance with some embodiments. The communication station 800 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.

[00103] The communication station 800 may include communications circuitry 802 and a transceiver 810 for transmitting and receiving signals to and from other communication

stations using one or more antennas 801. The transceiver 810 may be a device comprising both a transmitter and a receiver that are combined and share common circuitry (e.g., communication circuitry 802). The communication circuitry 802 may include amplifiers, filters, mixers, analog to digital and/or digital to analog converters. The transceiver 810 may transmit and receive analog or digital signals. The transceiver 810 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 810 may operate in a half-duplex mode, where the transceiver 810 may transmit or receive signals in one direction at a time.

[00104] The communications circuitry 802 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 800 may also include processing circuitry 806 and memory 808 arranged to perform the operations described herein. In some embodiments, the communications circuitry 802 and the processing circuitry 806 may be configured to perform operations detailed in FIGs. 2, 3, 4, 5, 6A, 6B, 7A and 7B.

[00105] In accordance with some embodiments, the communications circuitry 802 may be arranged to contend for a wireless medium and configure frames or packets for communicating over the wireless medium. The communications circuitry 802 may be arranged to transmit and receive signals. The communications circuitry 802 may also include circuitry for modulation/demodulation, upconversion/downconversion, filtering, amplification, etc. In some embodiments, the processing circuitry 806 of the communication station 800 may include one or more processors. In other embodiments, two or more antennas 801 may be coupled to the communications circuitry 802 arranged for sending and receiving signals. The memory 808 may store information for configuring the processing circuitry 806 to perform operations for configuring and transmitting message frames and performing the various operations described herein. The memory 808 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 808 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.

[00106] In some embodiments, the communication station 800 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.

[00107] In some embodiments, the communication station 800 may include one or more antennas 801. The antennas 801 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.

[00108] In some embodiments, the communication station 800 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.

[00109] Although the communication station 800 is illustrated as having several separate 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 (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 800 may refer to one or more processes operating on one or more processing elements.

[00110] Certain embodiments may be implemented in one or a combination of hardware, 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 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 800 may include one or more processors and may be configured with instructions stored on a computer-readable storage device memory.

[00111] FIG. 9 illustrates a block diagram of an example of a machine 900 or system upon which any one or more of the techniques (e.g., methodologies) discussed herein may be performed. In other embodiments, the machine 900 may operate as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine 900 may operate in the capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine 900 may act as a peer machine in peer-to-peer (P2P) (or other distributed) network environments. The machine 900 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.

[00112] 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., 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 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.

[00113] The machine (e.g., computer system) 900 may include a hardware processor 902 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 904 and a static memory 906, some or all of which may communicate with each other via an interlink (e.g., bus) 908. The machine 900 may further include a power management device 932, a graphics display device 910, an alphanumeric input device 912 (e.g., a keyboard), and a user interface (UI) navigation device 914 (e.g., a mouse). In an example, the graphics display device 910, alphanumeric input device 912, and UI navigation device 914 may be a touch screen display. The machine 900 may additionally include a storage device (i.e., drive unit) 916, a signal generation device 918 (e.g., a speaker), a CToA device 919, a network interface device/transceiver 920 coupled to antenna(s) 930, and one or more sensors 928, such as a global positioning system (GPS) sensor, a compass, an accelerometer, or other sensor. The machine 900 may include an output controller 934, 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.)).

[00114] The storage device 916 may include a machine readable medium 922 on which is stored one or more sets of data structures or instructions 924 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 924 may also reside, completely or at least partially, within the main memory 904, within the static memory 906, or within the hardware processor 902 during execution thereof by the machine 900. In an example, one or any combination of the hardware processor 902, the main memory 904, the static memory 906, or the storage device 916 may constitute machine-readable media.

[00115] The CToA device 919 may carry out or perform any of the operations and processes (e.g., processes 700 and 750) described and shown above. For example, the CToA device 919 may define a unidirectional protocol to enable client-receiver devices to estimate and track their own geographical position. The suggested protocol and position estimation algorithm enable unlimited system capacity in terms of the number of client receivers that can be supported simultaneously. Aside from the unlimited capacity enabled by the devised system, the CToA device 919 may rely on a network of unsynchronized Wi-Fi/IEEE802.11 responders, which make the solution efficient and desirable, as well as capable of providing

high-accuracy indoor navigation.

[00116] The CToA device 919 may determine the actual client position estimation similar to trilateration location principles, which are used in GNSS. Aside from its ability to provide location service indoors and in areas where GNSS does not have sufficient coverage, a difference between CToA and GNSS is in the fact that from the client device viewpoint, all GNSS satellites are synchronized (using atomic clocks, which are observed and controlled by the system ground control segment). As a result, the client device has to estimate and track its clock offset with respect to the offset of the system. In CToA, the “satellites” (i.e., the responders) are unsynchronized and independent (i.e., unlike GNSS there is no explicit “control segment” that tracks and controls the responders clock and status). Hence, the client device needs to estimate and track the offset (and drift) between its own clock and each responder clock. For example, each of the responder devices may be running with its own independent clock sources, which are unsynchronized. The CToA device 919 may use cheap crystals (XTALs) in unsynchronized Wi-Fi FTM responders (referred to as CToA broadcasting stations or bSTA), to build a high-precision geolocation network. These bSTAs are independent of each other, they are not connected to each other, they do not report to a centric server, they are not wire connected to any server, and they are not synchronized to each other. The CToA client receivers are referred to as cSTAs. Each of the bSTAs broadcast a CToA measurement frame, which is independent of other bSTAs.

[00117] A CToA system is different from an FTM system because it has fewer frame exchanges, and there are no time constraints as in an FTM system. Typically, FTM is a point-to-point protocol. For example, one FTM responder and one FTM receiver can establish a connection to each other and exchange at least six messages in order to establish timing measurements that could be translated into a range measurement between the FTM responder and the FTM receiver. This process also has to be repeated with other FTM responders. In a CToA system, multiple bSTA’s help determine the location of a cSTA.

[00118] The CToA device 919 may determine a CToA measurement frame to comprise two packets separated by a short inter-frame space (SIFS) interval of time. These two packets may periodic transmission that consists of IEEE 802.11az null data packet announcement (NDPA) and an null data packet (NDP). The CToA device 919 may cause to send one or more CToA measurement frame frames to one or more cSTAs. The NDPA and the NDP may include additional information to support the CToA system, such as, time of departure (ToD) and enables time of arrival (ToA) measurement.

[00119] The CToA device 919 may facilitate that each bSTA broadcasts a CToA measurement frame periodically, and measures the ToD of that CToA measurement frame. In one embodiment, each bSTA receives the CToA measurement frames transmitted by its neighbor bSTA and measures the ToA of the CToA measurement frames. In one  
5 embodiment, a bSTA publishes its ToA and ToD measurements of its neighbor bSTAs CToA measurement frames to other devices with the transmission range of the bSTA.

[00120] The CToA device 919 may facilitate that a cSTA receives and does not have to transmit any messages related to the measurement. In contrast, in FTM and other measurement protocols, the client device must initiate and transmit some messages in order to  
10 perform ranging or location determination.

[00121] The CToA device 919 may facilitate that a cSTA may broadcast a report of what the cSTA has collected from one or more bSTAs (e.g., a neighbors report). For example, a cSTA may use a CToA measurement frame in order to broadcast the report. The report may be sent periodically or at a predetermined time. For example, it may be sent after a certain  
15 number of entries have been added to a memory. Similar to the bSTA, each cSTA also receives the CToA measurement frame coming from the other bSTAs and measures their ToA. The cSTA would store that information in memory. Further, the cSTA collects the ToA and ToD measured and published by the bSTAs. The cSTA may use all of the information to calculate its own position.

[00122] It is understood that the above are only a subset of what the CToA device 919 may be configured to perform and that other functions included throughout this disclosure may also be performed by the CToA device 919.  
20

[00123] While the machine-readable medium 922 is illustrated as a single medium, the term “machine-readable medium” may include a single medium or multiple media (e.g., a  
25 centralized or distributed database, and/or associated caches and servers) configured to store the one or more instructions 924.

[00124] 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 a non-transitory computer-readable storage medium. Those instructions may then be read  
30 and executed by one or more processors to enable performance of the operations described herein. The instructions may be in any suitable form, such as but not limited to source code, compiled code, interpreted code, executable code, static code, dynamic code, and the like. Such a computer-readable medium may include any tangible non-transitory medium for storing information in a form readable by one or more computers, such as but not limited to

read only memory (ROM); random access memory (RAM); magnetic disk storage media; optical storage media; a flash memory, etc.

