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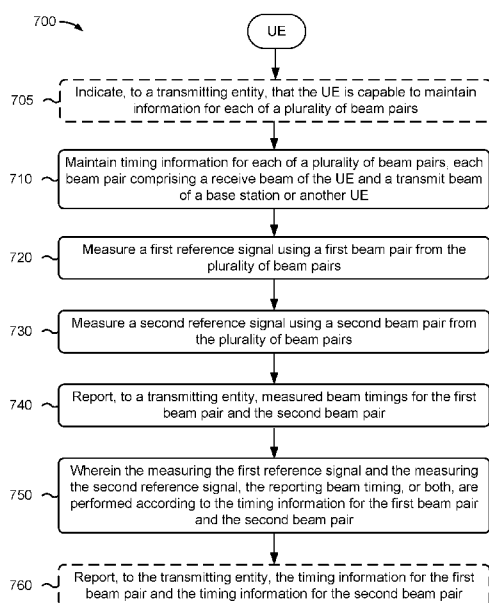


FIG. 7

(57) Abstract: Disclosed are techniques for wireless communication. In an aspect, a user equipment (UE) maintains timing information for each of a plurality of beam pairs, each beam pair comprising a downlink (DL) beam pair, comprising a base station transmit beam and a UE receive beam or a sidelink (SL) beam pair, comprising a UE transmit beam and a UE receive beam. The UE measures a first reference signal using a first beam pair from the plurality of beam pairs, measures a second reference signal using a second beam pair from the plurality of beam pairs, and reports, to a transmitting entity, beam timings for the first beam pair and the second beam pair. The measuring steps, the reporting step, or both, are performed according to the timing information for the first beam pair and the second beam pair.

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## APPARATUSES AND METHODS FOR PER BEAM TIMING FOR POSITIONING

**CROSS-REFERENCE TO RELATED APPLICATION**

[0001] This application claims priority to Indian Patent Application No. 202141001994, filed January 15, 2021, entitled "PER BEAM PAIR TIMING FOR POSITIONING", and to Indian Patent Application No. 202141002125, filed January 16, 2021, entitled "PER BEAM PAIR TIMING FOR POSITIONING," both of which are assigned to the assignee hereof and are expressly incorporated herein by reference in their entireties.

**BACKGROUND OF THE DISCLOSURE***1. Field of the Disclosure*

[0002] Aspects of the disclosure relate generally to wireless communications.

*2. Description of the Related Art*

[0003] Wireless communication systems have developed through various generations, including a first-generation analog wireless phone service (1G), a second-generation (2G) digital wireless phone service (including interim 2.5G and 2.75G networks), a third-generation (3G) high speed data, Internet-capable wireless service and a fourth-generation (4G) service (e.g., Long Term Evolution (LTE) or WiMax). There are presently many different types of wireless communication systems in use, including cellular and personal communications service (PCS) systems. Examples of known cellular systems include the cellular analog advanced mobile phone system (AMPS), and digital cellular systems based on code division multiple access (CDMA), frequency division multiple access (FDMA), time division multiple access (TDMA), the Global System for Mobile communications (GSM), etc.

[0004] A fifth generation (5G) wireless standard, referred to as New Radio (NR), calls for higher data transfer speeds, greater numbers of connections, and better coverage, among other improvements. The 5G standard, according to the Next Generation Mobile Networks Alliance, is designed to provide data rates of several tens of megabits per second to each of tens of thousands of users, with 1 gigabit per second to tens of workers on an office floor. Several hundreds of thousands of simultaneous connections should be supported in order to support large sensor deployments. Consequently, the spectral efficiency of 5G

mobile communications should be significantly enhanced compared to the current 4G standard. Furthermore, signaling efficiencies should be enhanced and latency should be substantially reduced compared to current standards.

### SUMMARY

- [0005] The following presents a simplified summary relating to one or more aspects disclosed herein. Thus, the following summary should not be considered an extensive overview relating to all contemplated aspects, nor should the following summary be considered to identify key or critical elements relating to all contemplated aspects or to delineate the scope associated with any particular aspect. Accordingly, the following summary has the sole purpose to present certain concepts relating to one or more aspects relating to the mechanisms disclosed herein in a simplified form to precede the detailed description presented below.
- [0006] In an aspect, a user equipment (UE) includes a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: maintain timing information for each of a plurality of beam pairs, each beam pair comprising a receive beam of the UE and a transmit beam of a base station or another UE; measure a first reference signal using a first beam pair from the plurality of beam pairs; measure a second reference signal using a second beam pair from the plurality of beam pairs; and report, to a transmitting entity, beam timings for the first beam pair and the second beam pair, wherein measuring the first reference signal and measuring the second reference signal, reporting the beam timings, or both, are performed according to the timing information for the first beam pair and the second beam pair.
- [0007] In an aspect, a UE includes a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: maintain timing information for each of a plurality of beam pairs, each beam pair comprising a transmit beam of the UE and a receive beam of a base station or another UE; cause the at least one transceiver to transmit, to a receiving entity, a first reference signal using a first beam pair from the plurality of beam pairs; and cause the at least one transceiver to transmit, to the receiving entity, a second reference signal using a second beam pair from the plurality of beam pairs, wherein the first reference signal and the second reference signal are transmitted to the receiving entity according to the timing

information for the first beam pair and the second beam pair, respectively, or wherein the at least one processor is further configured to cause the at least one transceiver to transmit, to the receiving entity, the timing information for the first beam pair and the second beam pair.

[0008] In an aspect, a base station (BS) includes a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: maintain timing information for each of a plurality of beam pairs, each beam pair comprising a transmit beam of the base station and a receive beam of a UE; cause the at least one transceiver to transmit a first reference signal using a first beam pair from the plurality of beam pairs; cause the at least one transceiver to transmit a second reference signal using a second beam pair from the plurality of beam pairs; and wherein the first reference signal and the second reference signal are transmitted according to the timing information for the first beam pair and the second beam pair, respectively; or wherein the at least one processor is further configured to: cause the at least one transceiver to transmit the timing information for the first beam pair and the second beam pair to the UE; cause the at least one transceiver to transmit the timing information for the first beam pair and the second beam pair to a positioning entity; or use the timing information for the first beam pair and the second beam pair to adjust a timing report received from the UE.

[0009] In an aspect, a BS includes a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: maintain timing information for each of a plurality of beam pairs, each beam pair comprising a receive beam of the base station and a transmit beam of a UE; measure a first reference signal using a first beam pair from the plurality of beam pairs according to the timing information for the first beam pair; and measure a second reference signal using a second beam pair from the plurality of beam pairs according to the timing information for the second beam pair; and report, to a positioning entity, beam timings for the first beam pair and the second beam pair, wherein measuring the first reference signal and measuring the second reference signal, the reporting the beam timings, or both, are performed according to the timing information for the first beam pair and the second beam pair.

[0010] In an aspect, a method of wireless communication performed by a UE includes maintaining timing information for each of a plurality of beam pairs, each beam pair

comprising a receive beam of the UE and a transmit beam of a base station or another UE; measuring a first reference signal using a first beam pair from the plurality of beam pairs; measuring a second reference signal using a second beam pair from the plurality of beam pairs; and reporting, to a transmitting entity, beam timings for the first beam pair and the second beam pair, wherein the measuring the first reference signal and the measuring the second reference signal, the reporting the beam timings, or both, are performed according to the timing information for the first beam pair and the second beam pair.

[0011] In an aspect, a method of wireless communication performed by a UE includes maintain timing information for each of a plurality of beam pairs, each beam pair comprising a transmit beam of the UE and a receive beam of a base station or another UE; transmitting, to a receiving entity, a first reference signal using a first beam pair from the plurality of beam pairs; and transmitting, to the receiving entity, a second reference signal using a second beam pair from the plurality of beam pairs, wherein the first reference signal and the second reference signal are transmitted to the receiving entity according to the timing information for the first beam pair and the second beam pair, respectively, or wherein the at least one processor is further configured to cause the at least one transceiver to transmit, to the receiving entity, the timing information for the first beam pair and the second beam pair.

[0012] In an aspect, a method of wireless communication performed by a BS includes maintaining timing information for each of a plurality of beam pairs, each beam pair comprising a transmit beam of the base station and a receive beam of a UE; transmitting a first reference signal using a first beam pair from the plurality of beam pairs; and transmitting a second reference signal using a second beam pair from the plurality of beam pairs; wherein the first reference signal and the second reference signal are transmitted according to the timing information for the first beam pair and the second beam pair, respectively; or transmitting the timing information for the first beam pair and the second beam pair to the UE, transmitting the timing information for the first beam pair and the second beam pair to a positioning entity, or using the timing information for the first beam pair and the second beam pair to adjust a timing report received from the UE.

[0013] In an aspect, a method of wireless communication performed by a BS includes maintaining timing information for each of a plurality of beam pairs, each beam pair

comprising a receive beam of the base station and a transmit beam of a UE; measuring a first reference signal using a first beam pair from the plurality of beam pairs according to the timing information for the first beam pair; measuring a second reference signal using a second beam pair from the plurality of beam pairs according to the timing information for the second beam pair; and reporting, to a positioning entity, beam timings for the first beam pair and the second beam pair, wherein measuring the first reference signal and measuring the second reference signal, the reporting the beam timings, or both, are performed according to the timing information for the first beam pair and the second beam pair.

[0014] Other objects and advantages associated with the aspects disclosed herein will be apparent to those skilled in the art based on the accompanying drawings and detailed description.

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

[0015] The accompanying drawings are presented to aid in the description of various aspects of the disclosure and are provided solely for illustration of the aspects and not limitation thereof.

[0016] FIG. 1 illustrates an example wireless communications system, according to aspects of the disclosure.

[0017] FIGS. 2A and 2B illustrate example wireless network structures, according to aspects of the disclosure.

[0018] FIGS. 3A to 3C are simplified block diagrams of several sample aspects of components that may be employed in a user equipment (UE), a base station, and a network entity, respectively, and configured to support communications as taught herein.

[0019] FIGS. 4A to 4D are diagrams illustrating example frame structures and channels within the frame structures, according to aspects of the disclosure.

[0020] FIG. 5 is a diagram illustrating an example base station in communication with an example UE, according to aspects of the disclosure.

[0021] FIG. 6 illustrates an example of downlink time difference of arrival (DL-TDoA).

[0022] FIGS. 7-10 illustrate example methods of wireless communication, according to aspects of the disclosure.

### **DETAILED DESCRIPTION**

- [0023] Aspects of the disclosure are provided in the following description and related drawings directed to various examples provided for illustration purposes. Alternate aspects may be devised without departing from the scope of the disclosure. Additionally, well-known elements of the disclosure will not be described in detail or will be omitted so as not to obscure the relevant details of the disclosure.
- [0024] The words “exemplary” and/or “example” are used herein to mean “serving as an example, instance, or illustration.” Any aspect described herein as “exemplary” and/or “example” is not necessarily to be construed as preferred or advantageous over other aspects. Likewise, the term “aspects of the disclosure” does not require that all aspects of the disclosure include the discussed feature, advantage or mode of operation.
- [0025] Those of skill in the art will appreciate that the information and signals described below may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the description below may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof, depending in part on the particular application, in part on the desired design, in part on the corresponding technology, etc.
- [0026] Further, many aspects are described in terms of sequences of actions to be performed by, for example, elements of a computing device. It will be recognized that various actions described herein can be performed by specific circuits (e.g., application specific integrated circuits (ASICs)), by program instructions being executed by one or more processors, or by a combination of both. Additionally, the sequence(s) of actions described herein can be considered to be embodied entirely within any form of non-transitory computer-readable storage medium having stored therein a corresponding set of computer instructions that, upon execution, would cause or instruct an associated processor of a device to perform the functionality described herein. Thus, the various aspects of the disclosure may be embodied in a number of different forms, all of which have been contemplated to be within the scope of the claimed subject matter. In addition, for each of the aspects described herein, the corresponding form of any such aspects may be described herein as, for example, “logic configured to” perform the described action.
- [0027] As used herein, the terms “user equipment” (UE) and “base station” are not intended to be specific or otherwise limited to any particular radio access technology (RAT), unless otherwise noted. In general, a UE may be any wireless communication device (e.g., a

mobile phone, router, tablet computer, laptop computer, consumer asset tracking device, wearable (e.g., smartwatch, glasses, augmented reality (AR) / virtual reality (VR) headset, etc.), vehicle (e.g., automobile, motorcycle, bicycle, etc.), Internet of Things (IoT) device, etc.) used by a user to communicate over a wireless communications network. A UE may be mobile or may (e.g., at certain times) be stationary, and may communicate with a radio access network (RAN). As used herein, the term “UE” may be referred to interchangeably as an “access terminal” or “AT,” a “client device,” a “wireless device,” a “subscriber device,” a “subscriber terminal,” a “subscriber station,” a “user terminal” or “UT,” a “mobile device,” a “mobile terminal,” a “mobile station,” or variations thereof. Generally, UEs can communicate with a core network via a RAN, and through the core network the UEs can be connected with external networks such as the Internet and with other UEs. Of course, other mechanisms of connecting to the core network and/or the Internet are also possible for the UEs, such as over wired access networks, wireless local area network (WLAN) networks (e.g., based on the Institute of Electrical and Electronics Engineers (IEEE) 802.11 specification, etc.) and so on.

[0028] A base station may operate according to one of several RATs in communication with UEs depending on the network in which it is deployed, and may be alternatively referred to as an access point (AP), a network node, a NodeB, an evolved NodeB (eNB), a next generation eNB (ng-eNB), a New Radio (NR) Node B (also referred to as a gNB or gNodeB), etc. A base station may be used primarily to support wireless access by UEs, including supporting data, voice, and/or signaling connections for the supported UEs. In some systems a base station may provide purely edge node signaling functions while in other systems it may provide additional control and/or network management functions. A communication link through which UEs can send signals to a base station is called an uplink (UL) channel (e.g., a reverse traffic channel, a reverse control channel, an access channel, etc.). A communication link through which the base station can send signals to UEs is called a downlink (DL) or forward link channel (e.g., a paging channel, a control channel, a broadcast channel, a forward traffic channel, etc.). As used herein the term traffic channel (TCH) can refer to either an uplink / reverse or downlink / forward traffic channel.

[0029] The term “base station” may refer to a single physical transmission-reception point (TRP) or to multiple physical TRPs that may or may not be co-located. For example, where the term “base station” refers to a single physical TRP, the physical TRP may be an antenna

of the base station corresponding to a cell (or several cell sectors) of the base station. Where the term “base station” refers to multiple co-located physical TRPs, the physical TRPs may be an array of antennas (e.g., as in a multiple-input multiple-output (MIMO) system or where the base station employs beamforming) of the base station. Where the term “base station” refers to multiple non-co-located physical TRPs, the physical TRPs may be a distributed antenna system (DAS) (a network of spatially separated antennas connected to a common source via a transport medium) or a remote radio head (RRH) (a remote base station connected to a serving base station). Alternatively, the non-co-located physical TRPs may be the serving base station receiving the measurement report from the UE and a neighbor base station whose reference radio frequency (RF) signals the UE is measuring. Because a TRP is the point from which a base station transmits and receives wireless signals, as used herein, references to transmission from or reception at a base station are to be understood as referring to a particular TRP of the base station.

- [0030] In some implementations that support positioning of UEs, a base station may not support wireless access by UEs (e.g., may not support data, voice, and/or signaling connections for UEs), but may instead transmit reference signals to UEs to be measured by the UEs, and/or may receive and measure signals transmitted by the UEs. Such a base station may be referred to as a positioning beacon (e.g., when transmitting signals to UEs) and/or as a location measurement unit (e.g., when receiving and measuring signals from UEs).
- [0031] An “RF signal” comprises an electromagnetic wave of a given frequency that transports information through the space between a transmitter and a receiver. As used herein, a transmitter may transmit a single “RF signal” or multiple “RF signals” to a receiver. However, the receiver may receive multiple “RF signals” corresponding to each transmitted RF signal due to the propagation characteristics of RF signals through multipath channels. The same transmitted RF signal on different paths between the transmitter and receiver may be referred to as a “multipath” RF signal.
- [0032] FIG. 1 illustrates an example wireless communications system 100. The wireless communications system 100 (which may also be referred to as a wireless wide area network (WWAN)) may include various base stations 102 and various UEs 104. The base stations 102 may include macro cell base stations (high power cellular base stations) and/or small cell base stations (low power cellular base stations). In an aspect, the macro cell base station may include eNBs and/or ng-eNBs where the wireless communications system 100 corresponds to an LTE network, or gNBs where the wireless communications

system 100 corresponds to a NR network, or a combination of both, and the small cell base stations may include femtocells, picocells, microcells, etc.

[0033] The base stations 102 may collectively form a RAN and interface with a core network 170 (e.g., an evolved packet core (EPC) or a 5G core (5GC)) through backhaul links 122, and through the core network 170 to one or more location servers 172 (which may be part of core network 170 or may be external to core network 170). In addition to other functions, the base stations 102 may perform functions that relate to one or more of transferring user data, radio channel ciphering and deciphering, integrity protection, header compression, mobility control functions (e.g., handover, dual connectivity), inter-cell interference coordination, connection setup and release, load balancing, distribution for non-access stratum (NAS) messages, NAS node selection, synchronization, RAN sharing, multimedia broadcast multicast service (MBMS), subscriber and equipment trace, RAN information management (RIM), paging, positioning, and delivery of warning messages. The base stations 102 may communicate with each other directly or indirectly (e.g., through the EPC / 5GC) over backhaul links 134, which may be wired or wireless.

[0034] The base stations 102 may wirelessly communicate with the UEs 104. Each of the base stations 102 may provide communication coverage for a respective geographic coverage area 110. In an aspect, one or more cells may be supported by a base station 102 in each geographic coverage area 110. A “cell” is a logical communication entity used for communication with a base station (e.g., over some frequency resource, referred to as a carrier frequency, component carrier, carrier, band, or the like), and may be associated with an identifier (e.g., a physical cell identifier (PCI), a virtual cell identifier (VCI), a cell global identifier (CGI)) for distinguishing cells operating via the same or a different carrier frequency. In some cases, different cells may be configured according to different protocol types (e.g., machine-type communication (MTC), narrowband IoT (NB-IoT), enhanced mobile broadband (eMBB), or others) that may provide access for different types of UEs. Because a cell is supported by a specific base station, the term “cell” may refer to either or both of the logical communication entity and the base station that supports it, depending on the context. In some cases, the term “cell” may also refer to a geographic coverage area of a base station (e.g., a sector), insofar as a carrier frequency can be detected and used for communication within some portion of geographic coverage areas 110.

- [0035] While neighboring macro cell base station 102 geographic coverage areas 110 may partially overlap (e.g., in a handover region), some of the geographic coverage areas 110 may be substantially overlapped by a larger geographic coverage area 110. For example, a small cell (SC) base station 102' may have a geographic coverage area 110' that substantially overlaps with the geographic coverage area 110 of one or more macro cell base stations 102. A network that includes both small cell and macro cell base stations may be known as a heterogeneous network. A heterogeneous network may also include home eNBs (HeNBs), which may provide service to a restricted group known as a closed subscriber group (CSG).
- [0036] The communication links 120 between the base stations 102 and the UEs 104 may include uplink (also referred to as reverse link) transmissions from a UE 104 to a base station 102 and/or downlink (also referred to as forward link) transmissions from a base station 102 to a UE 104. The communication links 120 may use MIMO antenna technology, including spatial multiplexing, beamforming, and/or transmit diversity. The communication links 120 may be through one or more carrier frequencies. Allocation of carriers may be asymmetric with respect to downlink and uplink (e.g., more or less carriers may be allocated for downlink than for uplink).
- [0037] The wireless communications system 100 may further include a wireless local area network (WLAN) access point (AP) 150 in communication with WLAN stations (STAs) 152 via communication links 154 in an unlicensed frequency spectrum (e.g., 5 GHz). When communicating in an unlicensed frequency spectrum, the WLAN STAs 152 and/or the WLAN AP 150 may perform a clear channel assessment (CCA) or listen-before-talk (LBT) procedure prior to communicating in order to determine whether the channel is available.
- [0038] The small cell base station 102' may operate in a licensed and/or an unlicensed frequency spectrum. When operating in an unlicensed frequency spectrum, the small cell base station 102' may employ LTE or NR technology and use the same 5 GHz unlicensed frequency spectrum as used by the WLAN AP 150. The small cell base station 102', employing LTE / 5G in an unlicensed frequency spectrum, may boost coverage to and/or increase capacity of the access network. NR in unlicensed spectrum may be referred to as NR-U. LTE in an unlicensed spectrum may be referred to as LTE-U, licensed assisted access (LAA), or MulteFire.

- [0039] The wireless communications system 100 may further include a millimeter wave (mmW) base station 180 that may operate in mmW frequencies and/or near mmW frequencies in communication with a UE 182. Extremely high frequency (EHF) is part of the RF in the electromagnetic spectrum. EHF has a range of 30 GHz to 300 GHz and a wavelength between 1 millimeter and 10 millimeters. Radio waves in this band may be referred to as a millimeter wave. Near mmW may extend down to a frequency of 3 GHz with a wavelength of 100 millimeters. The super high frequency (SHF) band extends between 3 GHz and 30 GHz, also referred to as centimeter wave. Communications using the mmW/near mmW radio frequency band have high path loss and a relatively short range. The mmW base station 180 and the UE 182 may utilize beamforming (transmit and/or receive) over a mmW communication link 184 to compensate for the extremely high path loss and short range. Further, it will be appreciated that in alternative configurations, one or more base stations 102 may also transmit using mmW or near mmW and beamforming. Accordingly, it will be appreciated that the foregoing illustrations are merely examples and should not be construed to limit the various aspects disclosed herein.
- [0040] Transmit beamforming is a technique for focusing an RF signal in a specific direction. Traditionally, when a network node (e.g., a base station) broadcasts an RF signal, it broadcasts the signal in all directions (omni-directionally). With transmit beamforming, the network node determines where a given target device (e.g., a UE) is located (relative to the transmitting network node) and projects a stronger downlink RF signal in that specific direction, thereby providing a faster (in terms of data rate) and stronger RF signal for the receiving device(s). To change the directionality of the RF signal when transmitting, a network node can control the phase and relative amplitude of the RF signal at each of the one or more transmitters that are broadcasting the RF signal. For example, a network node may use an array of antennas (referred to as a “phased array” or an “antenna array”) that creates a beam of RF waves that can be “steered” to point in different directions, without actually moving the antennas. Specifically, the RF current from the transmitter is fed to the individual antennas with the correct phase relationship so that the radio waves from the separate antennas add together to increase the radiation in a desired direction, while cancelling to suppress radiation in undesired directions.
- [0041] Transmit beams may be quasi-co-located, meaning that they appear to the receiver (e.g., a UE) as having the same parameters, regardless of whether or not the transmitting antennas of the network node themselves are physically co-located. In NR, there are four

types of quasi-co-location (QCL) relations. Specifically, a QCL relation of a given type means that certain parameters about a target reference RF signal on a target beam can be derived from information about a source reference RF signal on a source beam. If the source reference RF signal is QCL Type A, the receiver can use the source reference RF signal to estimate the Doppler shift, Doppler spread, average delay, and delay spread of a target reference RF signal transmitted on the same channel. If the source reference RF signal is QCL Type B, the receiver can use the source reference RF signal to estimate the Doppler shift and Doppler spread of a target reference RF signal transmitted on the same channel. If the source reference RF signal is QCL Type C, the receiver can use the source reference RF signal to estimate the Doppler shift and average delay of a target reference RF signal transmitted on the same channel. If the source reference RF signal is QCL Type D, the receiver can use the source reference RF signal to estimate the spatial receive parameter of a target reference RF signal transmitted on the same channel.

[0042] From a transceiver hardware perspective, there will be a Tx time delay from the time when the digital signal is generated at baseband to the time when the RF signal is transmitted from the Tx antenna, and a Rx time delay from the time when the RF signal arrives at the Rx antenna to the time when the signal is digitized and time-stamped at the baseband. Calibration attempts to compensate for these delays, but calibration may not be perfect, resulting in a residual timing error. A timing error group (TEG) is a group of signals that have timing errors within a certain margin. Thus, when two reference signals have timing errors that are within a certain margin, the two reference signals may be part of the same TEG. Two reference signals that are transmitted by the same TRP, for example, are likely to be in the same Tx TEG, while two reference signals that are transmitted by different TRPs are likely to be in different Tx TEGs. Similarly, two reference signals that are received by the same TRP are likely to be in the same Rx TEG, while two reference signals that are received by different TRPs are likely to be in different Rx TEGs.

[0043] In receive beamforming, the receiver uses a receive beam to amplify RF signals detected on a given channel. For example, the receiver can increase the gain setting and/or adjust the phase setting of an array of antennas in a particular direction to amplify (e.g., to increase the gain level of) the RF signals received from that direction. Thus, when a receiver is said to beamform in a certain direction, it means the beam gain in that direction is high relative to the beam gain along other directions, or the beam gain in that direction

is the highest compared to the beam gain in that direction of all other receive beams available to the receiver. This results in a stronger received signal strength (e.g., reference signal received power (RSRP), reference signal received quality (RSRQ), signal-to-interference-plus-noise ratio (SINR), etc.) of the RF signals received from that direction.

- [0044] Receive beams may be spatially related. A spatial relation means that parameters for a transmit beam for a second reference signal can be derived from information about a receive beam for a first reference signal. For example, a UE may use a particular receive beam to receive one or more reference downlink reference signals (e.g., positioning reference signals (PRS), tracking reference signals (TRS), phase tracking reference signal (PTRS), cell-specific reference signals (CRS), channel state information reference signals (CSI-RS), primary synchronization signals (PSS), secondary synchronization signals (SSS), synchronization signal blocks (SSBs), etc.) from a base station. The UE can then form a transmit beam for sending one or more uplink reference signals (e.g., uplink positioning reference signals (UL-PRS), sounding reference signal (SRS), demodulation reference signals (DMRS), PTRS, etc.) to that base station based on the parameters of the receive beam.
- [0045] Note that a “downlink” beam may be either a transmit beam or a receive beam, depending on the entity forming it. For example, if a base station is forming the downlink beam to transmit a reference signal to a UE, the downlink beam is a transmit beam. If the UE is forming the downlink beam, however, it is a receive beam to receive the downlink reference signal. Similarly, an “uplink” beam may be either a transmit beam or a receive beam, depending on the entity forming it. For example, if a base station is forming the uplink beam, it is an uplink receive beam, and if a UE is forming the uplink beam, it is an uplink transmit beam.
- [0046] In 5G, the frequency spectrum in which wireless nodes (e.g., base stations 102/180, UEs 104/182) operate is divided into multiple frequency ranges, FR1 (from 450 to 6000 MHz), FR2 (from 24250 to 52600 MHz), FR3 (above 52600 MHz), and FR4 (between FR1 and FR2). In a multi-carrier system, such as 5G, one of the carrier frequencies is referred to as the “primary carrier” or “anchor carrier” or “primary serving cell” or “PCell,” and the remaining carrier frequencies are referred to as “secondary carriers” or “secondary serving cells” or “SCells.” In carrier aggregation, the anchor carrier is the carrier operating on the primary frequency (e.g., FR1) utilized by a UE 104/182 and the cell in which the UE 104/182 either performs the initial radio resource control (RRC) connection

establishment procedure or initiates the RRC connection re-establishment procedure. The primary carrier carries all common and UE-specific control channels, and may be a carrier in a licensed frequency (however, this is not always the case). A secondary carrier is a carrier operating on a second frequency (e.g., FR2) that may be configured once the RRC connection is established between the UE 104 and the anchor carrier and that may be used to provide additional radio resources. In some cases, the secondary carrier may be a carrier in an unlicensed frequency. The secondary carrier may contain only necessary signaling information and signals, for example, those that are UE-specific may not be present in the secondary carrier, since both primary uplink and downlink carriers are typically UE-specific. This means that different UEs 104/182 in a cell may have different downlink primary carriers. The same is true for the uplink primary carriers. The network is able to change the primary carrier of any UE 104/182 at any time. This is done, for example, to balance the load on different carriers. Because a “serving cell” (whether a PCell or an SCell) corresponds to a carrier frequency / component carrier over which some base station is communicating, the term “cell,” “serving cell,” “component carrier,” “carrier frequency,” and the like can be used interchangeably.

- [0047] For example, still referring to FIG. 1, one of the frequencies utilized by the macro cell base stations 102 may be an anchor carrier (or “PCell”) and other frequencies utilized by the macro cell base stations 102 and/or the mmW base station 180 may be secondary carriers (“SCells”). The simultaneous transmission and/or reception of multiple carriers enables the UE 104/182 to significantly increase its data transmission and/or reception rates. For example, two 20 MHz aggregated carriers in a multi-carrier system would theoretically lead to a two-fold increase in data rate (i.e., 40 MHz), compared to that attained by a single 20 MHz carrier.
- [0048] The wireless communications system 100 may further include a UE 164 that may communicate with a macro cell base station 102 over a communication link 120 and/or the mmW base station 180 over a mmW communication link 184. For example, the macro cell base station 102 may support a PCell and one or more SCells for the UE 164 and the mmW base station 180 may support one or more SCells for the UE 164.
- [0049] In the example of FIG. 1, one or more Earth orbiting satellite positioning system (SPS) space vehicles (SVs) 112 (e.g., satellites) may be used as an independent source of location information for any of the illustrated UEs (shown in FIG. 1 as a single UE 104 for simplicity). A UE 104 may include one or more dedicated SPS receivers specifically

designed to receive SPS signals 124 for deriving geo location information from the SVs 112. An SPS typically includes a system of transmitters (e.g., SVs 112) positioned to enable receivers (e.g., UEs 104) to determine their location on or above the Earth based, at least in part, on signals (e.g., SPS signals 124) received from the transmitters. Such a transmitter typically transmits a signal marked with a repeating pseudo-random noise (PN) code of a set number of chips. While typically located in SVs 112, transmitters may sometimes be located on ground-based control stations, base stations 102, and/or other UEs 104.

[0050] The use of SPS signals 124 can be augmented by various satellite-based augmentation systems (SBAS) that may be associated with or otherwise enabled for use with one or more global and/or regional navigation satellite systems. For example an SBAS may include an augmentation system(s) that provides integrity information, differential corrections, etc., such as the Wide Area Augmentation System (WAAS), the European Geostationary Navigation Overlay Service (EGNOS), the Multi-functional Satellite Augmentation System (MSAS), the Global Positioning System (GPS) Aided Geo Augmented Navigation or GPS and Geo Augmented Navigation system (GAGAN), and/or the like. Thus, as used herein, an SPS may include any combination of one or more global and/or regional navigation satellite systems and/or augmentation systems, and SPS signals 124 may include SPS, SPS-like, and/or other signals associated with such one or more SPS.

[0051] The wireless communications system 100 may further include one or more UEs, such as UE 190, that connects indirectly to one or more communication networks via one or more device-to-device (D2D) peer-to-peer (P2P) links (referred to as “sidelinks”). In the example of FIG. 1, UE 190 has a D2D P2P link 192 with one of the UEs 104 connected to one of the base stations 102 (e.g., through which UE 190 may indirectly obtain cellular connectivity) and a D2D P2P link 194 with WLAN STA 152 connected to the WLAN AP 150 (through which UE 190 may indirectly obtain WLAN-based Internet connectivity). In an example, the D2D P2P links 192 and 194 may be supported with any well-known D2D RAT, such as LTE Direct (LTE-D), WiFi Direct (WiFi-D), Bluetooth®, and so on.

[0052] FIG. 2A illustrates an example wireless network structure 200. For example, a 5GC 210 (also referred to as a Next Generation Core (NGC)) can be viewed functionally as control plane functions 214 (e.g., UE registration, authentication, network access, gateway

selection, etc.) and user plane functions 212, (e.g., UE gateway function, access to data networks, IP routing, etc.) which operate cooperatively to form the core network. User plane interface (NG-U) 213 and control plane interface (NG-C) 215 connect the gNB 222 to the 5GC 210 and specifically to the control plane functions 214 and user plane functions 212. In an additional configuration, an ng-eNB 224 may also be connected to the 5GC 210 via NG-C 215 to the control plane functions 214 and NG-U 213 to user plane functions 212. Further, ng-eNB 224 may directly communicate with gNB 222 via a backhaul connection 223. In some configurations, the New RAN 220 may only have one or more gNBs 222, while other configurations include one or more of both ng-eNBs 224 and gNBs 222. Either gNB 222 or ng-eNB 224 may communicate with UEs 204 (e.g., any of the UEs depicted in FIG. 1). Another optional aspect may include location server 230, which may be in communication with the 5GC 210 to provide location assistance for UEs 204. The location server 230 can be implemented as a plurality of separate servers (e.g., physically separate servers, different software modules on a single server, different software modules spread across multiple physical servers, etc.), or alternately may each correspond to a single server. The location server 230 can be configured to support one or more location services for UEs 204 that can connect to the location server 230 via the core network, 5GC 210, and/or via the Internet (not illustrated). Further, the location server 230 may be integrated into a component of the core network, or alternatively may be external to the core network.

**[0053]** FIG. 2B illustrates another example wireless network structure 250. For example, a 5GC 260 can be viewed functionally as control plane functions, provided by an access and mobility management function (AMF) 264, and user plane functions, provided by a user plane function (UPF) 262, which operate cooperatively to form the core network (i.e., 5GC 260). User plane interface 263 and control plane interface 265 connect the ng-eNB 224 to the 5GC 260 and specifically to UPF 262 and AMF 264, respectively. In an additional configuration, a gNB 222 may also be connected to the 5GC 260 via control plane interface 265 to AMF 264 and user plane interface 263 to UPF 262. Further, ng-eNB 224 may directly communicate with gNB 222 via the backhaul connection 223, with or without gNB direct connectivity to the 5GC 260. In some configurations, the New RAN 220 may only have one or more gNBs 222, while other configurations include one or more of both ng-eNBs 224 and gNBs 222. Either gNB 222 or ng-eNB 224 may communicate with UEs 204 (e.g., any of the UEs depicted in FIG. 1). The base stations

of the New RAN 220 communicate with the AMF 264 over the N2 interface and with the UPF 262 over the N3 interface.

[0054] The functions of the AMF 264 include registration management, connection management, reachability management, mobility management, lawful interception, transport for session management (SM) messages between the UE 204 and a session management function (SMF) 266, transparent proxy services for routing SM messages, access authentication and access authorization, transport for short message service (SMS) messages between the UE 204 and the short message service function (SMSF) (not shown), and security anchor functionality (SEAF). The AMF 264 also interacts with an authentication server function (AUSF) (not shown) and the UE 204, and receives the intermediate key that was established as a result of the UE 204 authentication process. In the case of authentication based on a UMTS (universal mobile telecommunications system) subscriber identity module (USIM), the AMF 264 retrieves the security material from the AUSF. The functions of the AMF 264 also include security context management (SCM). The SCM receives a key from the SEAF that it uses to derive access-network specific keys. The functionality of the AMF 264 also includes location services management for regulatory services, transport for location services messages between the UE 204 and a location management function (LMF) 270 (which acts as a location server 230), transport for location services messages between the New RAN 220 and the LMF 270, evolved packet system (EPS) bearer identifier allocation for interworking with the EPS, and UE 204 mobility event notification. In addition, the AMF 264 also supports functionalities for non-3GPP (Third Generation Partnership Project) access networks.