[00125] The term “machine-readable medium” may include any medium that is capable of storing, encoding, or carrying instructions for execution by the machine 900 and that cause the machine 900 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 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.

[00126] The instructions 924 may further be transmitted or received over a communications network 926 using a transmission medium via the network interface device/transceiver 920 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 920 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 926. In an example, the network interface device/transceiver 920 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 900 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.

5 [00127] 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  
10 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.

[00128] As used within this document, the term “communicate” is intended to include  
15 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  
20 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  
25 communication signal to at 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.

[00129] 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  
30 instances of like objects are being referred to and are not intended to imply that the objects so described must be in a given sequence, either temporally, spatially, in ranking, or in any other manner.

[00130] 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),

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 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.

[00131] 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 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 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.

[00132] 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.

[00133] 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.

[00134] According to example embodiments of the disclosure, there may be a device. The device may include memory and processing circuitry configured to determine a first location associated with a first responder device of one or more responder devices. The processing circuitry may be further configured to determine a second location associated with a second responder device of the one or more responder devices. The processing circuitry may be further configured to identify a first broadcast measurement frame, received from the first responder device that indicates one or more first location determination parameters, the first broadcast measurement frame may include a first null data packet announcement (NDPA) and a first null data packet (NDP). The processing circuitry may be further configured to identify a second broadcast measurement frame, received from the second responder device, that indicates one or more second location determination parameters, the second broadcast measurement frame may include a second NDPA and a second NDP. The processing circuitry may be further configured to determine a third location associated with the device based on the one or more first location determination parameters, the one or more second location determination parameters, the first location, or the second location.

[00135] The implementations may include one or more of the following features. To determine the third location associated with the device comprises the processing circuitry being further configured to use a Kalman Filter. The one or more first location determination parameters comprise at least one of a packet identification, a first medium access control (MAC) address of the first responder device, a time of departure of the first broadcast measurement frame, a MAC address of the device, or a time of arrival of the first broadcast measurement frame. The processing circuitry may be further configured to identify one or more neighbors reports received from the first responder device, wherein a first neighbors report comprises one or more entries in a table at the first responder device. The processing circuitry may be further configured to add the one or more entries to a table associated with the device. The first NDPA and the first NDP are separated by a short inter-frame space (SIFS) interval of time. The processing circuitry may be further configured to

determine a table may include one or more table entries, wherein each table entry is associated with a packet identification (PID), each PID is associated with a broadcast measurement frame received from one of the one or more responder devices. To cause to determine the third location comprises the processing circuitry being further configured to  
5 determine two table entries that have a same PID associated with each respective one or more responder devices. The one or more neighbors reports comprise time of arrival measurements and time of departure measurements associated with various broadcast measurement frames collected by neighbor responder devices. The time of departure of the first broadcast measurement frame is determined by the first responder device. The time of  
10 arrival of the first broadcast measurement frame is determined by the device. The device may further include a transceiver configured to transmit and receive wireless signals. The device may further include one or more antennas coupled to the transceiver.

[00136] According to example embodiments of the disclosure, there may be a device. The device may include memory and processing circuitry configured to determine a first  
15 broadcast measurement frame may include a null data packet announcement (NDPA) and a first null data packet (NDP), the NDPA may include positioning related information, and the NDP is for estimating a time delay. The processing circuitry may be further configured to cause to broadcast the first broadcast measurement frame at a first interval to one or more devices within a collaborative time of arrival network, wherein the first broadcast  
20 measurement frame further comprises a neighbors report. The processing circuitry may be further configured to identify a second broadcast measurement frame from a device of the one or more devices, wherein the second broadcast measurement frame comprises a second neighbors report accumulated at the device.

[00137] The implementations may include one or more of the following features. The one  
25 or more devices are unsynchronized with each other. The processing circuitry may be further configured to determine a table may include one or more table entries, wherein each table entry is associated with a packet identification (PID), each PID is associated with a broadcast measurement frame received from one of the one or more devices. The NDPA and the NDP are separated by a short inter-frame space interval of time. The device may further include a  
30 transceiver configured to transmit and receive wireless signals. The device may further include one or more antennas coupled to the transceiver.

[00138] According to example embodiments of the disclosure, there may be a non-transitory computer-readable medium storing computer-executable instructions which, when executed by a processor, cause the processor to perform operations. The operations may

include determining a first broadcast measurement frame may include a null data packet announcement (NDPA) and a first null data packet (NDP), the NDPA may include positioning related information, and the NDP may be for estimating a time delay. The operations may include causing to broadcast the first broadcast measurement frame at a first interval to one or more devices within a collaborative time of arrival network, wherein the first broadcast measurement frame further comprises a neighbors report. The operations may include identifying a second broadcast measurement frame from a device of the one or more devices, wherein the second broadcast measurement frame comprises a second neighbors report accumulated at the device.

[00139] The implementations may include one or more of the following features. The one or more devices are unsynchronized with each other. The operations further comprise determining a table may include one or more table entries, wherein each table entry may be associated with a packet identification (PID), each PID may be associated with a broadcast measurement frame received from one of the one or more devices. The NDPA and the NDP are separated by a short inter-frame space interval of time.

[00140] According to example embodiments of the disclosure, there may be a non-transitory computer-readable medium storing computer-executable instructions which, when executed by a processor, cause the processor to perform operations. The operations may include determining a first location associated with a first responder device of one or more responder devices. The operations may include determining a second location associated with a second responder device of the one or more responder devices. The operations may include identifying a first broadcast measurement frame, received from the first responder device, that indicates one or more first location determination parameters, the first broadcast measurement frame may include a first null data packet announcement (NDPA) and a first null data packet (NDP). The operations may include identifying a second broadcast measurement frame, received from the second responder device, that indicates one or more second location determination parameters, the second broadcast measurement frame may include a second NDPA and a second NDP. The operations may include determining a third location associated with the device based on the one or more first location determination parameters, the one or more second location determination parameters, the first location, or the second location. Determining the third location associated with the device may further comprise the operations to use a Kalman Filter. The one or more first location determination parameters comprise at least one of a packet identification, a first medium access control (MAC) address of the first responder device, a time of departure of the first broadcast

measurement frame, a MAC address of the device, or a time of arrival of the first broadcast measurement frame. The operations further comprise identifying one or more neighbors reports received from the first responder device, wherein a first neighbors report comprises one or more entries in a table at the first responder device. The operations may include adding the one or more entries to a table associated with the device. The first NDPA and the first NDP are separated by a short inter-frame space (SIFS) interval of time. The operations may further comprise determining a table may include one or more table entries, wherein each table entry may be associated with a packet identification (PID), each PID may be associated with a broadcast measurement frame received from one of the one or more responder devices. Causing to determine the third location may further comprise the operations for determining two table entries that have a same PID associated with each respective one or more responder devices. The one or more neighbors reports comprise time of arrival measurements and time of departure measurements associated with various broadcast measurement frames collected by neighbor responder devices. The time of departure of the first broadcast measurement frame may be determined by the first responder device. The time of arrival of the first broadcast measurement frame may be determined by the device.

[00141] According to example embodiments of the disclosure, there may include a method. The method may include determining, by one or more processors, a first location associated with a first responder device of one or more responder devices. The method may include determining a second location associated with a second responder device of the one or more responder devices. The method may include identifying a first broadcast measurement frame indicating one or more first location determination parameters, received from the first responder device, the first broadcast measurement frame may include a first null data packet announcement (NDPA) and a first null data packet (NDP). The method may include identifying a second broadcast measurement frame indicating one or more second location determination parameters, received from the second responder device, the second broadcast measurement frame may include a second NDPA and a second NDP. The method may include determining a third location associated with a client device based on the one or more first location determination parameters, the one or more second location determination parameters, the first location, or the second location.