[0055] Functions of the UPF 262 include acting as an anchor point for intra-/inter-RAT mobility (when applicable), acting as an external protocol data unit (PDU) session point of interconnect to a data network (not shown), providing packet routing and forwarding, packet inspection, user plane policy rule enforcement (e.g., gating, redirection, traffic steering), lawful interception (user plane collection), traffic usage reporting, quality of service (QoS) handling for the user plane (e.g., uplink/ downlink rate enforcement, reflective QoS marking in the downlink), uplink traffic verification (service data flow (SDF) to QoS flow mapping), transport level packet marking in the uplink and downlink, downlink packet buffering and downlink data notification triggering, and sending and forwarding of one or more “end markers” to the source RAN node. The UPF 262 may also support transfer of location services messages over a user plane between the UE 204

and a location server, such as a secure user plane location (SUPL) location platform (SLP) 272.

- [0056] The functions of the SMF 266 include session management, UE Internet protocol (IP) address allocation and management, selection and control of user plane functions, configuration of traffic steering at the UPF 262 to route traffic to the proper destination, control of part of policy enforcement and QoS, and downlink data notification. The interface over which the SMF 266 communicates with the AMF 264 is referred to as the N11 interface.
- [0057] Another optional aspect may include an LMF 270, which may be in communication with the 5GC 260 to provide location assistance for UEs 204. The LMF 270 can be implemented as a plurality of separate servers (e.g., physically separate servers, different software modules on a single server, different software modules spread across multiple physical servers, etc.), or alternately may each correspond to a single server. The LMF 270 can be configured to support one or more location services for UEs 204 that can connect to the LMF 270 via the core network, 5GC 260, and/or via the Internet (not illustrated). The SLP 272 may support similar functions to the LMF 270, but whereas the LMF 270 may communicate with the AMF 264, New RAN 220, and UEs 204 over a control plane (e.g., using interfaces and protocols intended to convey signaling messages and not voice or data), the SLP 272 may communicate with UEs 204 and external clients (not shown in FIG. 2B) over a user plane (e.g., using protocols intended to carry voice and/or data like the transmission control protocol (TCP) and/or IP).
- [0058] FIGS. 3A, 3B, and 3C illustrate several example components (represented by corresponding blocks) that may be incorporated into a UE 302 (which may correspond to any of the UEs described herein), a base station 304 (which may correspond to any of the base stations described herein), and a network entity 306 (which may correspond to or embody any of the network functions described herein, including the location server 230 and the LMF 270) to support the file transmission operations as taught herein. It will be appreciated that these components may be implemented in different types of apparatuses in different implementations (e.g., in an ASIC, in a system-on-chip (SoC), etc.). The illustrated components may also be incorporated into other apparatuses in a communication system. For example, other apparatuses in a system may include components similar to those described to provide similar functionality. Also, a given apparatus may contain one or more of the components. For example, an apparatus may

include multiple transceiver components that enable the apparatus to operate on multiple carriers and/or communicate via different technologies.

**[0059]** The UE 302 and the base station 304 each include wireless wide area network (WWAN) transceiver 310 and 350, respectively, providing means for communicating (e.g., means for transmitting, means for receiving, means for measuring, means for tuning, means for refraining from transmitting, etc.) via one or more wireless communication networks (not shown), such as an NR network, an LTE network, a GSM network, and/or the like. The WWAN transceivers 310 and 350 may be connected to one or more antennas 316 and 356, respectively, for communicating with other network nodes, such as other UEs, access points, base stations (e.g., eNBs, gNBs), etc., via at least one designated RAT (e.g., NR, LTE, GSM, etc.) over a wireless communication medium of interest (e.g., some set of time/frequency resources in a particular frequency spectrum). The WWAN transceivers 310 and 350 may be variously configured for transmitting and encoding signals 318 and 358 (e.g., messages, indications, information, and so on), respectively, and conversely, for receiving and decoding signals 318 and 358 (e.g., messages, indications, information, pilots, and so on), respectively, in accordance with the designated RAT. Specifically, the WWAN transceivers 310 and 350 include one or more transmitters 314 and 354, respectively, for transmitting and encoding signals 318 and 358, respectively, and one or more receivers 312 and 352, respectively, for receiving and decoding signals 318 and 358, respectively.

**[0060]** The UE 302 and the base station 304 also include, at least in some cases, one or more short-range wireless transceivers 320 and 360, respectively. The short-range wireless transceivers 320 and 360 may be connected to one or more antennas 326 and 366, respectively, and provide means for communicating (e.g., means for transmitting, means for receiving, means for measuring, means for tuning, means for refraining from transmitting, etc.) with other network nodes, such as other UEs, access points, base stations, etc., via at least one designated RAT (e.g., WiFi, LTE-D, Bluetooth®, Zigbee®, Z-Wave®, PC5, dedicated short-range communications (DSRC), wireless access for vehicular environments (WAVE), near-field communication (NFC), etc.) over a wireless communication medium of interest. The short-range wireless transceivers 320 and 360 may be variously configured for transmitting and encoding signals 328 and 368 (e.g., messages, indications, information, and so on), respectively, and conversely, for receiving and decoding signals 328 and 368 (e.g., messages, indications, information, pilots, and so

on), respectively, in accordance with the designated RAT. Specifically, the short-range wireless transceivers 320 and 360 include one or more transmitters 324 and 364, respectively, for transmitting and encoding signals 328 and 368, respectively, and one or more receivers 322 and 362, respectively, for receiving and decoding signals 328 and 368, respectively. As specific examples, the short-range wireless transceivers 320 and 360 may be WiFi transceivers, Bluetooth® transceivers, Zigbee® and/or Z-Wave® transceivers, NFC transceivers, or vehicle-to-vehicle (V2V) and/or vehicle-to-everything (V2X) transceivers.

[0061] Transceiver circuitry including at least one transmitter and at least one receiver may comprise an integrated device (e.g., embodied as a transmitter circuit and a receiver circuit of a single communication device) in some implementations, may comprise a separate transmitter device and a separate receiver device in some implementations, or may be embodied in other ways in other implementations. In an aspect, a transmitter may include or be coupled to a plurality of antennas (e.g., antennas 316, 326, 356, 366), such as an antenna array, that permits the respective apparatus to perform transmit “beamforming,” as described herein. Similarly, a receiver may include or be coupled to a plurality of antennas (e.g., antennas 316, 326, 356, 366), such as an antenna array, that permits the respective apparatus to perform receive beamforming, as described herein. In an aspect, the transmitter and receiver may share the same plurality of antennas (e.g., antennas 316, 326, 356, 366), such that the respective apparatus can only receive or transmit at a given time, not both at the same time. A wireless communication device (e.g., one or both of the transceivers 310 and 320 and/or 350 and 360) of the UE 302 and/or the base station 304 may also comprise a network listen module (NLM) or the like for performing various measurements.

[0062] The UE 302 and the base station 304 also include, at least in some cases, satellite positioning systems (SPS) receivers 330 and 370. The SPS receivers 330 and 370 may be connected to one or more antennas 336 and 376, respectively, and may provide means for receiving and/or measuring SPS signals 338 and 378, respectively, such as global positioning system (GPS) signals, global navigation satellite system (GLONASS) signals, Galileo signals, Beidou signals, Indian Regional Navigation Satellite System (NAVIC), Quasi-Zenith Satellite System (QZSS), etc. The SPS receivers 330 and 370 may comprise any suitable hardware and/or software for receiving and processing SPS signals 338 and 378, respectively. The SPS receivers 330 and 370 request information and operations as

appropriate from the other systems, and performs calculations necessary to determine positions of the UE 302 and the base station 304 using measurements obtained by any suitable SPS algorithm.

- [0063] The base station 304 and the network entity 306 each include at least one network interfaces 380 and 390, respectively, providing means for communicating (e.g., means for transmitting, means for receiving, etc.) with other network entities. For example, the network interfaces 380 and 390 (e.g., one or more network access ports) may be configured to communicate with one or more network entities via a wire-based or wireless backhaul connection. In some aspects, the network interfaces 380 and 390 may be implemented as transceivers configured to support wire-based or wireless signal communication. This communication may involve, for example, sending and receiving messages, parameters, and/or other types of information.
- [0064] The UE 302, the base station 304, and the network entity 306 also include other components that may be used in conjunction with the operations as disclosed herein. The UE 302 includes processor circuitry implementing a processing system 332 for providing functionality relating to, for example, wireless positioning, and for providing other processing functionality. The base station 304 includes a processing system 384 for providing functionality relating to, for example, wireless positioning as disclosed herein, and for providing other processing functionality. The network entity 306 includes a processing system 394 for providing functionality relating to, for example, wireless positioning as disclosed herein, and for providing other processing functionality. The processing systems 332, 384, and 394 may therefore provide means for processing, such as means for determining, means for calculating, means for receiving, means for transmitting, means for indicating, etc. In an aspect, the processing systems 332, 384, and 394 may include, for example, one or more processors, such as one or more general purpose processors, multi-core processors, ASICs, digital signal processors (DSPs), field programmable gate arrays (FPGA), other programmable logic devices or processing circuitry, or various combinations thereof.
- [0065] The UE 302, the base station 304, and the network entity 306 include memory circuitry implementing memory components 340, 386, and 396 (e.g., each including a memory device), respectively, for maintaining information (e.g., information indicative of reserved resources, thresholds, parameters, and so on). The memory components 340, 386, and 396 may therefore provide means for storing, means for retrieving, means for

maintaining, etc. In some cases, the UE 302, the base station 304, and the network entity 306 may include positioning components 342, 388, and 398, respectively. The positioning components 342, 388, and 398 may be hardware circuits that are part of or coupled to the processing systems 332, 384, and 394, respectively, that, when executed, cause the UE 302, the base station 304, and the network entity 306 to perform the functionality described herein. In other aspects, the positioning components 342, 388, and 398 may be external to the processing systems 332, 384, and 394 (e.g., part of a modem processing system, integrated with another processing system, etc.). Alternatively, the positioning components 342, 388, and 398 may be memory modules stored in the memory components 340, 386, and 396, respectively, that, when executed by the processing systems 332, 384, and 394 (or a modem processing system, another processing system, etc.), cause the UE 302, the base station 304, and the network entity 306 to perform the functionality described herein. FIG. 3A illustrates possible locations of the positioning component 342, which may be part of the WWAN transceiver 310, the memory component 340, the processing system 332, or any combination thereof, or may be a standalone component. FIG. 3B illustrates possible locations of the positioning component 388, which may be part of the WWAN transceiver 350, the memory component 386, the processing system 384, or any combination thereof, or may be a standalone component. FIG. 3C illustrates possible locations of the positioning component 398, which may be part of the network interface(s) 390, the memory component 396, the processing system 394, or any combination thereof, or may be a standalone component.

[0066] The UE 302 may include one or more sensors 344 coupled to the processing system 332 to provide means for sensing or detecting movement and/or orientation information that is independent of motion data derived from signals received by the WWAN transceiver 310, the short-range wireless transceiver 320, and/or the SPS receiver 330. By way of example, the sensor(s) 344 may include an accelerometer (e.g., a micro-electrical mechanical systems (MEMS) device), a gyroscope, a geomagnetic sensor (e.g., a compass), an altimeter (e.g., a barometric pressure altimeter), and/or any other type of movement detection sensor. Moreover, the sensor(s) 344 may include a plurality of different types of devices and combine their outputs in order to provide motion information. For example, the sensor(s) 344 may use a combination of a multi-axis

accelerometer and orientation sensors to provide the ability to compute positions in 2D and/or 3D coordinate systems.

- [0067] In addition, the UE 302 includes a user interface 346 providing means for providing indications (e.g., audible and/or visual indications) to a user and/or for receiving user input (e.g., upon user actuation of a sensing device such a keypad, a touch screen, a microphone, and so on). Although not shown, the base station 304 and the network entity 306 may also include user interfaces.
- [0068] Referring to the processing system 384 in more detail, in the downlink, IP packets from the network entity 306 may be provided to the processing system 384. The processing system 384 may implement functionality for an RRC layer, a packet data convergence protocol (PDCP) layer, a radio link control (RLC) layer, and a medium access control (MAC) layer. The processing system 384 may provide RRC layer functionality associated with broadcasting of system information (e.g., master information block (MIB), system information blocks (SIBs)), RRC connection control (e.g., RRC connection paging, RRC connection establishment, RRC connection modification, and RRC connection release), inter-RAT mobility, and measurement configuration for UE measurement reporting; PDCP layer functionality associated with header compression/decompression, security (ciphering, deciphering, integrity protection, integrity verification), and handover support functions; RLC layer functionality associated with the transfer of upper layer PDUs, error correction through automatic repeat request (ARQ), concatenation, segmentation, and reassembly of RLC service data units (SDUs), re-segmentation of RLC data PDUs, and reordering of RLC data PDUs; and MAC layer functionality associated with mapping between logical channels and transport channels, scheduling information reporting, error correction, priority handling, and logical channel prioritization.
- [0069] The transmitter 354 and the receiver 352 may implement Layer-1 (L1) functionality associated with various signal processing functions. Layer-1, which includes a physical (PHY) layer, may include error detection on the transport channels, forward error correction (FEC) coding/decoding of the transport channels, interleaving, rate matching, mapping onto physical channels, modulation/demodulation of physical channels, and MIMO antenna processing. The transmitter 354 handles mapping to signal constellations based on various modulation schemes (e.g., binary phase-shift keying (BPSK), quadrature phase-shift keying (QPSK), M-phase-shift keying (M-PSK), M-quadrature amplitude modulation (M-QAM)). The coded and modulated symbols may then be split into parallel

streams. Each stream may then be mapped to an orthogonal frequency division multiplexing (OFDM) subcarrier, multiplexed with a reference signal (e.g., pilot) in the time and/or frequency domain, and then combined together using an inverse fast Fourier transform (IFFT) to produce a physical channel carrying a time domain OFDM symbol stream. The OFDM symbol stream is spatially precoded to produce multiple spatial streams. Channel estimates from a channel estimator may be used to determine the coding and modulation scheme, as well as for spatial processing. The channel estimate may be derived from a reference signal and/or channel condition feedback transmitted by the UE 302. Each spatial stream may then be provided to one or more different antennas 356. The transmitter 354 may modulate an RF carrier with a respective spatial stream for transmission.

- [0070] At the UE 302, the receiver 312 receives a signal through its respective antenna(s) 316. The receiver 312 recovers information modulated onto an RF carrier and provides the information to the processing system 332. The transmitter 314 and the receiver 312 implement Layer-1 functionality associated with various signal processing functions. The receiver 312 may perform spatial processing on the information to recover any spatial streams destined for the UE 302. If multiple spatial streams are destined for the UE 302, they may be combined by the receiver 312 into a single OFDM symbol stream. The receiver 312 then converts the OFDM symbol stream from the time-domain to the frequency domain using a fast Fourier transform (FFT). The frequency domain signal comprises a separate OFDM symbol stream for each subcarrier of the OFDM signal. The symbols on each subcarrier, and the reference signal, are recovered and demodulated by determining the most likely signal constellation points transmitted by the base station 304. These soft decisions may be based on channel estimates computed by a channel estimator. The soft decisions are then decoded and de-interleaved to recover the data and control signals that were originally transmitted by the base station 304 on the physical channel. The data and control signals are then provided to the processing system 332, which implements Layer-3 (L3) and Layer-2 (L2) functionality.
- [0071] In the uplink, the processing system 332 provides demultiplexing between transport and logical channels, packet reassembly, deciphering, header decompression, and control signal processing to recover IP packets from the core network. The processing system 332 is also responsible for error detection.

- [0072] Similar to the functionality described in connection with the downlink transmission by the base station 304, the processing system 332 provides RRC layer functionality associated with system information (e.g., MIB, SIBs) acquisition, RRC connections, and measurement reporting; PDCP layer functionality associated with header compression/decompression, and security (ciphering, deciphering, integrity protection, integrity verification); RLC layer functionality associated with the transfer of upper layer PDUs, error correction through ARQ, concatenation, segmentation, and reassembly of RLC SDUs, re-segmentation of RLC data PDUs, and reordering of RLC data PDUs; and MAC layer functionality associated with mapping between logical channels and transport channels, multiplexing of MAC SDUs onto transport blocks (TBs), demultiplexing of MAC SDUs from TBs, scheduling information reporting, error correction through hybrid automatic repeat request (HARQ), priority handling, and logical channel prioritization.
- [0073] Channel estimates derived by the channel estimator from a reference signal or feedback transmitted by the base station 304 may be used by the transmitter 314 to select the appropriate coding and modulation schemes, and to facilitate spatial processing. The spatial streams generated by the transmitter 314 may be provided to different antenna(s) 316. The transmitter 314 may modulate an RF carrier with a respective spatial stream for transmission.
- [0074] The uplink transmission is processed at the base station 304 in a manner similar to that described in connection with the receiver function at the UE 302. The receiver 352 receives a signal through its respective antenna(s) 356. The receiver 352 recovers information modulated onto an RF carrier and provides the information to the processing system 384.
- [0075] In the uplink, the processing system 384 provides demultiplexing between transport and logical channels, packet reassembly, deciphering, header decompression, control signal processing to recover IP packets from the UE 302. IP packets from the processing system 384 may be provided to the core network. The processing system 384 is also responsible for error detection.
- [0076] For convenience, the UE 302, the base station 304, and/or the network entity 306 are shown in FIGS. 3A-C as including various components that may be configured according to the various examples described herein. It will be appreciated, however, that the illustrated blocks may have different functionality in different designs.