[00142] The implementations may include one or more of the following features. The one or more first location determination parameters comprise at least one of a packet identification, a first medium access control (MAC) address of the first responder device, a

time of departure of the first broadcast measurement frame, a MAC address of a device, or a time of arrival of the first broadcast measurement frame. The method may further include identifying one or more neighbors reports received from the first responder device, wherein a first neighbors report comprises one or more entries in a respective table at the first responder device. The method may include adding the one or more entries to a first table. Determining the third location associated with a client device comprises using a Kalman Filter. The first NDPA and the first NDP are separated by a short inter-frame space (SIFS) interval of time. The method may include determining a table may include one or more table entries, wherein each table entry is associated with a packet identification (PID), each PID is associated with a broadcast measurement frame received from one of the one or more responder devices. Determining the third location further includes determining two table entries that have a same PID associated with each respective one or more responder devices. The one or more neighbors reports comprise time of arrival measurements and time of departure measurements associated with various broadcast measurement frames collected by neighbor responder devices. The time of departure of the first broadcast measurement frame is determined by the first responder device. The time of arrival of the first broadcast measurement frame is determined by the device.

[00143] According to example embodiments of the disclosure, there may include a method. The method may include determining a first broadcast measurement frame may include a null data packet announcement (NDPA) and a first null data packet (NDP), the NDPA may include positioning related information, and the NDP is for estimating a time delay. The method may include causing to broadcast the first broadcast measurement frame at a first interval to one or more devices within a collaborative time of arrival network, wherein the first broadcast measurement frame further comprises a neighbors report. The method may include identifying a second broadcast measurement frame from a device of the one or more devices, wherein the second broadcast measurement frame comprises a second neighbors report accumulated at the device. The implementations may include one or more of the following features. The one or more devices are unsynchronized with each other. The method may further include determining a table may include one or more table entries, wherein each table entry is associated with a packet identification (PID), each PID is associated with a broadcast measurement frame received from one of the one or more devices. The NDPA and the NDP are separated by a short inter-frame space interval of time.

[00144] In example embodiments of the disclosure, there may be an apparatus. The apparatus may include means for determining a first location associated with a first responder

device of one or more responder devices. The apparatus may include means for determining a second location associated with a second responder device of the one or more responder devices. The apparatus may include means for identifying a first broadcast measurement frame, received from the first responder device, that indicates one or more first location determination parameters, the first broadcast measurement frame may include a first null data packet announcement (NDPA) and a first null data packet (NDP). The apparatus may include means for identifying a second broadcast measurement frame, received from the second responder device, that indicates one or more second location determination parameters, the second broadcast measurement frame may include a second NDPA and a second NDP. The apparatus may include means for determining a third location associated with the device based on the one or more first location determination parameters, the one or more second location determination parameters, the first location, or the second location.

[00145] The implementations may include one or more of the following features. The means for determining the third location associated with the device comprises means for using a Kalman Filter. The one or more first location determination parameters comprise at least one of a packet identification, a first medium access control (MAC) address of the first responder device, a time of departure of the first broadcast measurement frame, a MAC address of the device, or a time of arrival of the first broadcast measurement frame. The apparatus may further include means for identifying one or more neighbors reports received from the first responder device, wherein a first neighbors report comprises one or more entries in a table at the first responder device; and means for adding the one or more entries to a table associated with the device. The first NDPA and the first NDP are separated by a short inter-frame space (SIFS) interval of time. The apparatus may further include means for determining a table may include one or more table entries, wherein each table entry may be associated with a packet identification (PID), each PID may be associated with a broadcast measurement frame received from one of the one or more responder devices. The means for causing to determine the third location comprises means for determining two table entries that have a same PID associated with each respective one or more responder devices. The one or more neighbors reports comprise time of arrival measurements and time of departure measurements associated with various broadcast measurement frames collected by neighbor responder devices. The time of departure of the first broadcast measurement frame may be determined by the first responder device. The time of arrival of the first broadcast measurement frame may be determined by the device.

[00146] In example embodiments of the disclosure, there may be an apparatus. The

apparatus may include means for determining a first broadcast measurement frame may include a null data packet announcement (NDPA) and a first null data packet (NDP), the NDPA may include positioning related information, and the NDP may be for estimating a time delay. The apparatus may include means for causing to broadcast the first broadcast measurement frame at a first interval to one or more devices within a collaborative time of arrival network, wherein the first broadcast measurement frame further comprises a neighbors report. The apparatus may include means for identifying a second broadcast measurement frame from a device of the one or more devices, wherein the second broadcast measurement frame comprises a second neighbors report accumulated at the device. The one or more devices are unsynchronized with each other. The apparatus may further include means for determining a table may include one or more table entries, wherein each table entry may be associated with a packet identification (PID), each PID may be associated with a broadcast measurement frame received from one of the one or more devices. The NDPA and the NDP are separated by a short inter-frame space interval of time.

[00147] 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 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.

[00148] 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 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 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 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  
5 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.

[00149] Accordingly, blocks of the block diagrams and flow diagrams support  
10 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 special-purpose, hardware-based computer systems that perform the  
15 specified functions, elements or steps, or combinations of special-purpose hardware and computer instructions.

[00150] 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  
20 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  
25 performed in any particular implementation.

[00151] 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 to the specific implementations disclosed and that modifications and other  
30 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 first location associated with a first responder device of one or more responder devices;
  - determine a second location associated with a second responder device of the one or more responder devices;
  - identify a first broadcast measurement frame, received from the first responder device, that indicates one or more first location determination parameters, the first broadcast measurement frame comprising a first null data packet announcement (NDPA) and a first null data packet (NDP);
  - identify a second broadcast measurement frame, received from the second responder device, that indicates one or more second location determination parameters, the second broadcast measurement frame comprising a second NDPA and a second NDP; and
  - determine a third location associated with the device based on the one or more first location determination parameters, the one or more second location determination parameters, the first location, or the second location.
2. The device of claim 1, wherein to determine the third location associated with the device comprises the processing circuitry being further configured to use a Kalman Filter.
3. The device of claim 1, wherein the one or more first location determination parameters comprise at least one of a packet identification, a first medium access control (MAC) address of the first responder device, a time of departure of the first broadcast measurement frame, a MAC address of the device, or a time of arrival of the first broadcast measurement frame.
4. The device of claim 1, wherein the processing circuitry is further configured to:
  - identify one or more neighbors reports received from the first responder device, wherein a first neighbors report comprises one or more entries in a table at the first responder device; and
  - add the one or more entries to a table associated with the device.

5. The device of claim 1, wherein the first NDPA and the first NDP are separated by a short inter-frame space (SIFS) interval of time;
6. The device of claim 1, wherein the processing circuitry is further configured to determine a table comprising one or more table entries, wherein each table entry is associated with a packet identification (PID), each PID is associated with a broadcast measurement frame received from one of the one or more responder devices.
7. The device of claim 1, wherein to cause to determine the third location comprises the processing circuitry being further configured to determine two table entries that have a same PID associated with each respective one or more responder devices.
8. The device of claim 4, wherein the one or more neighbors reports comprise time of arrival measurements and time of departure measurements associated with various broadcast measurement frames collected by neighbor responder devices.
9. The device of claim 8, wherein the time of departure of the first broadcast measurement frame is determined by the first responder device.
10. The device of claim 8, wherein the time of arrival of the first broadcast measurement frame is determined by the device.
11. The device of claim 1, further comprising a transceiver configured to transmit and receive wireless signals.
12. The device of any one of claims 1-11, 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:

determining a first broadcast measurement frame comprising a null data packet announcement (NDPA) and a first null data packet (NDP), the NDPA comprising positioning related information, and the NDP is for estimating a time delay;

causing to broadcast the first broadcast measurement frame at a first interval to one or more devices within a collaborative time of arrival network, wherein the first broadcast measurement frame further comprises a neighbors report; and

identifying a second broadcast measurement frame from a device of the one or more devices, wherein the second broadcast measurement frame comprises a second neighbors report accumulated at the device.

14. The non-transitory computer-readable medium of claim 13, wherein the one or more devices are unsynchronized with each other.

15. The non-transitory computer-readable medium of claim 13, wherein the operations further comprise determining a table comprising one or more table entries, wherein each table entry is associated with a packet identification (PID), each PID is associated with a broadcast measurement frame received from one of the one or more devices.

16. The non-transitory computer-readable medium of any one of claims 13-15, wherein the NDPA and the NDP are separated by a short inter-frame space interval of time.

17. A method comprising:

determining, by one or more processors, a first location associated with a first responder device of one or more responder devices;

determining a second location associated with a second responder device of the one or more responder devices;

identifying a first broadcast measurement frame indicating one or more first location determination parameters, received from the first responder device, the first broadcast measurement frame comprising a first null data packet announcement (NDPA) and a first null data packet (NDP);

identifying a second broadcast measurement frame indicating one or more second location determination parameters, received from the second responder device, the second broadcast measurement frame comprising a second NDPA and a second NDP; and

determining a third location associated with a client device based on the one or more first location determination parameters, the one or more second location determination parameters, the first location, or the second location.