- [0077] The various components of the UE 302, the base station 304, and the network entity 306 may communicate with each other over data buses 334, 382, and 392, respectively. The components of FIGS. 3A-C may be implemented in various ways. In some implementations, the components of FIGS. 3A-C may be implemented in one or more circuits such as, for example, one or more processors and/or one or more ASICs (which may include one or more processors). Here, each circuit may use and/or incorporate at least one memory component for storing information or executable code used by the circuit to provide this functionality. For example, some or all of the functionality represented by blocks 310 to 346 may be implemented by processor and memory component(s) of the UE 302 (e.g., by execution of appropriate code and/or by appropriate configuration of processor components). Similarly, some or all of the functionality represented by blocks 350 to 388 may be implemented by processor and memory component(s) of the base station 304 (e.g., by execution of appropriate code and/or by appropriate configuration of processor components). Also, some or all of the functionality represented by blocks 390 to 398 may be implemented by processor and memory component(s) of the network entity 306 (e.g., by execution of appropriate code and/or by appropriate configuration of processor components). For simplicity, various operations, acts, and/or functions are described herein as being performed “by a UE,” “by a base station,” “by a network entity,” etc. However, as will be appreciated, such operations, acts, and/or functions may actually be performed by specific components or combinations of components of the UE 302, base station 304, network entity 306, etc., such as the processing systems 332, 384, 394, the transceivers 310, 320, 350, and 360, the memory components 340, 386, and 396, the positioning components 342, 388, and 398, etc.
- [0078] FIGS. 4A to 4D are diagrams illustrating example frame structures and channels within the frame structures, according to aspects of the disclosure. FIG. 4A is a diagram 400 illustrating an example of a downlink frame structure, according to aspects of the disclosure. FIG. 4B is a diagram 430 illustrating an example of channels within the downlink frame structure, according to aspects of the disclosure. FIG. 4C is a diagram 450 illustrating an example of an uplink frame structure, according to aspects of the disclosure. FIG. 4D is a diagram 470 illustrating an example of channels within an uplink frame structure, according to aspects of the disclosure. Other wireless communications technologies may have different frame structures and/or different channels.

- [0079] LTE, and in some cases NR, utilizes OFDM on the downlink and single-carrier frequency division multiplexing (SC-FDM) on the uplink. Unlike LTE, however, NR has an option to use OFDM on the uplink as well. OFDM and SC-FDM partition the system bandwidth into multiple ( $K$ ) orthogonal subcarriers, which are also commonly referred to as tones, bins, etc. Each subcarrier may be modulated with data. In general, modulation symbols are sent in the frequency domain with OFDM and in the time domain with SC-FDM. The spacing between adjacent subcarriers may be fixed, and the total number of subcarriers ( $K$ ) may be dependent on the system bandwidth. For example, the spacing of the subcarriers may be 15 kilohertz (kHz) and the minimum resource allocation (resource block) may be 12 subcarriers (or 180 kHz). Consequently, the nominal FFT size may be equal to 128, 256, 512, 1024, or 2048 for system bandwidth of 1.25, 2.5, 5, 10, or 20 megahertz (MHz), respectively. The system bandwidth may also be partitioned into subbands. For example, a subband may cover 1.08 MHz (i.e., 6 resource blocks), and there may be 1, 2, 4, 8, or 16 subbands for system bandwidth of 1.25, 2.5, 5, 10, or 20 MHz, respectively.
- [0080] LTE supports a single numerology (subcarrier spacing (SCS), symbol length, etc.). In contrast, NR may support multiple numerologies ( $\mu$ ), for example, subcarrier spacings of 15 kHz ( $\mu=0$ ), 30 kHz ( $\mu=1$ ), 60 kHz ( $\mu=2$ ), 120 kHz ( $\mu=3$ ), and 240 kHz ( $\mu=4$ ) or greater may be available. In each subcarrier spacing, there are 14 symbols per slot. For 15 kHz SCS ( $\mu=0$ ), there is one slot per subframe, 10 slots per frame, the slot duration is 1 millisecond (ms), the symbol duration is 66.7 microseconds ( $\mu$ s), and the maximum nominal system bandwidth (in MHz) with a 4K FFT size is 50. For 30 kHz SCS ( $\mu=1$ ), there are two slots per subframe, 20 slots per frame, the slot duration is 0.5 ms, the symbol duration is 33.3  $\mu$ s, and the maximum nominal system bandwidth (in MHz) with a 4K FFT size is 100. For 60 kHz SCS ( $\mu=2$ ), there are four slots per subframe, 40 slots per frame, the slot duration is 0.25 ms, the symbol duration is 16.7  $\mu$ s, and the maximum nominal system bandwidth (in MHz) with a 4K FFT size is 200. For 120 kHz SCS ( $\mu=3$ ), there are eight slots per subframe, 80 slots per frame, the slot duration is 0.125 ms, the symbol duration is 8.33  $\mu$ s, and the maximum nominal system bandwidth (in MHz) with a 4K FFT size is 400. For 240 kHz SCS ( $\mu=4$ ), there are 16 slots per subframe, 160 slots per frame, the slot duration is 0.0625 ms, the symbol duration is 4.17  $\mu$ s, and the maximum nominal system bandwidth (in MHz) with a 4K FFT size is 800.

- [0081] In the example of FIGS. 4A to 4D, a numerology of 15 kHz is used. Thus, in the time domain, a 10 ms frame is divided into 10 equally sized subframes of 1 ms each, and each subframe includes one time slot. In FIGS. 4A to 4D, time is represented horizontally (on the X axis) with time increasing from left to right, while frequency is represented vertically (on the Y axis) with frequency increasing (or decreasing) from bottom to top.
- [0082] A resource grid may be used to represent time slots, each time slot including one or more time-concurrent resource blocks (RBs) (also referred to as physical RBs (PRBs)) in the frequency domain. The resource grid is further divided into multiple resource elements (REs). An RE may correspond to one symbol length in the time domain and one subcarrier in the frequency domain. In the numerology of FIGS. 4A to 4D, for a normal cyclic prefix, an RB may contain 12 consecutive subcarriers in the frequency domain and seven consecutive symbols in the time domain, for a total of 84 REs. For an extended cyclic prefix, an RB may contain 12 consecutive subcarriers in the frequency domain and six consecutive symbols in the time domain, for a total of 72 REs. The number of bits carried by each RE depends on the modulation scheme.
- [0083] Some of the REs carry downlink reference (pilot) signals (DL-RS). The DL-RS may include PRS, TRS, PTRS, CRS, CSI-RS, DMRS, PSS, SSS, SSB, etc. FIG. 4A illustrates example locations of REs carrying PRS (labeled “R”).
- [0084] A collection of resource elements (REs) that are used for transmission of PRS is referred to as a “PRS resource.” The collection of resource elements can span multiple PRBs in the frequency domain and ‘N’ (such as 1 or more) consecutive symbol(s) within a slot in the time domain. In a given OFDM symbol in the time domain, a PRS resource occupies consecutive PRBs in the frequency domain.
- [0085] The transmission of a PRS resource within a given PRB has a particular comb size (also referred to as the “comb density”). A comb size ‘N’ represents the subcarrier spacing (or frequency/tone spacing) within each symbol of a PRS resource configuration. Specifically, for a comb size ‘N,’ PRS are transmitted in every Nth subcarrier of a symbol of a PRB. For example, for comb-4, for each symbol of the PRS resource configuration, REs corresponding to every fourth subcarrier (such as subcarriers 0, 4, 8) are used to transmit PRS of the PRS resource. Currently, comb sizes of comb-2, comb-4, comb-6, and comb-12 are supported for DL-PRS. FIG. 4A illustrates an example PRS resource configuration for comb-6 (which spans six symbols). That is, the locations of the shaded REs (labeled “R”) indicate a comb-6 PRS resource configuration.

- [0086] Currently, a DL-PRS resource may span 2, 4, 6, or 12 consecutive symbols within a slot with a fully frequency-domain staggered pattern. A DL-PRS resource can be configured in any higher layer configured downlink or flexible (FL) symbol of a slot. There may be a constant energy per resource element (EPRE) for all REs of a given DL-PRS resource. The following are the frequency offsets from symbol to symbol for comb sizes 2, 4, 6, and 12 over 2, 4, 6, and 12 symbols. 2-symbol comb-2: {0, 1}; 4-symbol comb-2: {0, 1, 0, 1}; 6-symbol comb-2: {0, 1, 0, 1, 0, 1}; 12-symbol comb-2: {0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1}; 4-symbol comb-4: {0, 2, 1, 3}; 12-symbol comb-4: {0, 2, 1, 3, 0, 2, 1, 3, 0, 2, 1, 3}; 6-symbol comb-6: {0, 3, 1, 4, 2, 5}; 12-symbol comb-6: {0, 3, 1, 4, 2, 5, 0, 3, 1, 4, 2, 5}; and 12-symbol comb-12: {0, 6, 3, 9, 1, 7, 4, 10, 2, 8, 5, 11}.
- [0087] A “PRS resource set” is a set of PRS resources used for the transmission of PRS signals, where each PRS resource has a PRS resource ID. In addition, the PRS resources in a PRS resource set are associated with the same TRP. A PRS resource set is identified by a PRS resource set ID and is associated with a particular TRP (identified by a TRP ID). In addition, the PRS resources in a PRS resource set have the same periodicity, a common muting pattern configuration, and the same repetition factor (such as “PRS-ResourceRepetitionFactor”) across slots. The periodicity is the time from the first repetition of the first PRS resource of a first PRS instance to the same first repetition of the same first PRS resource of the next PRS instance. The periodicity may have a length selected from  $2^{\mu} \cdot \{4, 5, 8, 10, 16, 20, 32, 40, 64, 80, 160, 320, 640, 1280, 2560, 5120, 10240\}$  slots, with  $\mu = 0, 1, 2, 3$ . The repetition factor may have a length selected from  $\{1, 2, 4, 6, 8, 16, 32\}$  slots.
- [0088] A PRS resource ID in a PRS resource set is associated with a single beam (or beam ID) transmitted from a single TRP (where a TRP may transmit one or more beams). That is, each PRS resource of a PRS resource set may be transmitted on a different beam, and as such, a “PRS resource,” or simply “resource,” also can be referred to as a “beam.” Note that this does not have any implications on whether the TRPs and the beams on which PRS are transmitted are known to the UE.
- [0089] A “PRS instance” or “PRS occasion” is one instance of a periodically repeated time window (such as a group of one or more consecutive slots) where PRS are expected to be transmitted. A PRS occasion also may be referred to as a “PRS positioning occasion,” a “PRS positioning instance, a “positioning occasion,” “a positioning instance,” a “positioning repetition,” or simply an “occasion,” an “instance,” or a “repetition.”

- [0090] A “positioning frequency layer” (also referred to simply as a “frequency layer”) is a collection of one or more PRS resource sets across one or more TRPs that have the same values for certain parameters. Specifically, the collection of PRS resource sets has the same subcarrier spacing and cyclic prefix (CP) type (meaning all numerologies supported for the PDSCH are also supported for PRS), the same Point A, the same value of the downlink PRS bandwidth, the same start PRB (and center frequency), and the same comb-size. The Point A parameter takes the value of the parameter “ARFCN-ValueNR” (where “ARFCN” stands for “absolute radio-frequency channel number”) and is an identifier/code that specifies a pair of physical radio channel used for transmission and reception. The downlink PRS bandwidth may have a granularity of four PRBs, with a minimum of 24 PRBs and a maximum of 272 PRBs. Currently, up to four frequency layers have been defined, and up to two PRS resource sets may be configured per TRP per frequency layer.
- [0091] The concept of a frequency layer is somewhat like the concept of component carriers and bandwidth parts (BWPs), but different in that component carriers and BWPs are used by one base station (or a macro cell base station and a small cell base station) to transmit data channels, while frequency layers are used by several (usually three or more) base stations to transmit PRS. A UE may indicate the number of frequency layers it can support when it sends the network its positioning capabilities, such as during an LTE positioning protocol (LPP) session. For example, a UE may indicate whether it can support one or four positioning frequency layers.
- [0092] FIG. 4B illustrates an example of various channels within a downlink slot of a radio frame. In NR, the channel bandwidth, or system bandwidth, is divided into multiple BWPs. A BWP is a contiguous set of PRBs selected from a contiguous subset of the common RBs for a given numerology on a given carrier. Generally, a maximum of four BWPs can be specified in the downlink and uplink. That is, a UE can be configured with up to four BWPs on the downlink, and up to four BWPs on the uplink. Only one BWP (uplink or downlink) may be active at a given time, meaning the UE may only receive or transmit over one BWP at a time. On the downlink, the bandwidth of each BWP should be equal to or greater than the bandwidth of the SSB, but it may or may not contain the SSB.
- [0093] Referring to FIG. 4B, a primary synchronization signal (PSS) is used by a UE to determine subframe/symbol timing and a physical layer identity. A secondary

synchronization signal (SSS) is used by a UE to determine a physical layer cell identity group number and radio frame timing. Based on the physical layer identity and the physical layer cell identity group number, the UE can determine a PCI. Based on the PCI, the UE can determine the locations of the aforementioned DL-RS. The physical broadcast channel (PBCH), which carries an MIB, may be logically grouped with the PSS and SSS to form an SSB (also referred to as an SS/PBCH). The MIB provides a number of RBs in the downlink system bandwidth and a system frame number (SFN). The physical downlink shared channel (PDSCH) carries user data, broadcast system information not transmitted through the PBCH, such as system information blocks (SIBs), and paging messages.

- [0094] The physical downlink control channel (PDCCH) carries downlink control information (DCI) within one or more control channel elements (CCEs), each CCE including one or more RE group (REG) bundles (which may span multiple symbols in the time domain), each REG bundle including one or more REGs, each REG corresponding to 12 resource elements (one resource block) in the frequency domain and one OFDM symbol in the time domain. The set of physical resources used to carry the PDCCH/DCI is referred to in NR as the control resource set (CORESET). In NR, a PDCCH is confined to a single CORESET and is transmitted with its own DMRS. This enables UE-specific beamforming for the PDCCH.
- [0095] In the example of FIG. 4B, there is one CORESET per BWP, and the CORESET spans three symbols (although it may be only one or two symbols) in the time domain. Unlike LTE control channels, which occupy the entire system bandwidth, in NR, PDCCH channels are localized to a specific region in the frequency domain (i.e., a CORESET). Thus, the frequency component of the PDCCH shown in FIG. 4B is illustrated as less than a single BWP in the frequency domain. Note that although the illustrated CORESET is contiguous in the frequency domain, it need not be. In addition, the CORESET may span less than three symbols in the time domain.
- [0096] The DCI within the PDCCH carries information about uplink resource allocation (persistent and non-persistent) and descriptions about downlink data transmitted to the UE, referred to as uplink and downlink grants, respectively. More specifically, the DCI indicates the resources scheduled for the downlink data channel (e.g., PDSCH) and the uplink data channel (e.g., PUSCH). Multiple (e.g., up to eight) DCIs can be configured in the PDCCH, and these DCIs can have one of multiple formats. For example, there are

different DCI formats for uplink scheduling, for downlink scheduling, for uplink transmit power control (TPC), etc. A PDCCH may be transported by 1, 2, 4, 8, or 16 CCEs in order to accommodate different DCI payload sizes or coding rates.

- [0097] As illustrated in FIG. 4C, some of the REs (labeled “R”) carry DMRS for channel estimation at the receiver (e.g., a base station, another UE, etc.). A UE may additionally transmit SRS in, for example, the last symbol of a slot. The SRS may have a comb structure, and a UE may transmit SRS on one of the combs. In the example of FIG. 4C, the illustrated SRS is comb-2 over one symbol. The SRS may be used by a base station to obtain the channel state information (CSI) for each UE. CSI describes how an RF signal propagates from the UE to the base station and represents the combined effect of scattering, fading, and power decay with distance. The system uses the SRS for resource scheduling, link adaptation, massive MIMO, beam management, etc.
- [0098] Currently, an SRS resource may span 1, 2, 4, 8, or 12 consecutive symbols within a slot with a comb size of comb-2, comb-4, or comb-8. The following are the frequency offsets from symbol to symbol for the SRS comb patterns that are currently supported. 1-symbol comb-2: {0}; 2-symbol comb-2: {0, 1}; 4-symbol comb-2: {0, 1, 0, 1}; 4-symbol comb-4: {0, 2, 1, 3}; 8-symbol comb-4: {0, 2, 1, 3, 0, 2, 1, 3}; 12-symbol comb-4: {0, 2, 1, 3, 0, 2, 1, 3, 0, 2, 1, 3}; 4-symbol comb-8: {0, 4, 2, 6}; 8-symbol comb-8: {0, 4, 2, 6, 1, 5, 3, 7}; and 12-symbol comb-8: {0, 4, 2, 6, 1, 5, 3, 7, 0, 4, 2, 6}.
- [0099] A collection of resource elements that are used for transmission of SRS is referred to as an “SRS resource,” and may be identified by the parameter “SRS-ResourceId.” The collection of resource elements can span multiple PRBs in the frequency domain and N (e.g., one or more) consecutive symbol(s) within a slot in the time domain. In a given OFDM symbol, an SRS resource occupies consecutive PRBs. An “SRS resource set” is a set of SRS resources used for the transmission of SRS signals, and is identified by an SRS resource set ID (“SRS-ResourceSetId”).
- [0100] Generally, a UE transmits SRS to enable the receiving base station (either the serving base station or a neighboring base station) to measure the channel quality between the UE and the base station. However, SRS also can be used as uplink positioning reference signals for uplink positioning procedures, such as UL-TDOA, multi-RTT, DL-AoA, etc.
- [0101] Several enhancements over the previous definition of SRS have been proposed for SRS-for-positioning (also referred to as “UL-PRS”), such as a new staggered pattern within an SRS resource (except for single-symbol/comb-2), a new comb type for SRS, new

sequences for SRS, a higher number of SRS resource sets per component carrier, and a higher number of SRS resources per component carrier. In addition, the parameters “SpatialRelationInfo” and “PathLossReference” are to be configured based on a downlink reference signal or SSB from a neighboring TRP. Further still, one SRS resource may be transmitted outside the active BWP, and one SRS resource may span across multiple component carriers. Also, SRS may be configured in RRC connected state and only transmitted within an active BWP. Further, there may be no frequency hopping, no repetition factor, a single antenna port, and new lengths for SRS (e.g., 8 and 12 symbols). There also may be open-loop power control and not closed-loop power control, and comb-8 (i.e., an SRS transmitted every eighth subcarrier in the same symbol) may be used. Lastly, the UE may transmit through the same transmit beam from multiple SRS resources for UL-AoA. All of these are features that are additional to the current SRS framework, which is configured through RRC higher layer signaling (and potentially triggered or activated through MAC control element (CE) or DCI).

[0102] FIG. 4D illustrates an example of various channels within an uplink slot of a frame, according to aspects of the disclosure. A random-access channel (RACH), also referred to as a physical random-access channel (PRACH), may be within one or more slots within a frame based on the PRACH configuration. The PRACH may include six consecutive RB pairs within a slot. The PRACH allows the UE to perform initial system access and achieve uplink synchronization. A physical uplink control channel (PUCCH) may be located on edges of the uplink system bandwidth. The PUCCH carries uplink control information (UCI), such as scheduling requests, CSI reports, a channel quality indicator (CQI), a precoding matrix indicator (PMI), a rank indicator (RI), and HARQ ACK/NACK feedback. The physical uplink shared channel (PUSCH) carries data, and may additionally be used to carry a buffer status report (BSR), a power headroom report (PHR), and/or UCI.

[0103] Note that the terms “positioning reference signal” and “PRS” generally refer to specific reference signals that are used for positioning in NR and LTE systems. However, as used herein, the terms “positioning reference signal” and “PRS” may also refer to any type of reference signal that can be used for positioning, such as but not limited to, PRS as defined in LTE and NR, TRS, PTRS, CRS, CSI-RS, DMRS, PSS, SSS, SSB, SRS, UL-PRS, etc. In addition, the terms “positioning reference signal” and “PRS” may refer to downlink or uplink positioning reference signals, unless otherwise indicated by the context. If needed

to further distinguish the type of PRS, a downlink positioning reference signal may be referred to as a “DL-PRS,” and an uplink positioning reference signal (e.g., an SRS-for-positioning, PTRS) may be referred to as an “UL-PRS.” In addition, for signals that may be transmitted in both the uplink and downlink (e.g., DMRS, PTRS), the signals may be prepended with “UL” or “DL” to distinguish the direction. For example, “UL-DMRS” may be differentiated from “DL-DMRS.”

[0104] FIG. 5 is a diagram 500 illustrating a base station (BS) 502 (which may correspond to any of the base stations described herein) in communication with a UE 504 (which may correspond to any of the UEs described herein). Referring to FIG. 5, the base station 502 may transmit a beamformed signal to the UE 504 on one or more transmit beams 502a, 502b, 502c, 502d, 502e, 502f, 502g, 502h, each having a beam identifier that can be used by the UE 504 to identify the respective beam. Where the base station 502 is beamforming towards the UE 504 with a single array of antennas (e.g., a single TRP/cell), the base station 502 may perform a “beam sweep” by transmitting first beam 502a, then beam 502b, and so on until lastly transmitting beam 502h. Alternatively, the base station 502 may transmit beams 502a – 502h in some pattern, such as beam 502a, then beam 502h, then beam 502b, then beam 502g, and so on. Where the base station 502 is beamforming towards the UE 504 using multiple arrays of antennas (e.g., multiple TRPs/cells), each antenna array may perform a beam sweep of a subset of the beams 502a – 502h. Alternatively, each of beams 502a – 502h may correspond to a single antenna or antenna array.

[0105] FIG. 5 further illustrates the paths 512c, 512d, 512e, 512f, and 512g followed by the beamformed signal transmitted on beams 502c, 502d, 502e, 502f, and 502g, respectively. Each path 512c, 512d, 512e, 512f, 512g may correspond to a single “multipath” or, due to the propagation characteristics of radio frequency (RF) signals through the environment, may be comprised of a plurality (a cluster) of “multipaths.” Note that although only the paths for beams 502c – 502g are shown, this is for simplicity, and the signal transmitted on each of beams 502a – 502h will follow some path. In the example shown, the paths 512c, 512d, 512e, and 512f are straight lines, while path 512g reflects off an obstacle 520 (e.g., a building, vehicle, terrain feature, etc.).

[0106] The UE 504 may receive the beamformed signal from the base station 502 on one or more receive beams 504a, 504b, 504c, 504d. Note that for simplicity, the beams illustrated in FIG. 5 represent either transmit beams or receive beams, depending on which of the base

station 502 and the UE 504 is transmitting and which is receiving. Thus, the UE 504 may also transmit a beamformed signal to the base station 502 on one or more of the beams 504a – 504d, and the base station 502 may receive the beamformed signal from the UE 504 on one or more of the beams 502a – 502h.

- [0107] In an aspect, the base station 502 and the UE 504 may perform beam training to align the transmit and receive beams of the base station 502 and the UE 504. For example, depending on environmental conditions and other factors, the base station 502 and the UE 504 may determine that the best transmit and receive beams are 502d and 504b, respectively, or beams 502e and 504c, respectively. The direction of the best transmit beam for the base station 502 may or may not be the same as the direction of the best receive beam, and likewise, the direction of the best receive beam for the UE 504 may or may not be the same as the direction of the best transmit beam. Note, however, that aligning the transmit and receive beams is not necessary to perform a downlink angle-of-departure (DL-AoD) or uplink angle-of-arrival (UL-AoA) positioning procedure.
- [0108] To perform a DL-AoD positioning procedure, the base station 502 may transmit reference signals (e.g., PRS, CRS, TRS, CSI-RS, PSS, SSS, etc.) to the UE 504 on one or more of beams 502a – 502h, with each beam having a different transmit angle. The different transmit angles of the beams will result in different received signal strengths (e.g., RSRP, RSRQ, SINR, etc.) at the UE 504. Specifically, the received signal strength will be lower for transmit beams 502a – 502h that are further from the line of sight (LOS) path 510 between the base station 502 and the UE 504 than for transmit beams 502a – 502h that are closer to the LOS path 510.
- [0109] In the example of FIG. 5, if the base station 502 transmits reference signals to the UE 504 on beams 502c, 502d, 502e, 502f, and 502g, then transmit beam 502e is best aligned with the LOS path 510, while transmit beams 502c, 502d, 502f, and 502g are not. As such, beam 502e is likely to have a higher received signal strength at the UE 504 than beams 502c, 502d, 502f, and 502g. Note that the reference signals transmitted on some beams (e.g., beams 502c and/or 502f) may not reach the UE 504, or energy reaching the UE 504 from these beams may be so low that the energy may not be detectable or at least can be ignored.
- [0110] The UE 504 can report the received signal strength, and optionally, the associated measurement quality, of each measured transmit beam 502c – 502g to the base station 502, or alternatively, the identity of the transmit beam having the highest received signal

strength (beam 502e in the example of FIG. 5). Alternatively or additionally, if the UE 504 is also engaged in a round-trip-time (RTT) or time-difference of arrival (TDOA) positioning session with at least one base station 502 or a plurality of base stations 502, respectively, the UE 504 can report reception-to-transmission (Rx-Tx) or reference signal time difference (RSTD) measurements (and optionally the associated measurement qualities), respectively, to the serving base station 502 or other positioning entity. In any case, the positioning entity (e.g., the base station 502, a location server, a third-party client, UE 504, etc.) can estimate the angle from the base station 502 to the UE 504 as the AoD of the transmit beam having the highest received signal strength at the UE 504, here, transmit beam 502e.

- [0111] In one aspect of DL-AoD-based positioning, where there is only one involved base station 502, the base station 502 and the UE 504 can perform a round-trip-time (RTT) procedure to determine the distance between the base station 502 and the UE 504. Thus, the positioning entity can determine both the direction to the UE 504 (using DL-AoD positioning) and the distance to the UE 504 (using RTT positioning) to estimate the location of the UE 504. Note that the AoD of the transmit beam having the highest received signal strength does not necessarily lie along the LOS path 510, as shown in FIG. 5. However, for DL-AoD-based positioning purposes, it is assumed to do so.
- [0112] In another aspect of DL-AoD-based positioning, where there are multiple involved base stations 502, each base station 502 can report the determined AoD to the UE 504 to the positioning entity. The positioning entity receives multiple such AoDs from a plurality of involved base stations 502 (or other geographically separated transmission points) for the UE 504. With this information, and knowledge of the base stations' 502 geographic locations, the positioning entity can estimate a location of the UE 504 as the intersection of the received AoDs. There should be at least two involved base stations 502 for a two-dimensional (2D) location solution, but as will be appreciated, the more base stations 502 that are involved in the positioning procedure, the more accurate the estimated location of the UE 504 will be.
- [0113] To perform an UL-AoA positioning procedure, the UE 504 transmits uplink reference signals (e.g., UL-PRS, SRS, DMRS, etc.) to the base station 502 on one or more of uplink transmit beams 504a – 504d. The base station 502 receives the uplink reference signals on one or more of uplink receive beams 502a – 502h. The base station 502 determines the angle of the best receive beams 502a – 502h used to receive the one or more reference

signals from the UE 504 as the AoA from itself to the UE 504. Specifically, each of the receive beams 502a – 502h will result in a different received signal strength (e.g., RSRP, RSRQ, SINR, etc.) of the one or more reference signals at the base station 502. Further, the channel impulse response of the one or more reference signals will be smaller for receive beams 502a – 502h that are further from the actual LOS path between the base station 502 and the UE 504 than for receive beams 502a – 502h that are closer to the LOS path. Likewise, the received signal strength will be lower for receive beams 502a – 502h that are further from the LOS path than for receive beams 502a – 502h that are closer to the LOS path. As such, the base station 502 identifies the receive beam 502a – 502h that results in the highest received signal strength and, optionally, the strongest channel impulse response, and estimates the angle from itself to the UE 504 as the AoA of that receive beam 502a – 502h. Note that as with DL-AoD-based positioning, the AoA of the receive beam 502a – 502h resulting in the highest received signal strength (and strongest channel impulse response if measured) does not necessarily lie along the LOS path 510. However, for UL-AoA-based positioning purposes, it is assumed to do so.

- [0114] Note that while the UE 504 is illustrated as being capable of beamforming, this is not necessary for DL-AoD and UL-AoA positioning procedures. Rather, the UE 504 may receive and transmit on an omni-directional antenna.
- [0115] Where the UE 504 is estimating its location (i.e., the UE is the positioning entity), it needs to obtain the geographic location of the base station 502. The UE 504 may obtain the location from, for example, the base station 502 itself or a location server (e.g., location server 230, LMF 270, SLP 272). With the knowledge of the distance to the base station 502 (based on the RTT or timing advance), the angle between the base station 502 and the UE 504 (based on the UL-AoA of the best receive beam 502a – 502h), and the known geographic location of the base station 502, the UE 504 can estimate its location.
- [0116] Alternatively, where a positioning entity, such as the base station 502 or a location server, is estimating the location of the UE 504, the base station 502 reports the AoA of the receive beam 502a – 502h resulting in the highest received signal strength (and optionally strongest channel impulse response) of the reference signals received from the UE 504, or all received signal strengths and channel impulse responses for all receive beams 502a – 502h (which allows the positioning entity to determine the best receive beam 502a – 502h). The base station 502 may additionally report the distance to the UE 504. The positioning entity can then estimate the location of the UE 504 based on the UE's 504

distance to the base station 502, the AoA of the identified receive beam 502a – 502h, and the known geographic location of the base station 502.

[0117] FIG. 6 illustrates an example of DL-TDoA, where the UE reports the reference signal time difference between a TP of interest (TP i) and a reference TP (TP j) as the TDoA time difference. TDoA is a technique in which the UE measures the time of arrival (TOA) of signals got from multiple base stations (TPs). The TOAs from a few neighbor TPs are subtracted from a TOA of a reference TP to shape the TDoA. Geometrically, each time (or range) difference decides a hyperbola, and the time where these hyperbolas intersect is the located UE area. Three or more planning estimations from geographically scattered TPs are needed to determine a location of the UE. In FIG. 6, the UE measures three TOA's relative to the UE internal time base,  $\tau_1$ ,  $\tau_2$ , and  $\tau_3$ , and the measurement from TP1 is selected as reference base station. From this, two TDOA curves are formed:  $t_{2,1} = \tau_2 - \tau_1$  and  $t_{3,1} = \tau_3 - \tau_1$ .

[0118] In the current NR positioning framework, the timing of each PRS resource is reported with respect to subframe timing. Third Generation Partnership Project (3GPP) technical specification (TS) 38.215 defines downlink (DL) reference signal time difference (RSTD) as the DL relative timing difference between the Transmission Point (TP) j and the reference TP i, defined as

$$T_{\text{SubframeRxj}} - T_{\text{SubframeRxi}},$$

where  $T_{\text{SubframeRxj}}$  is the time when the UE receives the start of one subframe from TP j, and  $T_{\text{SubframeRxi}}$  is the time when the UE receives the corresponding start of one subframe from TP i that is closest in time to the subframe received from TP j. For frequency range 1 (FR1), the reference point for the DL RSTD shall be the antenna connector of the UE. For frequency range 2 (FR2), the reference point for the DL RSTD shall be the antenna of the UE.

[0119] The problem is that the subframe timing doesn't distinguish whether it came from one beam pair link or another beam pair link, but instead assumes that for one TP there is only one timing, and that a UE can derive that timing from the subframe that it observes. This idea is reinforced by the statement, in 3GPP TS 38.215, that multiple DL PRS resources can be used to determine the start of one subframe from a TP, which suggests that whatever FFT timing the UE uses also applies to all DL PRS resources from that TP.

- [0120] This creates a constraint that the subframe timing is presumed to be the same for all beam pairs between a base station and a UE. The same presumption is made for other timing reporting as well, such as uplink relative time of arrival (UL-RToA), UE Rx-Tx timing difference, and gNB Rx-Tx timing difference. That is, there is a presumption that all beam pair links from the same TP will have the same FFT timing. One technical challenge caused by this presumption is that, at higher frequencies, it is difficult to maintain the condition that multiple DL PRS resources can be used to determine the subframe timing.
- [0121] In frequency range 4 (FR4), for example, the subcarrier spacing (SCS) is 960kHz and the cyclic prefix (CP) duration is approximately 75ns. This implies that the maximum difference in the length of the beam paths arriving at the UE cannot be more than  $75\text{ns} * 3\text{e}8\text{m/s} = 22.5\text{m}$ . Otherwise, within the fast Fourier transform (FFT) window, the CP of one path will overlap with the data portion of another path, which negatively affects the signal to noise ratio (SNR). Using the example illustrated in FIG. 6, the presumption that subframe timing is the same for all beam pairs between the TPs and the UE means that, assuming a common FFT timing for all of the beams, the lengths of paths  $\tau_3$  and  $\tau_3'$  (which are different beam pairs from each other,  $\tau_3'$  being reflected off of obstacle 600) can differ by no more than 22.5 meters.
- [0122] In contrast, many conventional systems operating in a lower frequency range can tolerate a larger maximum difference in beam path length. In FR2 for example, with an SCS of 120kHz and a CP duration of approximately 600ns, systems using a common FFT can tolerate a difference in path length of up to approximately 200 meters, which is sufficient for those systems.
- [0123] Thus, while the current presumption that subframe timing is the same for all beam pairs between a BS and UE is not a problem for existing systems operating in lower frequency ranges, this presumption severely limits the operation of systems transmitting in higher frequency ranges such as FR4, e.g., causing small to severe SNR degradation if one path differs from another path by more than about 22 meters.
- [0124] In order to address the technical challenge described above, techniques for per-beam-pair timing are herein presented. By considering timing on a per-beam-pair basis, the constraint that all beam pairs must be presumed to use the same subframe timing (and by extension, the same FFT timing) is relaxed, which allows a system to tolerate a much larger difference in beam pair path lengths. In one aspect, a UE maintains separate

subframe and/or slot timing for each beam pair that it monitors. In another aspect, the UE performs a timing correction with respect to the timing difference between a chosen beam and a reference beam pair link.