18. The method of claim 17, wherein the one or more first location determination parameters comprise at least one of a packet identification, a first medium access control (MAC) address of the first responder device, a time of departure of the first broadcast measurement frame, a MAC address of a device, or a time of arrival of the first broadcast measurement frame

19. The method of claim 17, further comprising:  
identifying one or more neighbors reports received from the first responder device, wherein a first neighbors report comprises one or more entries in a respective table at the first responder device ; and  
adding the one or more entries to a first table.

20. The method of claim 17, wherein determining the third location associated with a client device comprises using a Kalman Filter.

21. The method of claim 17, wherein the first NDPA and the first NDP are separated by a short inter-frame space (SIFS) interval of time;

22. The method of claim 17, wherein the processing circuitry is further configured to determine a table comprising one or more table entries, wherein each table entry is associated with a packet identification (PID), each PID is associated with a broadcast measurement frame received from one of the one or more responder devices.

23. The method of claim 17, wherein to cause to determine the third location comprises the processing circuitry being further configured to determine two table entries that have a same PID associated with each respective one or more responder devices.

24. The method of claim 19, wherein the one or more neighbors reports comprise time of arrival measurements and time of departure measurements associated with various broadcast measurement frames collected by neighbor responder devices.

25. The method any one of claims 17-24, wherein the time of departure of the first broadcast measurement frame is determined by the first responder device.