- [0125] In some aspects, a UE maintains separate subframe and/or slot timing for each DL beam pair that it monitors. The UE may be configured to maintain this timing information or the UE may maintain this timing information autonomously. In some aspects, even for the same DL PRS resource beam, different timing may be maintained for different Rx beams that can detect that DL PRS resource beam. The same principle may be applied to UL beams, e.g., the base station maintains separate timing for each UL beam pair that it monitors. In some aspects, the base station reports these beam timings to the LMF, and the LMF performs the timing computations.
- [0126] In some aspects, the UE or base station can indicate whether or not it has the capability to maintain separate timing per beam, e.g., on a per band, per band combination, or per carrier basis. In some aspects, the capability can be indicated to the base station, a location management function (LMF) or other positioning entity, or both, e.g., as part of capability reporting by the UE when requested.
- [0127] In some aspects, the UE performs a timing correction with respect to the timing difference between a chosen beam and a reference beam pair link. In some aspects, for reporting DL-RSTD or other timing metrics for positioning, the UE performs a correction with respect to the timing difference between the chosen beam [pair link?] and a reference beam pair link. The UE maintains individual timing for each beam pair link, so that when the UE reports the timing, e.g., for the purpose of RSTD, the UE corrects for the timing difference between the two beam pair links that are being compared before reporting the RSTD to the base station.
- [0128] In some aspects, one of the beams is identified as the reference beam to be corrected against. In some aspects, the node that is doing the measuring, referred to herein as the “measuring entity” (e.g., the UE or the base station) chooses the reference beam for maintaining the timing, and reports the correct measurement, by correcting for the timing difference between the two beam pair links that are being compared. In some aspects, the LMF or other positioning entity selects and indicates the reference beam to the measuring entity, e.g., based on some prior knowledge that a particular reference beam is a good beam to use, and the measuring entity performs the correction with respect to the indicated reference beam. In some aspects, the LMF or other positioning entity selects and indicates

the reference beam to the measuring entity, but the measuring entity overrides that selection, e.g., because of conditions local to the measuring entity, such as obstructions, interference, or other reasons. In some aspects, the measuring entity does not override the selection by the LMF but provides information about a different reference beam that might be a better reference beam to use, e.g., for future configuration optimization. In some aspects, the measuring entity may select the beam having the highest SNR as the reference beam; the beam having the highest SNR is also likely to be the beam that has the most direct line of sight (LOS) angle between the TP and UE. In some aspects, the beam having the earliest time of arrival may be selected as the reference beam, even if that beam has a lower SNR than a reflected beam having a later time of arrival.

[0129] For SRS and other UL transmissions, in some aspects, the UE can apply the different timings to each UL transmit beam towards the base station, which will allow the base station to use a common FFT window for simplicity. In some aspects, the UE can use a common transmit time for each beam but notify the base station of the different timing corrections for each path, e.g., the UE reports the difference in timing between the chosen beam pair and the reference beam pair, so that the base station or the positioning entity can make an appropriate timing correction. In some aspects, the UE can apply different transmit times to each UL transmit beam and also notify the base station of this fact so that the base station or positioning entity can make the appropriate correction to the calculated value of RSTD or other timing difference related positioning measurements.

[0130] It is noted that the timing adjustment can be made at the transmit side, at the receive side, or at both, and that the adjustment could be made by the base station, the UE, or both. In some aspects, one entity, e.g., either the UE or the base station, maintains a common timing and the other entity makes the adjustments. In some aspects, where the base station makes a timing adjustment, it may make a different set of per-beam timing adjustments for each UE that it serves. Likewise, where the UE makes the adjustment, the UE may make a different set of per-beam-timing adjustments for each TP that it measures. Because a transmitting entity may be sending signals that are received and processed by more than one measuring entity, in some aspects, the measuring entity, rather than the transmitting entity, makes the adjustments. For example, in some aspects, the UE maintains the different timings for different DL beam pairs and the base station maintains the different timings for different UL beam pairs.

- [0131] In some aspects, where either the transmitting entity or the measuring entity does not support per-beam timing adjustments, then the conventional, common beam timing methods may be used. It is noted that while the techniques described herein are useful for higher frequency bands with shorter CPs, such as FR3, FR4, etc., the same principles may be applied to lower frequency bands, such as FR1 and FR2, as well.
- [0132] FIG. 7 is a flowchart of an example process 700 associated with per beam pair timing for positioning. In some implementations, one or more process blocks of FIG. 7 may be performed by a UE (e.g., UE 104 in FIG. 1). In some implementations, one or more process blocks of FIG. 7 may be performed by another device or a group of devices separate from or including the UE. Additionally, or alternatively, one or more process blocks of FIG. 7 may be performed by one or more components of device 302, such as processing system 332, memory 340, WWAN transceiver 310, transceiver 320, or user interface 346.
- [0133] As shown in FIG. 7, process 700 may optionally include indicating, to a transmitting entity, that the UE is capable to maintain information for each of a plurality of beam pairs, each beam pair comprising a transmit beam pair and a receive beam pair (optional block 705).
- [0134] As shown in FIG. 7, process 700 may include maintaining timing information for each of a plurality of beam pairs, each beam pair comprising a receive beam of the UE and a transmit beam of a base station or another UE (block 710). For example, each beam pair may comprise a downlink (DL) beam pair, comprising a base station transmit beam and a UE receive beam, or a sidelink (SL) beam pair, comprising a UE transmit beam and a UE receive beam. In some aspects, the transmit beam of the first beam pair is the same as the transmit beam of the second beam pair, and the receive beam of the first beam pair is different from the receive beam of the second beam pair. In some aspects, the receive beam of the first beam pair and the receive beam of the second beam pair are in different timing error groups.
- [0135] As further shown in FIG. 7, process 700 may include measuring a first reference signal using a first beam pair from the plurality of beam pairs (block 720). For example, the UE may measure a first DL or SL signal using a first beam pair from the plurality of beam pairs, as described above.
- [0136] As further shown in FIG. 7, process 700 may include measuring a second reference signal using a second beam pair from the plurality of beam pairs (block 730). For example, the

UE may measure a second DL or SL signal using a second beam pair from the plurality of beam pairs, as described above.

- [0137] As further shown in FIG. 7, process 700 may include reporting, to a transmitting entity, beam timings for the first beam pair and the second beam pair (block 740). For example, the UE may report, to a transmitting entity, beam timings for the first beam pair and the second beam pair, as described above.
- [0138] As further shown in FIG. 7, the measuring the first reference signal and the measuring the second reference signal, the reporting beam timing, or both, may be performed according to the timing information for the first beam pair and the second beam pair (block 750). For example, the UE may consider the timing information while the measuring the first and second reference signals, the UE may use the timing information to correct the beam timing before it is reported, or both.
- [0139] As further shown in FIG. 7, process 700 may optionally include reporting, to the transmitting entity, the timing information for the first beam pair and the timing information for the second beam pair (optional block 760).
- [0140] Process 700 may include additional aspects, such as any single aspect or any combination of aspects described below and/or in connection with one or more other processes described elsewhere herein.
- [0141] In some aspects, each of the first reference signal and the second reference signal comprises a positioning reference signal (PRS) beam.
- [0142] In some aspects, the first reference signal and the second reference signal comprise a same PRS beam.
- [0143] In some aspects, the first reference signal and the second reference signal comprise different PRS beams.
- [0144] In some aspects, performing the measuring steps according to the timing information for each of the plurality of beam pairs comprises, for each beam pair, calculating a time of arrival (ToA) of the respective reference signal based on the timing information of the respective beam pair.
- [0145] In some aspects, performing the reporting step according to the timing information for each of the plurality of beam pairs comprises calculating a time difference of arrival (TDoA) of the first reference signal and the second reference signal based on a time of arrival (ToA) of the respective reference signal and the timing information for each of the first beam pair and the second beam pair.

- [0146] In some aspects, maintaining timing information for each of a plurality of beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
- [0147] Although FIG. 7 shows example blocks of process 700, in some aspects, process 700 may include additional blocks, fewer blocks, different blocks, or differently arranged blocks than those depicted in FIG. 7. Additionally, or alternatively, two or more of the blocks of process 700 may be performed in parallel.
- [0148] FIG. 8 is a flowchart of an example process 800 associated with per beam pair timing for positioning. In some aspects, one or more process blocks of FIG. 8 may be performed by a UE (e.g., UE 104 in FIG. 1). In some aspects, one or more process blocks of FIG. 8 may be performed by another device or a group of devices separate from or including the UE. Additionally, or alternatively, one or more process blocks of FIG. 8 may be performed by one or more components of device 302, such as processing system 332, memory 340, WWAN transceiver 310, transceiver 320, or user interface 346.
- [0149] As shown in FIG. 8, process 800 may optionally include indicating, to a receiving entity, that the UE is capable to maintain information for each of a plurality of beam pairs, each beam pair comprising a transmit beam pair and a receive beam pair (optional block 805).
- [0150] As shown in FIG. 8, process 800 may include maintaining timing information for each of a plurality of beam pairs, each beam pair comprising a transmit beam of the UE and a receive beam of a base station or another UE (block 810). For example, each beam pair may comprise an uplink (UL) beam pair, comprising a UE transmit beam and a base station receive beam, or a sidelink (SL) beam pair, comprising a UE transmit beam and a UE receive beam. In some aspects, the transmit beam of the first beam pair is the same as the transmit beam of the second beam pair, and the receive beam of the first beam pair is different from the receive beam of the second beam pair.
- [0151] As further shown in FIG. 8, process 800 may include transmitting, to a receiving entity, a first reference signal using a first beam pair from the plurality of beam pairs (block 820). For example, the UE may transmit, to a receiving entity, a first UL or SL reference signal using a first beam pair from the plurality of beam pairs, as described above.
- [0152] As further shown in FIG. 8, process 800 may include transmitting, to the receiving entity, a second reference signal using a second beam pair from the plurality of beam pairs (block 830). For example, the UE may transmit, to the receiving entity, a second UL or SL

reference signal using a second beam pair from the plurality of beam pairs, as described above.

- [0153] As further shown in FIG. 8, the first and second reference signals may be transmitted to the receiving entity according to the timing information for the first beam pair and the second beam pair, respectively. In some aspects, the method further comprises transmitting, to the receiving entity, the timing information for the first beam pair and the second beam pair (block 840). For example, the UE may adjust the transmit timing of the first and second reference signals to the receiving entity according to the timing information for the first and second beam pairs. In some aspects, the method further comprises transmitting, to the receiving entity, the timing information for the first beam pair and the second beam pair.
- [0154] In some aspects, process 800 may optionally include reporting, to the receiving entity, the timing information for the first beam pair and the timing information for the second beam pair (optional block 850).
- [0155] Process 800 may include additional aspects, such as any single aspect or any combination of aspects described below and/or in connection with one or more other processes described elsewhere herein.
- [0156] In some aspects, each of the first reference signal and the second reference signal comprises a sounding reference signal (SRS) beam.
- [0157] In some aspects, the first reference signal and the second reference signal comprise a same SRS beam.
- [0158] In some aspects, the first reference signal and the second reference signal comprise different SRS beams.
- [0159] In some aspects, maintaining timing information for each of a plurality of beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
- [0160] Although FIG. 8 shows example blocks of process 800, in some aspects, process 800 may include additional blocks, fewer blocks, different blocks, or differently arranged blocks than those depicted in FIG. 8. Additionally, or alternatively, two or more of the blocks of process 800 may be performed in parallel.
- [0161] FIG. 9 is a flowchart of an example process 900 associated with per beam pair timing for positioning. In some aspects, one or more process blocks of FIG. 9 may be performed by a base station (e.g., base station 102 in FIG. 1). In some aspects, one or more process

blocks of FIG. 9 may be performed by another device or a group of devices separate from or including the base station. Additionally, or alternatively, one or more process blocks of FIG. 9 may be performed by one or more components of device 304, such as processing system 384, memory 386, WWAN transceiver 350, transceiver 360, or network interface 380.

- [0162] As shown in FIG. 9, process 900 may optionally include receiving, from a UE, an indication that the UE is capable to maintain information for each of a plurality of beam pairs, each beam pair comprising a transmit beam pair and a receive beam pair (optional block 905).
- [0163] As shown in FIG. 9, process 900 may include maintaining timing information for each of a plurality of beam pairs, each beam pair comprising a transmit beam of the base station and a receive beam of a UE (block 910). For example, each beam pair may comprise a downlink (DL) beam pair comprising a base station transmit beam and a UE receive beam. For example, the BS may maintain timing information for each of a plurality of downlink (DL) beam pairs, each DL beam pair comprising a base station transmit beam and a UE receive beam, as described above. In some aspects, the transmit beam of the first beam pair is the same as the transmit beam of the second beam pair, and the receive beam of the first beam pair is different from the receive beam of the second beam pair.
- [0164] As further shown in FIG. 9, process 900 may include transmitting a first reference signal using a first beam pair from the plurality of beam pairs (block 920). For example, the BS may transmit, to a UE, a first reference signal using a first DL beam pair from the plurality of DL beam pairs, as described above.
- [0165] As further shown in FIG. 9, process 900 may include transmitting a second reference signal using a second beam pair from the plurality of beam pairs (block 930). For example, the BS may transmit, to the UE, a second reference signal using a second DL beam pair from the plurality of DL beam pairs, as described above.
- [0166] As further shown in FIG. 9, the first reference signal and the second reference signal may be transmitted according to the timing information for the first beam pair and the second beam pair, respectively (block 940). For example, the BS may adjust the transmit timing of the first and second reference signals to the UE according to the timing information for the first and second DL beam pairs, respectively.
- [0167] As further shown in FIG. 9, in addition to or alternative to block 940, the method may further comprise transmitting the timing information for the first beam pair and the second

- beam pair to the UE, transmitting the timing information for the first beam pair and the second beam pair to a positioning entity, or using the timing information for the first beam pair and the second beam pair to adjust a timing report received from the UE (block 950).
- [0168] As further shown in FIG. 9, process 900 may optionally include receiving, from the UE, the measured beam timings for the first beam pair and the second beam pair (optional block 960).
- [0169] Process 900 may include additional aspects, such as any single aspect or any combination of aspects described below and/or in connection with one or more other processes described elsewhere herein.
- [0170] In some aspects, each of the first reference signal and the second reference signal comprises a positioning reference signal (PRS) beam.
- [0171] In some aspects, the first reference signal and the second reference signal comprise a same PRS beam.
- [0172] In some aspects, the first reference signal and the second reference signal comprise different PRS beams.
- [0173] In some aspects, maintaining timing information for each of a plurality of downlink (DL) beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
- [0174] Although FIG. 9 shows example blocks of process 900, in some aspects, process 900 may include additional blocks, fewer blocks, different blocks, or differently arranged blocks than those depicted in FIG. 9. Additionally, or alternatively, two or more of the blocks of process 900 may be performed in parallel.
- [0175] FIG. 10 is a flowchart of an example process 1000 associated with per beam pair timing for positioning. In some aspects, one or more process blocks of FIG. 10 may be performed by a base station (e.g., base station 102 of FIG. 1). In some aspects, one or more process blocks of FIG. 10 may be performed by another device or a group of devices separate from or including the base station. Additionally, or alternatively, one or more process blocks of FIG. 9 may be performed by one or more components of device 304, such as processing system 384, memory 386, WWAN transceiver 350, transceiver 360, or network interface 380.
- [0176] As shown in FIG. 10, process 1000 may optionally include indicating, to the UE, that the base station has a capability to maintain timing information for each of the plurality of UL beam pairs (optional block 1005).

- [0177] As shown in FIG. 10, process 1000 may include maintaining timing information for each of a plurality of beam pairs, each beam pair comprising a receive beam of the base station and a transmit beam of a UE (block 1010). For example, each beam pair may comprise an UL beam pair comprising a UE transmit beam and a base station receive beam. For example, the BS may maintain timing information for each of a plurality of uplink (UL) beam pairs, each UL beam pair comprising a UE transmit beam and a base station receive beam, as described above.
- [0178] As further shown in FIG. 10, process 1000 may include measuring a first reference signal using a first beam pair from the plurality of beam pairs according to the timing information for the first beam pair (block 1020). For example, the BS may measure a first reference signal using a first UL beam pair from the plurality of UL beam pairs according to the timing information for the first UL beam pair, as described above.
- [0179] As further shown in FIG. 10, process 1000 may include measuring a second reference signal using a second beam pair from the plurality of beam pairs according to the timing information for the second beam pair (block 1030). For example, the BS may measure a second reference signal using a second UL beam pair from the plurality of UL beam pairs according to the timing information for the second UL beam pair, as described above.
- [0180] As further shown in FIG. 10, process 1000 may include reporting, to a positioning entity, beam timings for the first beam pair and the second beam pair, wherein the measuring the first reference signal and the measuring the second reference signal, the reporting the beam timings, or both, are performed according to the timing information for the first beam pair and the second beam pair (block 1040). For example, the BS may report, to a positioning entity, beam timings for the first UL beam pair and the second UL beam pair, as described above. In some aspects, the measuring the first reference signal and the measuring the second reference signal, the reporting the beam timings, or both, are performed according to the timing information for the first UL beam pair and the second UL beam pair.
- [0181] As further shown in FIG. 10, process 1000 may optionally include reporting, to the positioning entity, the timing information for the first beam pair and the timing information for the second beam pair (optional block 1050).
- [0182] As further shown in FIG. 10, process 1000 may optionally include calculating a reference signal timing according to the timing information for the first beam pair and the second beam pair (optional block 1060).