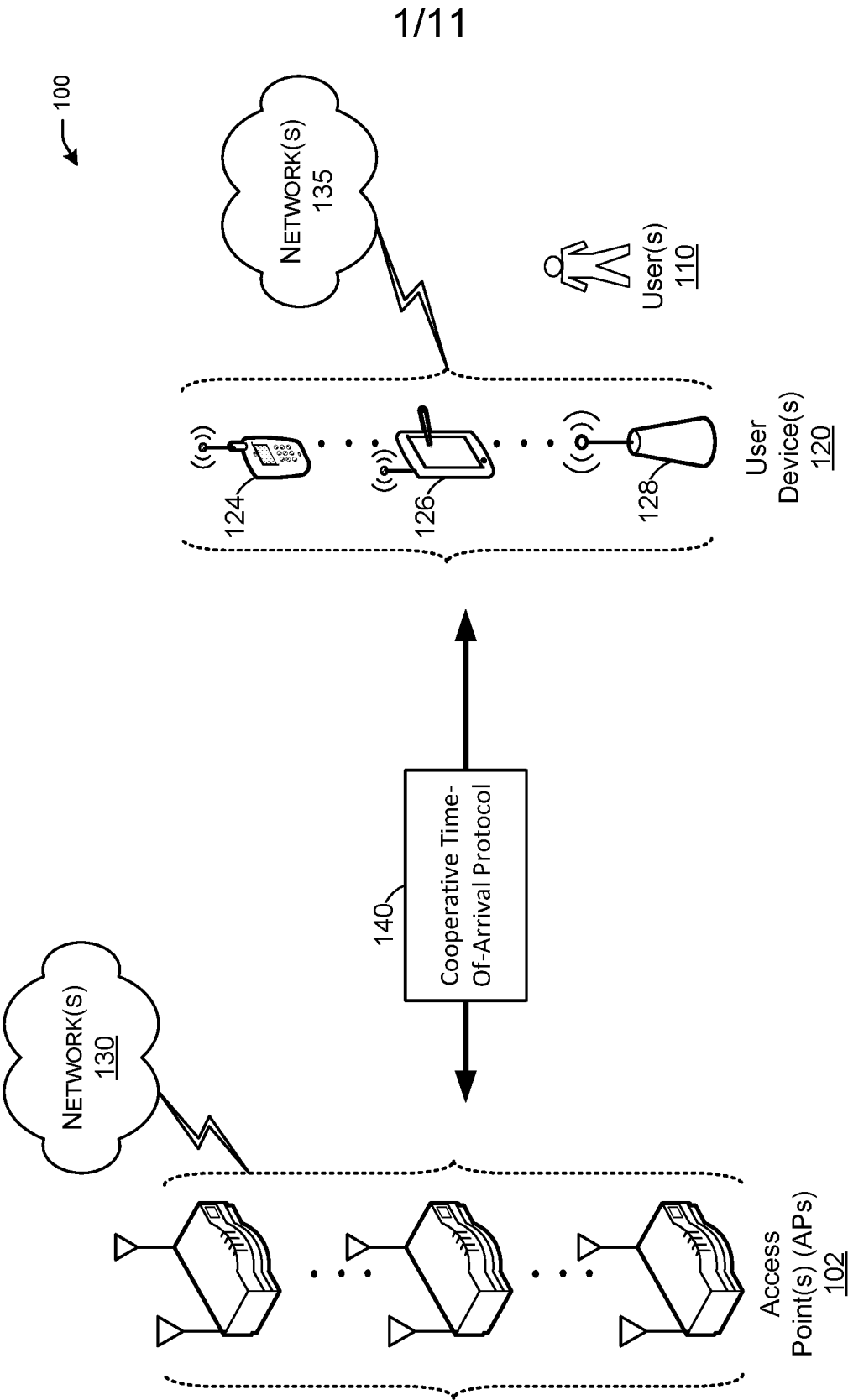


FIG. 1

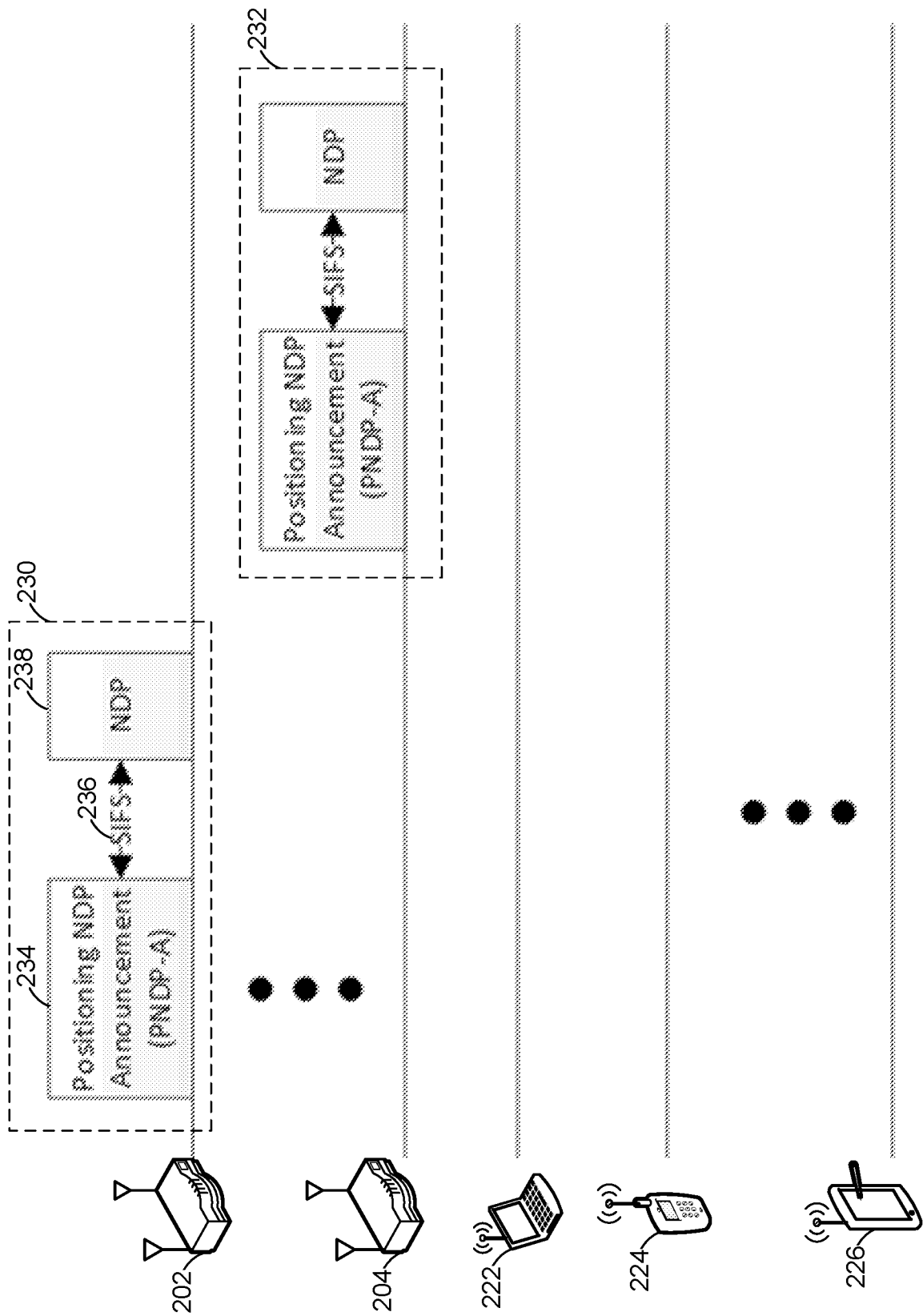


FIG. 2

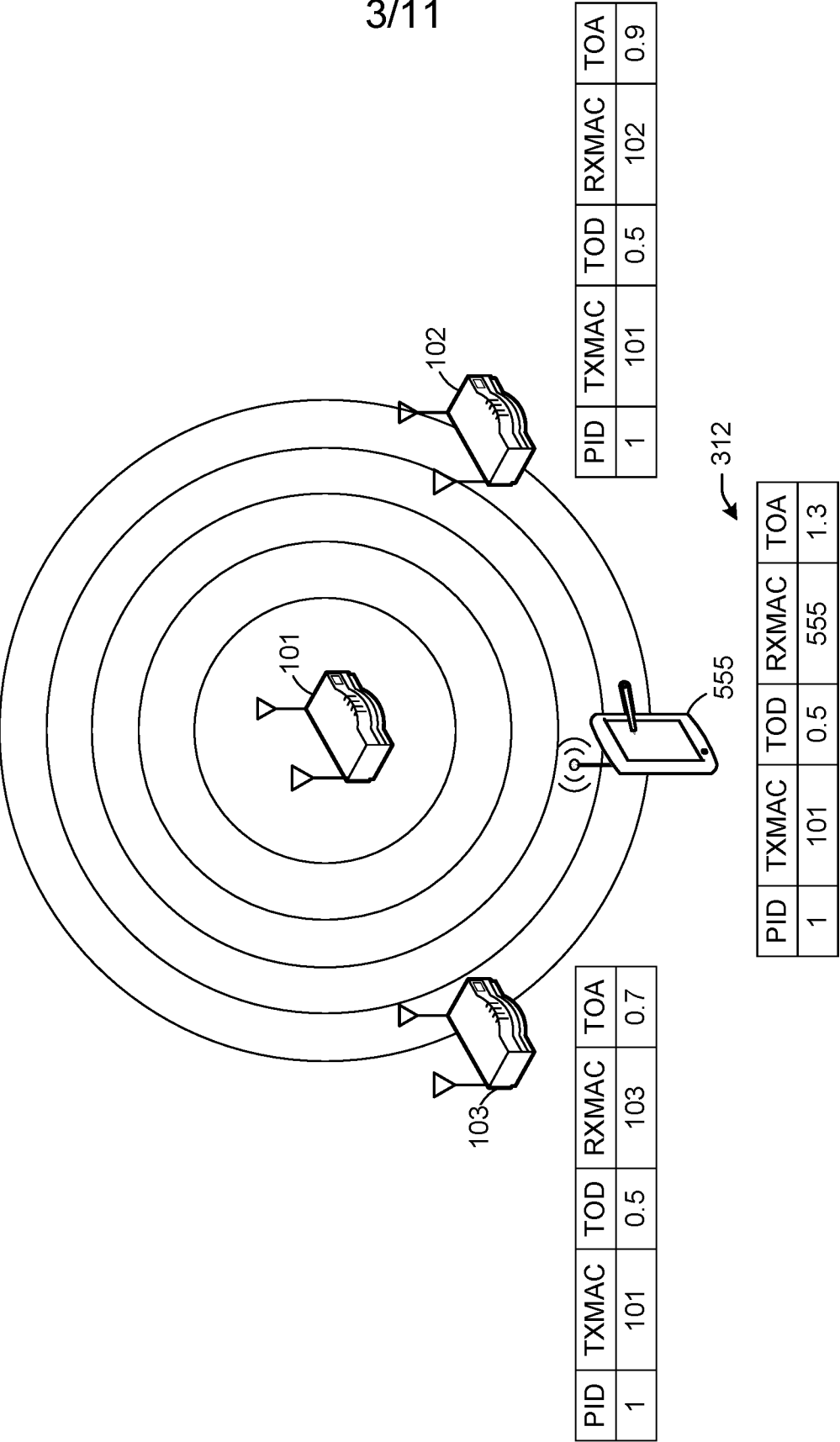


FIG. 3

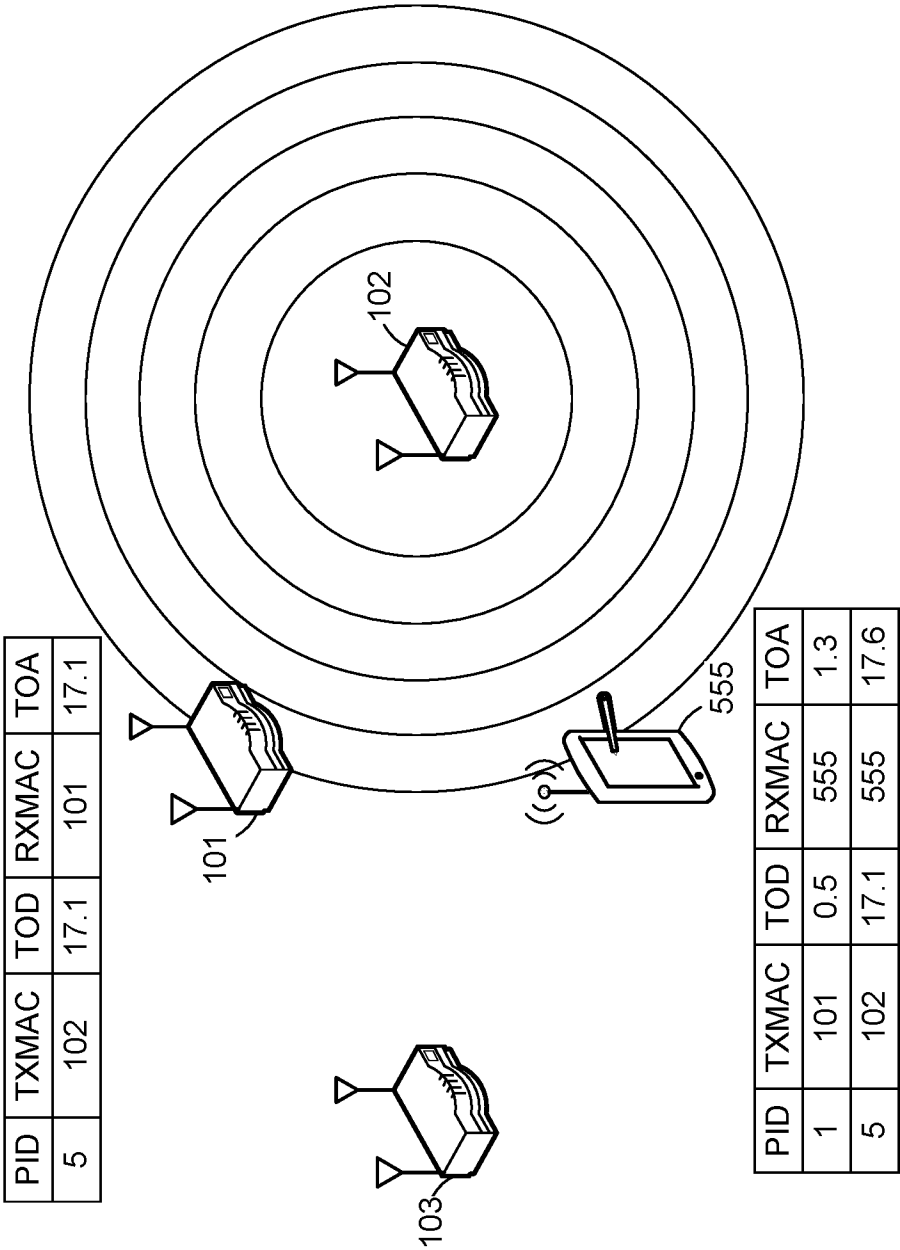


FIG. 4

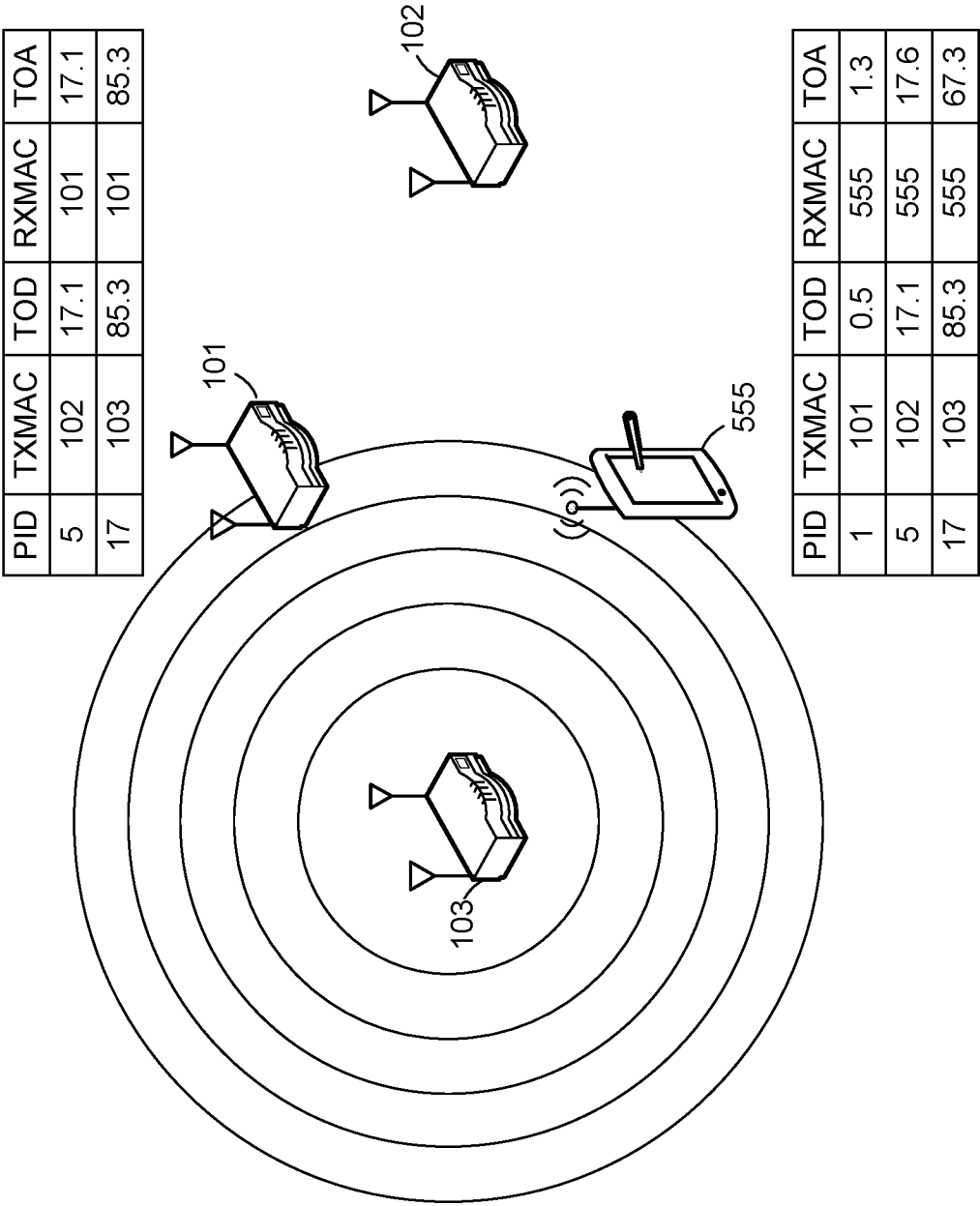


FIG. 5

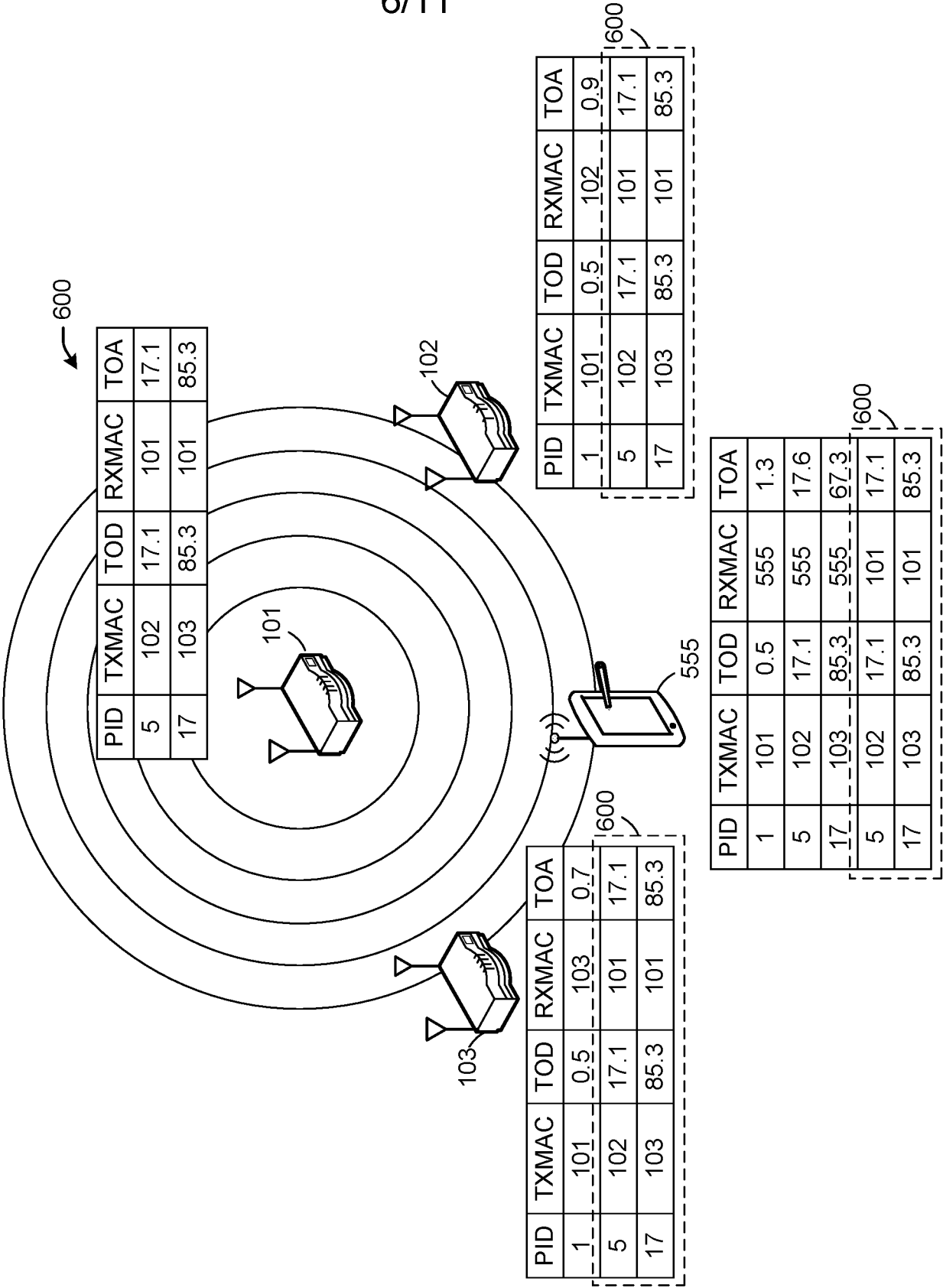


FIG. 6A