- [0183] Process 1000 may include additional aspects, such as any single aspect or any combination of aspects described below and/or in connection with one or more other processes described elsewhere herein.
- [0184] In some aspects, each of the first reference signal and the second reference signal comprises a sounding reference signal (SRS) beam.
- [0185] In some aspects, the first reference signal and the second reference signal comprise a same SRS beam.
- [0186] In some aspects, the first reference signal and the second reference signal comprise different SRS beams.
- [0187] In some aspects, performing the measuring steps according to the timing information for each of the plurality of UL beam pairs comprises, for each UL beam pair, calculating a time of arrival (ToA) of the respective reference signal based on the timing information of the respective UL beam pair.
- [0188] In some aspects, performing the reporting step according to the timing information for each of the plurality of UL beam pairs comprises calculating a time difference of arrival (TDoA) of the first reference signal and the second reference signal based on a time of arrival (ToA) of the respective reference signal and the timing information for each of the first UL beam pair and the second UL beam pair.
- [0189] In some aspects, maintaining timing information for each of a plurality of UL beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
- [0190] Although FIG. 10 shows example blocks of process 1000, in some aspects, process 1000 may include additional blocks, fewer blocks, different blocks, or differently arranged blocks than those depicted in FIG. 10. Additionally, or alternatively, two or more of the blocks of process 1000 may be performed in parallel.
- [0191] In the detailed description above it can be seen that different features are grouped together in examples. This manner of disclosure should not be understood as an intention that the example clauses have more features than are explicitly mentioned in each clause. Rather, the various aspects of the disclosure may include fewer than all features of an individual example clause disclosed. Therefore, the following clauses should hereby be deemed to be incorporated in the description, wherein each clause by itself can stand as a separate example. Although each dependent clause can refer in the clauses to a specific combination with one of the other clauses, the aspect(s) of that dependent clause are not

limited to the specific combination. It will be appreciated that other example clauses can also include a combination of the dependent clause aspect(s) with the subject matter of any other dependent clause or independent clause or a combination of any feature with other dependent and independent clauses. The various aspects disclosed herein expressly include these combinations, unless it is explicitly expressed or can be readily inferred that a specific combination is not intended (e.g., contradictory aspects, such as defining an element as both an insulator and a conductor). Furthermore, it is also intended that aspects of a clause can be included in any other independent clause, even if the clause is not directly dependent on the independent clause.

[0192] Implementation examples are described in the following numbered clauses:

[0193] Clause 1. A user equipment (UE), comprising: a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: maintain timing information for each of a plurality of beam pairs, each beam pair comprising a receive beam of the UE and a transmit beam of a base station or another UE; measure a first reference signal using a first beam pair from the plurality of beam pairs; measure a second reference signal using a second beam pair from the plurality of beam pairs; and report, to a transmitting entity, beam timings for the first beam pair and the second beam pair, wherein measuring the first reference signal and measuring the second reference signal, reporting the beam timings, or both, are performed according to the timing information for the first beam pair and the second beam pair.

[0194] Clause 2. The UE of clause 1, wherein the at least one processor is further configured to at least one of: report, to the transmitting entity, the timing information for the first beam pair and the timing information for the second beam pair; or indicate, to the transmitting entity, that the UE has a capability to maintain timing information for each of the plurality of beam pairs.

[0195] Clause 3. The UE of any of clauses 1 to 2, wherein the first reference signal comprises a positioning reference signal (PRS) beam and the second reference signal comprises the same PRS beam or a different PRS beam.

[0196] Clause 4. The UE of any of clauses 1 to 3, wherein the transmit beam of the first beam pair is the same as the transmit beam of the second beam pair, and wherein the receive beam of the first beam pair is different from the receive beam of the second beam pair.

- [0197] Clause 5. The UE of clause 4, wherein the receive beam of the first beam pair and the receive beam of the second beam pair are in different receive timing error groups.
- [0198] Clause 6. The UE of any of clauses 1 to 5, wherein measuring the first reference signal and measuring the second reference signal according to the timing information for the first beam pair and the second beam pair comprises calculating a time of arrival (ToA) of the respective reference signal based on the timing information of the respective beam pair.
- [0199] Clause 7. The UE of any of clauses 1 to 6, wherein reporting the beam timings according to the timing information for the first beam pair and the second beam pair comprises calculating a time difference of arrival (TDoA) of the first reference signal and the second reference signal based on a time of arrival (ToA) of the respective reference signal and the timing information of the respective beam pair.
- [0200] Clause 8. The UE of any of clauses 1 to 7, wherein maintaining timing information for each of the plurality of beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
- [0201] Clause 9. A user equipment (UE), comprising: a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: maintain timing information for each of a plurality of beam pairs, each beam pair comprising a transmit beam of the UE and a receive beam of a base station or another UE; cause the at least one transceiver to transmit, to a receiving entity, a first reference signal using a first beam pair from the plurality of beam pairs; and cause the at least one transceiver to transmit, to the receiving entity, a second reference signal using a second beam pair from the plurality of beam pairs, wherein the first reference signal and the second reference signal are transmitted to the receiving entity according to the timing information for the first beam pair and the second beam pair, respectively, or wherein the at least one processor is further configured to cause the at least one transceiver to transmit, to the receiving entity, the timing information for the first beam pair and the second beam pair.
- [0202] Clause 10. The UE of clause 9, wherein the at least one processor is further configured to at least one of: report, to the receiving entity, the timing information for the first beam pair and the timing information for the second beam pair; or indicate, to the receiving

entity, that the UE has a capability to maintain timing information for each of the plurality of beam pairs.

- [0203] Clause 11. The UE of any of clauses 9 to 10, wherein the first reference signal comprises a sounding reference signal (SRS) beam and the second reference signal comprises the same SRS beam or a different SRS beam.
- [0204] Clause 12. The UE of clause 11, wherein the transmit beam of the first beam pair is the same as the transmit beam of the second beam pair, and wherein the receive beam of the first beam pair is different from the receive beam of the second beam pair.
- [0205] Clause 13. The UE of any of clauses 9 to 12, wherein maintaining timing information for each of the plurality of beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
- [0206] Clause 14. A base station (BS), comprising: a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: maintain timing information for each of a plurality of beam pairs, each beam pair comprising a transmit beam of the base station and a receive beam of a user equipment (UE); cause the at least one transceiver to transmit a first reference signal using a first beam pair from the plurality of beam pairs; cause the at least one transceiver to transmit a second reference signal using a second beam pair from the plurality of beam pairs; and wherein the first reference signal and the second reference signal are transmitted according to the timing information for the first beam pair and the second beam pair, respectively; or wherein the at least one processor is further configured to: cause the at least one transceiver to transmit the timing information for the first beam pair and the second beam pair to the UE; cause the at least one transceiver to transmit the timing information for the first beam pair and the second beam pair to a positioning entity; or use the timing information for the first beam pair and the second beam pair to adjust a timing report received from the UE.
- [0207] Clause 15. The BS of clause 14, wherein the at least one processor is further configured to at least one of: receive, from the UE, the timing information for the first beam pair and the timing information for the second beam pair; or receive, from the UE, an indication that the UE has a capability to maintain timing information for each of the plurality of beam pairs.

- [0208] Clause 16. The BS of any of clauses 14 to 15, wherein the first reference signal comprises a positioning reference signal (PRS) beam and the second reference signal comprises the same PRS beam or a different PRS beam.
- [0209] Clause 17. The BS of clause 16, wherein the transmit beam of the first beam pair is the same as the transmit beam of the second beam pair, and wherein the receive beam of the first beam pair is different from the receive beam of the second beam pair.
- [0210] Clause 18. The BS of any of clauses 14 to 17, wherein maintaining timing information for each of the plurality of beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
- [0211] Clause 19. A base station (BS), comprising: a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: maintain timing information for each of a plurality of beam pairs, each beam pair comprising a receive beam of the base station and a transmit beam of a user equipment (UE); measure a first reference signal using a first beam pair from the plurality of beam pairs according to the timing information for the first beam pair; and measure a second reference signal using a second beam pair from the plurality of beam pairs according to the timing information for the second beam pair; and report, to a positioning entity, beam timings for the first beam pair and the second beam pair, wherein measuring the first reference signal and measuring the second reference signal, the reporting the beam timings, or both, are performed according to the timing information for the first beam pair and the second beam pair.
- [0212] Clause 20. The BS of clause 19, wherein the at least one processor is further configured to at least one of: calculate a reference signal timing according to the timing information for the first beam pair and the second beam pair; report, to the positioning entity, the timing information for the first beam pair and the timing information for the second beam pair; or indicate, to the UE, that the base station has a capability to maintain timing information for each of the plurality of beam pairs.
- [0213] Clause 21. The BS of any of clauses 19 to 20, wherein the first reference signal comprises a sounding reference signal (SRS) beam and the second reference signal comprises the same SRS beam or a different SRS beam.

- [0214] Clause 22. The BS of any of clauses 19 to 21, wherein the transmit beam of the first beam pair is the same as the transmit beam of the second beam pair, and wherein the receive beam of the first beam pair is different from the receive beam of the second beam pair.
- [0215] Clause 23. The BS of clause 22, wherein the receive beam of the first beam pair and the receive beam of the second beam pair are in different receive timing error groups.
- [0216] Clause 24. The BS of any of clauses 19 to 23, wherein measuring the first reference signal and measuring the second reference signal according to the timing information for the first beam pair and the second beam pair comprises calculating a time of arrival (ToA) of the respective reference signal based on the timing information of the respective beam pair.
- [0217] Clause 25. The BS of any of clauses 19 to 24, wherein reporting the beam timings according to the timing information for the first beam pair and the second beam pair comprises calculating a time difference of arrival (TDoA) of the first reference signal and the second reference signal based on a time of arrival (ToA) of the respective reference signal and the timing information of the respective beam pair.
- [0218] Clause 26. The BS of any of clauses 19 to 25, wherein maintaining timing information for each of the plurality of beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
- [0219] Clause 27. A method of wireless communication performed by a user equipment (UE), the method comprising: maintaining timing information for each of a plurality of beam pairs, each beam pair comprising a receive beam of the UE and a transmit beam of a base station or another UE; measuring a first reference signal using a first beam pair from the plurality of beam pairs; measuring a second reference signal using a second beam pair from the plurality of beam pairs; and reporting, to a transmitting entity, beam timings for the first beam pair and the second beam pair, wherein the measuring the first reference signal and the measuring the second reference signal, the reporting the beam timings, or both, are performed according to the timing information for the first beam pair and the second beam pair.
- [0220] Clause 28. The method of clause 27, further comprising at least one of: reporting, to the transmitting entity, the timing information for the first beam pair and the timing information for the second beam pair; or indicating, to the transmitting entity, that the UE has a capability to maintain timing information for each of the plurality of beam pairs.

- [0221] Clause 29. The method of any of clauses 27 to 28, wherein the first reference signal comprises a positioning reference signal (PRS) beam and the second reference signal comprises the same PRS beam or a different PRS beam.
- [0222] Clause 30. The method of any of clauses 27 to 29, wherein the transmit beam of the first beam pair is the same as the transmit beam of the second beam pair, and wherein the receive beam of the first beam pair is different from the receive beam of the second beam pair.
- [0223] Clause 31. The method of clause 30, wherein the receive beam of the first beam pair and the receive beam of the second beam pair are in different receive timing error groups.
- [0224] Clause 32. The method of any of clauses 27 to 31, wherein the measuring the first reference signal and the measuring the second reference signal according to the timing information for the first beam pair and the second beam pair comprises calculating a time of arrival (ToA) of the respective reference signal based on the timing information of the respective beam pair.
- [0225] Clause 33. The method of any of clauses 27 to 32, wherein reporting the beam timings according to the timing information for the first beam pair and the second beam pair comprises calculating a time difference of arrival (TDoA) of the first reference signal and the second reference signal based on a time of arrival (ToA) of the respective reference signal and the timing information of the respective beam pair.
- [0226] Clause 34. The method of any of clauses 27 to 33, wherein maintaining timing information for each of the plurality of beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
- [0227] Clause 35. A method of wireless communication performed by a user equipment (UE), the method comprising: maintain timing information for each of a plurality of beam pairs, each beam pair comprising a transmit beam of the UE and a receive beam of a base station or another UE; transmitting, to a receiving entity, a first reference signal using a first beam pair from the plurality of beam pairs; and transmitting, to the receiving entity, a second reference signal using a second beam pair from the plurality of beam pairs, wherein the first reference signal and the second reference signal are transmitted to the receiving entity according to the timing information for the first beam pair and the second beam pair, respectively, or wherein the UE transmits, to the receiving entity, the timing information for the first beam pair and the second beam pair.

- [0228] Clause 36. The method of clause 35, further comprising at least one of: reporting, to the receiving entity, the timing information for the first beam pair and the timing information for the second beam pair; or indicating, to the receiving entity, that the UE has a capability to maintain timing information for each of the plurality of beam pairs.
- [0229] Clause 37. The method of any of clauses 35 to 36, wherein the first reference signal comprises a sounding reference signal (SRS) beam and the second reference signal comprises the same SRS beam or a different SRS beam.
- [0230] Clause 38. A method of wireless communication performed by a base station (BS), the method comprising: maintaining timing information for each of a plurality of beam pairs, each beam pair comprising a transmit beam of the base station and a receive beam of a user equipment (UE); transmitting a first reference signal using a first beam pair from the plurality of beam pairs; and transmitting a second reference signal using a second beam pair from the plurality of beam pairs; wherein the first reference signal and the second reference signal are transmitted according to the timing information for the first beam pair and the second beam pair, respectively; or transmitting the timing information for the first beam pair and the second beam pair to the UE, transmitting the timing information for the first beam pair and the second beam pair to a positioning entity, or using the timing information for the first beam pair and the second beam pair to adjust a timing report received from the UE.
- [0231] Clause 39. The method of clause 38, further comprising at least one of: receiving, from the UE, the timing information for the first beam pair and the timing information for the second beam pair; or receiving, from the UE, an indication that the UE has a capability to maintain timing information for each of the plurality of beam pairs.
- [0232] Clause 40. The method of any of clauses 38 to 39, wherein the first reference signal comprises a positioning reference signal (PRS) beam and the second reference signal comprises the same PRS beam or a different PRS beam.
- [0233] Clause 41. A method of wireless communication performed by a base station (BS), the method comprising: maintaining timing information for each of a plurality of beam pairs, each beam pair comprising a receive beam of the base station and a transmit beam of a user equipment (UE); measuring a first reference signal using a first beam pair from the plurality of beam pairs according to the timing information for the first beam pair; measuring a second reference signal using a second beam pair from the plurality of beam pairs according to the timing information for the second beam pair; and reporting, to a

positioning entity, beam timings for the first beam pair and the second beam pair, wherein measuring the first reference signal and measuring the second reference signal, the reporting the beam timings, or both, are performed according to the timing information for the first beam pair and the second beam pair.

- [0234] Clause 42. The method of clause 41, further comprising at least one of: calculating a reference signal timing according to the timing information for the first beam pair and the second beam pair; reporting, to the positioning entity, the timing information for the first beam pair and the timing information for the second beam pair; or indicating, to the UE, that the base station has a capability to maintain timing information for each of the plurality of beam pairs.
- [0235] Clause 43. The method of any of clauses 41 to 42, wherein the first reference signal comprises a sounding reference signal (SRS) beam and the second reference signal comprises the same SRS beam or a different SRS beam.
- [0236] Clause 44. An apparatus comprising a memory, a transceiver, and a processor communicatively coupled to the memory and the transceiver, the memory, the transceiver, and the processor configured to perform a method according to any of clauses 27 to 43.
- [0237] Clause 45. An apparatus comprising means for performing a method according to any of clauses 27 to 43.
- [0238] Clause 46. A non-transitory computer-readable medium storing computer-executable instructions, the computer-executable comprising at least one instruction for causing a computer or processor to perform a method according to any of clauses 27 to 43.
- [0239] Additional aspects include, but are not limited to, the following:
- [0240] In an aspect, a method of wireless communication performed by a user equipment (UE) includes maintaining timing information for each of a plurality of beam pairs, each beam pair comprising a downlink (DL) beam pair, comprising a base station transmit beam and a UE receive beam, or a sidelink (SL) beam pair, comprising a UE transmit beam and a UE receive beam; measuring a first reference signal using a first beam pair from the plurality of beam pairs; measuring a second reference signal using a second beam pair from the plurality of beam pairs; and reporting, to a transmitting entity, beam timings for the first beam pair and the second beam pair, wherein the measuring the first reference signal and the measuring the second reference signal, the reporting the beam timings, or

both, are performed according to the timing information for the first beam pair and the second beam pair.