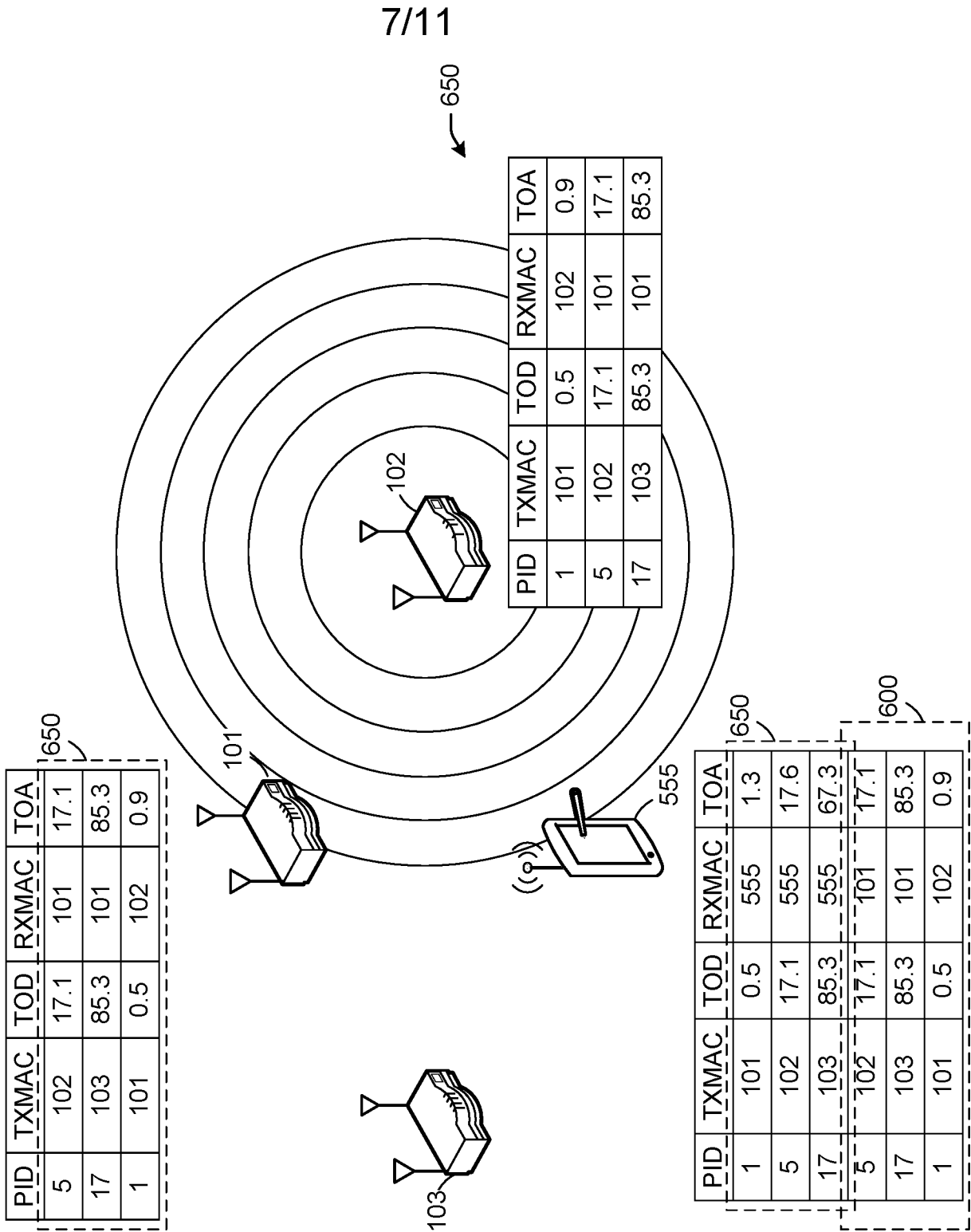


FIG. 6B

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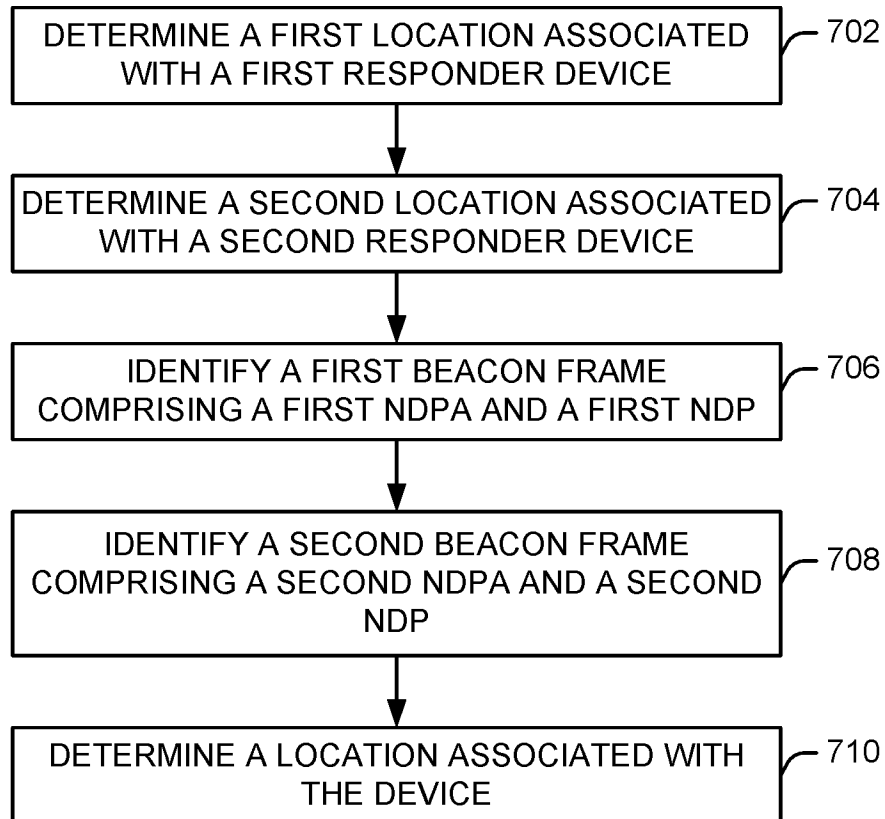
 700

FIG. 7A

9/11

750

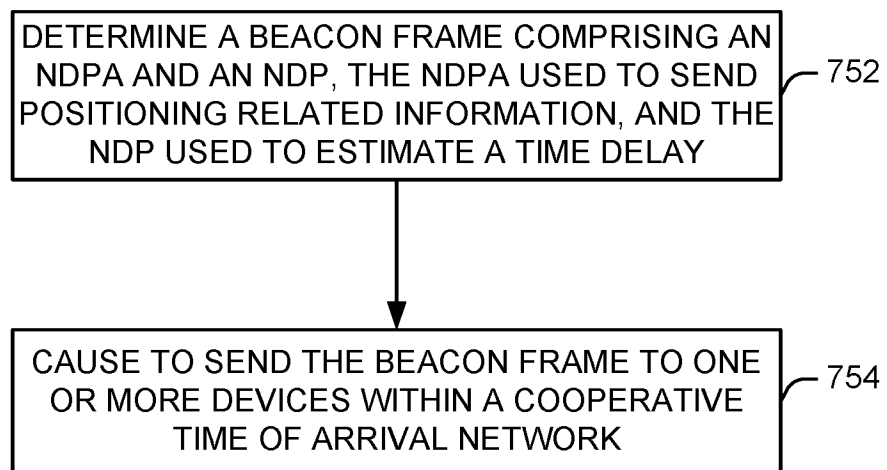


FIG. 7B

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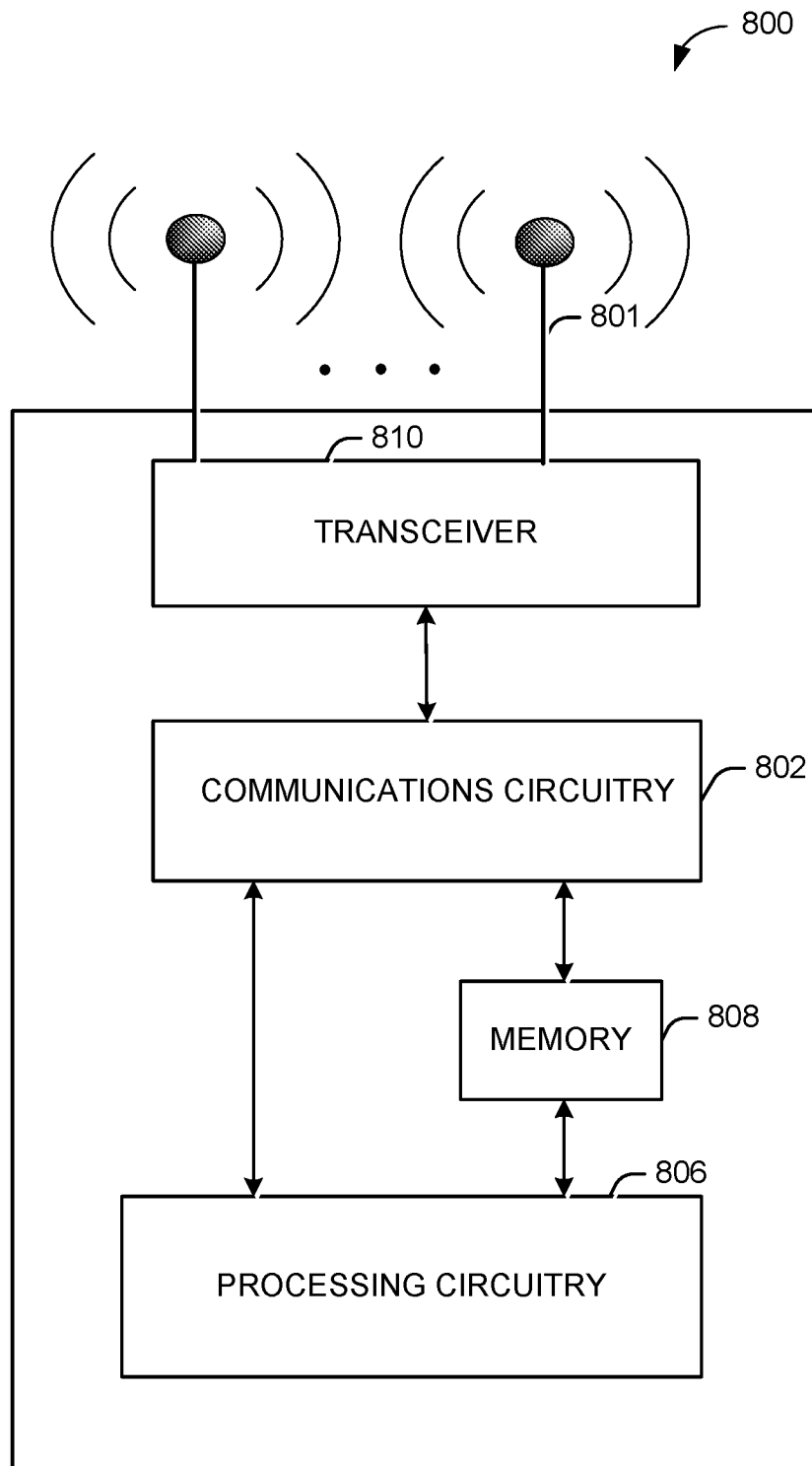


FIG. 8

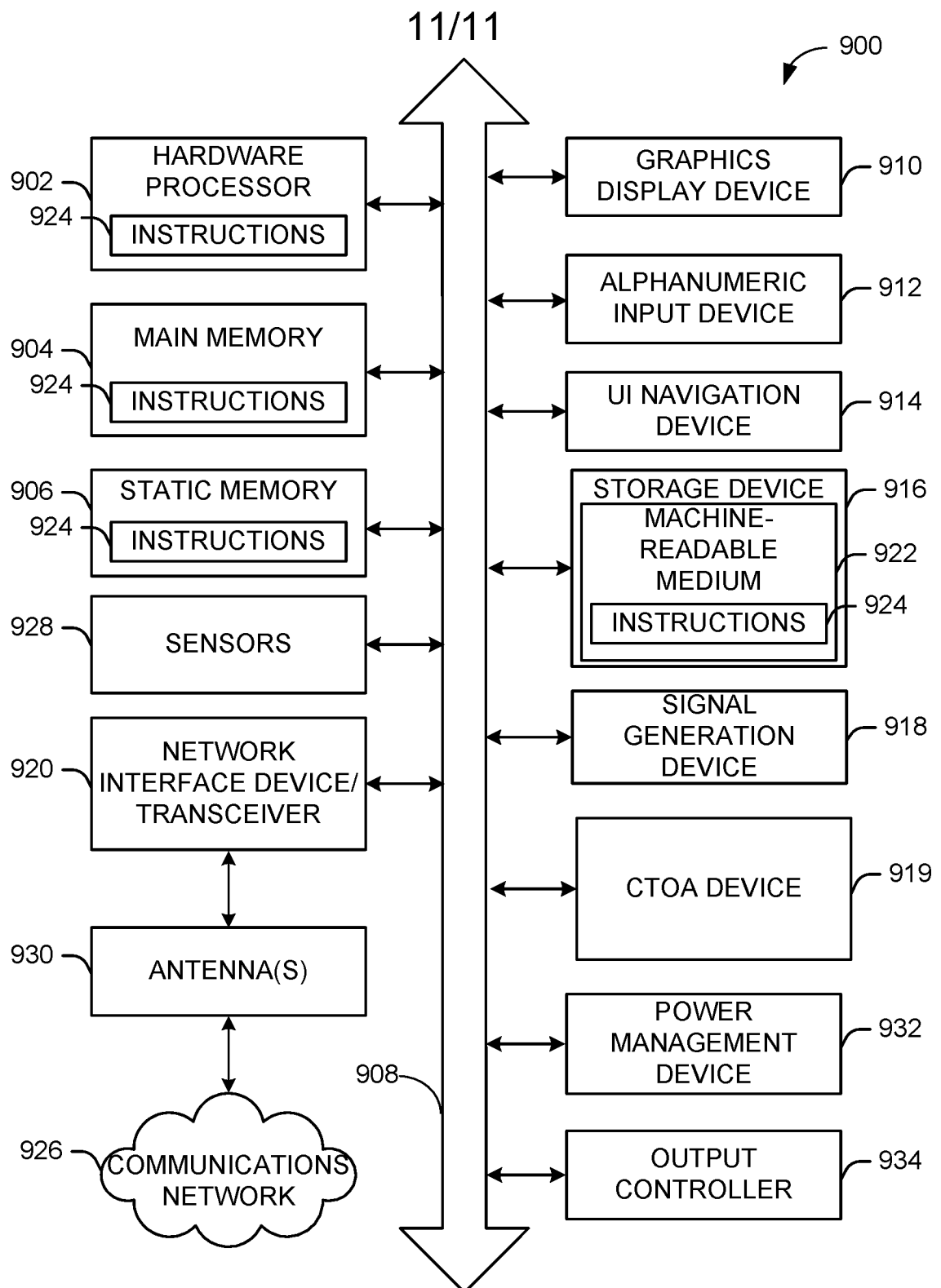


FIG. 9

**A. CLASSIFICATION OF SUBJECT MATTER****G01S 5/02(2010.01)i, H04W 64/00(2009.01)i**

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

G01S 5/02; H04W 24/02; H04W 16/22; H04L 25/02; H04L 29/06; H04W 4/02; H04L 12/18; H04W 64/00

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) &amp; Keywords: wireless device, positioning, location, second, broadcast measurement frame, null data packet (NDP)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                    | Relevant to claim No. |
|-----------|-----------------------------------------------------------------------------------------------------------------------|-----------------------|
| A         | US 2016-0277197 A1 (QUALCOMM INCORPORATED) 22 September 2016<br>See paragraph [0101]; claim 15; and figures 4, 6, 10. | 1-25                  |
| A         | US 2015-0237513 A1 (BROADCOM CORPORATION) 20 August 2015<br>See claims 1-2; and figures 1A, 2-3.                      | 1-25                  |
| A         | US 2017-0070893 A1 (WANG et al.) 09 March 2017<br>See figures 2A-2B.                                                  | 1-25                  |
| A         | US 9532239 B2 (INTEL IP CORPORATION) 27 December 2016<br>See figures 1-2.                                             | 1-25                  |
| A         | US 2014-0233550 A1 (APPLE INC.) 21 August 2014<br>See figures 1-3.                                                    | 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

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

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

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

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

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

"&amp;" document member of the same patent family

Date of the actual completion of the international search

05 January 2018 (05.01.2018)

Date of mailing of the international search report

**05 January 2018 (05.01.2018)**

Name and mailing address of the ISA/KR

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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No.

**PCT/US2017/053500**

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s)                                                                                                                            | Publication<br>date                                                                                          |
|-------------------------------------------|---------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
| US 2016-0277197 A1                        | 22/09/2016          | KR 10-2017-0128320 A<br>US 2016-0277196 A1<br>WO 2016-148818 A1<br>WO 2016-148820 A1                                                                  | 22/11/2017<br>22/09/2016<br>22/09/2016<br>22/09/2016                                                         |
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| US 2014-0233550 A1                        | 21/08/2014          | None                                                                                                                                                  |                                                                                                              |