- [0241] In some aspects, the method includes reporting, to the transmitting entity, the timing information for the first beam pair and the timing information for the second beam pair.
- [0242] In some aspects, the method includes indicating, to the transmitting entity, that the UE has a capability to maintain timing information for each of the plurality of beam pairs.
- [0243] In some aspects, each of the first reference signal and the second reference signal comprises a positioning reference signal (PRS) beam.
- [0244] In some aspects, the first reference signal and the second reference signal comprise a same PRS beam.
- [0245] In some aspects, the first reference signal and the second reference signal comprise different PRS beams.
- [0246] In some aspects, the measuring the first reference signal and the measuring the second reference signal according to the timing information for each of the plurality of beam pairs comprises, for each beam pair, calculating a time of arrival (ToA) of the respective reference signal based on the timing information of the respective beam pair.
- [0247] In some aspects, reporting the beam timings according to the timing information for each of the plurality of beam pairs comprises calculating a time difference of arrival (TDoA) of the first reference signal and the second reference signal based on a time of arrival (ToA) of the respective reference signal and the timing information for each of the first beam pair and the second beam pair.
- [0248] In some aspects, maintaining timing information for each of a plurality of beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
- [0249] In an aspect, a method of wireless communication performed by a user equipment (UE) includes maintaining timing information for each of a plurality of beam pairs, each beam pair comprising an uplink (UL) beam pair, comprising a UE transmit beam and a base station receive beam, or a sidelink (SL) beam pair, comprising a UE transmit beam and a UE receive beam; transmitting, to a receiving entity, a first reference signal using a first beam pair from the plurality of beam pairs; and transmitting, to the receiving entity, a second reference signal using a second beam pair from the plurality of beam pairs, wherein the first reference signal and the second reference signal are transmitted to the receiving entity according to the timing information for the first beam pair and the second

- beam pair, respectively, or wherein the method further comprises transmitting, to the receiving entity, the timing information for the first beam pair and the second beam pair.
- [0250] In some aspects, the method includes reporting, to the receiving entity, the timing information for the first beam pair and the timing information for the second beam pair.
- [0251] In some aspects, the method includes indicating, to the receiving entity, that the UE has a capability to maintain timing information for each of the plurality of beam pairs.
- [0252] In some aspects, each of the first reference signal and the second reference signal comprises a sounding reference signal (SRS) beam.
- [0253] In some aspects, the first reference signal and the second reference signal comprise a same SRS beam.
- [0254] In some aspects, the first reference signal and the second reference signal comprise different SRS beams.
- [0255] In some aspects, maintaining timing information for each of a plurality of beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
- [0256] In an aspect, a method of wireless communication performed by a base station includes maintaining timing information for each of a plurality of downlink (DL) beam pairs, each DL beam pair comprising a base station transmit beam and a UE receive beam; transmitting, to a user equipment (UE), a first reference signal using a first DL beam pair from the plurality of DL beam pairs; and transmitting, to the UE, a second reference signal using a second DL beam pair from the plurality of DL beam pairs, wherein the first reference signal and the second reference signal are transmitted to the UE according to the timing information for the first DL beam pair and the second DL beam pair, respectively, or wherein the method further comprises: transmitting the timing information for the first DL beam pair and the second DL beam pair to the UE; transmitting the timing information for the first DL beam pair and the second DL beam pair to a positioning entity; or using the timing information for the first DL beam pair and the second DL beam pair to adjust a timing report received from the UE.
- [0257] In some aspects, the method includes receiving, from the UE, beam timings for the first beam pair and the second beam pair.
- [0258] In some aspects, the method includes receiving, from the UE, an indication that the UE has a capability to maintain timing information for each of the plurality of DL beam pairs.

- [0259] In some aspects, each of the first reference signal and the second reference signal comprises a positioning reference signal (PRS) beam.
- [0260] In some aspects, the first reference signal and the second reference signal comprise a same PRS beam.
- [0261] In some aspects, the first reference signal and the second reference signal comprise different PRS beams.
- [0262] In some aspects, maintaining timing information for each of a plurality of downlink (DL) beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
- [0263] In an aspect, a method of wireless communication performed by a base station includes maintaining timing information for each of a plurality of uplink (UL) beam pairs, each UL beam pair comprising a UE transmit beam and a base station receive beam; measuring a first reference signal using a first UL beam pair from the plurality of UL beam pairs according to the timing information for the first UL beam pair; and measuring a second reference signal using a second UL beam pair from the plurality of UL beam pairs according to the timing information for the second UL beam pair; and reporting, to a positioning entity, beam timings for the first UL beam pair and the second UL beam pair, wherein the measuring the first reference signal and the measuring the second reference signal, the reporting the beam timings, or both, are performed according to the timing information for the first UL beam pair and the second UL beam pair.
- [0264] In some aspects, the method includes calculating a reference signal timing according to the timing information for the first UL beam pair and the second UL beam pair.
- [0265] In some aspects, the method includes reporting, to the positioning entity, the timing information for the first UL beam pair and the timing information for the second UL beam pair.
- [0266] In some aspects, the method includes indicating, to the UE, that the base station has a capability to maintain timing information for each of the plurality of UL beam pairs.
- [0267] In some aspects, each of the first reference signal and the second reference signal comprises a sounding reference signal (SRS) beam.
- [0268] In some aspects, the first reference signal and the second reference signal comprise a same SRS beam.
- [0269] In some aspects, the first reference signal and the second reference signal comprise different SRS beams.

- [0270] In some aspects, the measuring the first reference signal and the measuring the second reference signal according to the timing information for each of the plurality of UL beam pairs comprises, for each UL beam pair, calculating a time of arrival (ToA) of the respective reference signal based on the timing information of the respective UL beam pair.
- [0271] In some aspects, reporting the beam timings according to the timing information for each of the plurality of UL beam pairs comprises calculating a time difference of arrival (TDoA) of the first reference signal and the second reference signal based on a time of arrival (ToA) of the respective reference signal and the timing information for each of the first UL beam pair and the second UL beam pair.
- [0272] In some aspects, maintaining timing information for each of a plurality of UL beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
- [0273] In an aspect, a user equipment (UE) includes a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: maintain timing information for each of a plurality of beam pairs, each beam pair comprising a downlink (DL) beam pair, comprising a base station transmit beam and a UE receive beam, or a sidelink (SL) beam pair, comprising a UE transmit beam and a UE receive beam; measure a first reference signal using a first beam pair from the plurality of beam pairs; measure a second reference signal using a second beam pair from the plurality of beam pairs; and report, to a transmitting entity, beam timings for the first beam pair and the second beam pair, wherein the measuring the first reference signal and the measuring the second reference signal, the reporting beam timings, or both, are performed according to the timing information for the first beam pair and the second beam pair.
- [0274] In some aspects, the at least one processor is further configured to: report, to the transmitting entity, the timing information for the first beam pair and the timing information for the second beam pair.
- [0275] In some aspects, the at least one processor is further configured to: indicate, to the transmitting entity, that the UE has a capability to maintain timing information for each of the plurality of beam pairs.
- [0276] In some aspects, each of the first reference signal and the second reference signal comprises a positioning reference signal (PRS) beam.

- [0277] In some aspects, the first reference signal and the second reference signal comprise a same PRS beam.
- [0278] In some aspects, the first reference signal and the second reference signal comprise different PRS beams.
- [0279] In some aspects, the measuring the first reference signal and the measuring the second reference signal according to the timing information for each of the plurality of beam pairs comprises calculating a time of arrival (ToA) of the respective reference signal based on the timing information of the respective beam pair.
- [0280] In some aspects, reporting the beam timings according to the timing information for each of the plurality of beam pairs comprises calculating a time difference of arrival (TDoA) of the first reference signal and the second reference signal based on a time of arrival (ToA) of the respective reference signal and the timing information for each of the first beam pair and the second beam pair.
- [0281] In some aspects, maintaining timing information for each of a plurality of beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
- [0282] In an aspect, a user equipment (UE) includes a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: maintain timing information for each of a plurality of beam pairs, each beam pair comprising an uplink (UL) beam pair, comprising a UE transmit beam and a base station receive beam, or a sidelink (SL) beam pair, comprising a UE transmit beam and a UE receive beam; cause the at least one transceiver to transmit, to a receiving entity, a first reference signal using a first beam pair from the plurality of beam pairs; and cause the at least one transceiver to transmit, to the receiving entity, a second reference signal using a second beam pair from the plurality of beam pairs, wherein the first reference signal and the second reference signal are transmitted to the receiving entity according to the timing information for the first beam pair and the second beam pair, respectively, or wherein the at least one processor is further configured to cause the at least one transceiver to transmit, to the receiving entity, the timing information for the first beam pair and the second beam pair.
- [0283] In some aspects, the at least one processor is further configured to: report, to the receiving entity, the timing information for the first beam pair and the timing information for the second beam pair.

- [0284] In some aspects, the at least one processor is further configured to: indicate, to the receiving entity, that the UE has a capability to maintain timing information for each of the plurality of beam pairs.
- [0285] In some aspects, each of the first reference signal and the second reference signal comprises a sounding reference signal (SRS) beam.
- [0286] In some aspects, the first reference signal and the second reference signal comprise a same SRS beam.
- [0287] In some aspects, the first reference signal and the second reference signal comprise different SRS beams.
- [0288] In some aspects, maintaining timing information for each of a plurality of beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
- [0289] In an aspect, a base station (BS) includes a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: maintain timing information for each of a plurality of downlink (DL) beam pairs, each DL beam pair comprising a base station transmit beam and a UE receive beam; cause the at least one transceiver to transmit, to a user equipment (UE), a first reference signal using a first DL beam pair from the plurality of DL beam pairs; cause the at least one transceiver to transmit, to the UE, a second reference signal using a second DL beam pair from the plurality of DL beam pairs; and wherein the first reference signal and the second reference signal are transmitted to the UE according to the timing information for the first DL beam pair and the second DL beam pair, respectively; or wherein the at least one processor is further configured to: cause the at least one transceiver to transmit the timing information for the first DL beam pair and the second DL beam pair to the UE; cause the at least one transceiver to transmit the timing information for the first DL beam pair and the second DL beam pair to a positioning entity; or use the timing information for the first DL beam pair and the second DL beam pair to adjust a timing report received from the UE.
- [0290] In some aspects, the at least one processor is further configured to: receive, from the UE, the timing information for the first DL beam pair and the timing information for the second DL beam pair.

- [0291] In some aspects, the at least one processor is further configured to: receive, from the UE, an indication that the UE has a capability to maintain timing information for each of the plurality of DL beam pairs.
- [0292] In some aspects, each of the first reference signal and the second reference signal comprises a positioning reference signal (PRS) beam.
- [0293] In some aspects, the first reference signal and the second reference signal comprise a same PRS beam.
- [0294] In some aspects, the first reference signal and the second reference signal comprise different PRS beams.
- [0295] In some aspects, maintaining timing information for each of a plurality of downlink (DL) beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
- [0296] In an aspect, a base station (BS) includes a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: maintain timing information for each of a plurality of uplink (UL) beam pairs, each UL beam pair comprising a UE transmit beam and a base station receive beam; measure a first reference signal using a first UL beam pair from the plurality of UL beam pairs according to the timing information for the first UL beam pair; and measure a second reference signal using a second UL beam pair from the plurality of UL beam pairs according to the timing information for the second UL beam pair; and report, to a positioning entity, beam timings for the first UL beam pair and the second UL beam pair, wherein the measuring the first reference signal and the measuring the second reference signal, the reporting the beam timings, or both, are performed according to the timing information for the first UL beam pair and the second UL beam pair.
- [0297] In some aspects, the at least one processor is further configured to: calculate a reference signal timing according to the timing information for the first UL beam pair and the second UL beam pair.
- [0298] In some aspects, the at least one processor is further configured to: report, to the positioning entity, the timing information for the first UL beam pair and the timing information for the second UL beam pair.

- [0299] In some aspects, the at least one processor is further configured to: indicate, to the UE, that the base station has a capability to maintain timing information for each of the plurality of UL beam pairs.
- [0300] In some aspects, each of the first reference signal and the second reference signal comprises a sounding reference signal (SRS) beam.
- [0301] In some aspects, the first reference signal and the second reference signal comprise a same SRS beam.
- [0302] In some aspects, the first reference signal and the second reference signal comprise different SRS beams.
- [0303] In some aspects, the measuring the first reference signal and the measuring the second reference signal according to the timing information for each of the plurality of UL beam pairs comprises, for each UL beam pair, calculating a time of arrival (ToA) of the respective reference signal based on the timing information of the respective UL beam pair.
- [0304] In some aspects, reporting the beam timings according to the timing information for each of the plurality of UL beam pairs comprises calculating a time difference of arrival (TDoA) of the first reference signal and the second reference signal based on a time of arrival (ToA) of the respective reference signal and the timing information for each of the first UL beam pair and the second UL beam pair.
- [0305] In some aspects, maintaining timing information for each of a plurality of UL beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
- [0306] In an aspect, a user equipment (UE) includes means for maintaining timing information for each of a plurality of beam pairs, each beam pair comprising a downlink (DL) beam pair, comprising a base station transmit beam and a UE receive beam, or a sidelink (SL) beam pair, comprising a UE transmit beam and a UE receive beam; means for measuring a first reference signal using a first beam pair from the plurality of beam pairs; means for measuring a second reference signal using a second beam pair from the plurality of beam pairs; means for reporting, to a transmitting entity, beam timings for the first beam pair and the second beam pair; and wherein the measuring the first reference signal and the measuring the second reference signal, the reporting the beam timings, or both, are performed according to the timing information for the first beam pair and the second beam pair.

- [0307] In an aspect, a user equipment (UE) includes means for maintaining timing information for each of a plurality of beam pairs, each beam pair comprising an uplink (UL) beam pair, comprising a UE transmit beam and a base station receive beam, or a sidelink (SL) beam pair, comprising a UE transmit beam and a UE receive beam; means for transmitting, to a receiving entity, a first reference signal using a first beam pair from the plurality of beam pairs; means for transmitting, to the receiving entity, a second reference signal using a second beam pair from the plurality of beam pairs; and wherein the first reference signal and the second reference signal are transmitted to the receiving entity according to the timing information for the first beam pair and the second beam pair, respectively, or wherein the UE further comprises means for transmitting, to the receiving entity, the timing information for the first beam pair and the second beam pair.
- [0308] In an aspect, a base station (BS) includes means for maintaining timing information for each of a plurality of downlink (DL) beam pairs, each DL beam pair comprising a base station transmit beam and a UE receive beam; means for transmitting, to a user equipment (UE), a first reference signal using a first DL beam pair from the plurality of DL beam pairs; means for transmitting, to the UE, a second reference signal using a second DL beam pair from the plurality of DL beam pairs; and wherein the first reference signal and the second reference signal are transmitted to the UE according to the timing information for the first DL beam pair and the second DL beam pair, respectively; or wherein the BS further comprises means for transmitting the timing information for the first DL beam pair and the second DL beam pair to the UE; means for transmitting the timing information for the first DL beam pair and the second DL beam pair to a positioning entity; or means for using the timing information for the first DL beam pair and the second DL beam pair to adjust a timing report received from the UE.
- [0309] In an aspect, a base station (BS) includes means for maintaining timing information for each of a plurality of uplink (UL) beam pairs, each UL beam pair comprising a UE transmit beam and a base station receive beam; means for measuring a first reference signal using a first UL beam pair from the plurality of UL beam pairs according to the timing information for the first UL beam pair; and means for measuring a second reference signal using a second UL beam pair from the plurality of UL beam pairs according to the timing information for the second UL beam pair; and means for reporting, to a positioning entity, beam timings for the first UL beam pair and the second UL beam pair, wherein the measuring the first reference signal and the measuring the

second reference signal, the reporting the beam timings, or both, are performed according to the timing information for the first UL beam pair and the second UL beam pair.

- [0310] In an aspect, a non-transitory computer-readable medium storing a set of instructions, the set of instructions comprising one or more instructions that, when executed by one or more processors of a user equipment (UE), cause the UE to: maintain timing information for each of a plurality of beam pairs, each beam pair comprising a downlink (DL) beam pair, comprising a base station transmit beam and a UE receive beam, or a sidelink (SL) beam pair, comprising a UE transmit beam and a UE receive beam; measure a first reference signal using a first beam pair from the plurality of beam pairs; measure a second reference signal using a second beam pair from the plurality of beam pairs; report, to a transmitting entity, beam timings for the first beam pair and the second beam pair; and wherein the measuring the first reference signal and the measuring the second reference signal, the reporting the beam timings, or both, are performed according to the timing information for the first beam pair and the second beam pair.
- [0311] In an aspect, a non-transitory computer-readable medium storing a set of instructions, the set of instructions comprising one or more instructions that, when executed by one or more processors of an UE, cause the UE to: maintain timing information for each of a plurality of beam pairs, each beam pair comprising an uplink (UL) beam pair, comprising a UE transmit beam and a base station receive beam, or a sidelink (SL) beam pair, comprising a UE transmit beam and a UE receive beam; transmit, to a receiving entity, a first reference signal using a first beam pair from the plurality of beam pairs; and transmit, to the receiving entity, a second reference signal using a second beam pair from the plurality of beam pairs, wherein the first reference signal and the second reference signal are transmitted to the receiving entity according to the timing information for the first beam pair and the second beam pair, respectively, or wherein the instructions further cause the UE to transmit, to the receiving entity, the timing information for the first beam pair and the second beam pair.
- [0312] In an aspect, a non-transitory computer-readable medium storing a set of instructions, the set of instructions comprising one or more instructions that, when executed by one or more processors of a base station (BS), cause the BS to: maintain timing information for each of a plurality of downlink (DL) beam pairs, each DL beam pair comprising a base station transmit beam and a UE receive beam; transmit, to a user equipment (UE), a first reference signal using a first DL beam pair from the plurality of DL beam pairs; and

transmit, to the UE, a second reference signal using a second DL beam pair from the plurality of DL beam pairs, wherein the first reference signal and the second reference signal are transmitted to the UE according to the timing information for the first DL beam pair and the second DL beam pair, respectively; or wherein the instruction further cause the BS to: transmit the timing information for the first DL beam pair and the second DL beam pair to the UE; transmit the timing information for the first DL beam pair and the second DL beam pair to a positioning entity; or use the timing information for the first DL beam pair and the second DL beam pair to adjust a timing report received from the UE.

- [0313] In an aspect, a non-transitory computer-readable medium storing a set of instructions, the set of instructions comprising one or more instructions that, when executed by one or more processors of a base station (BS), cause the BS to: maintain timing information for each of a plurality of uplink (UL) beam pairs, each UL beam pair comprising a UE transmit beam and a base station receive beam; measure a first reference signal using a first UL beam pair from the plurality of UL beam pairs according to the timing information for the first UL beam pair; and measure a second reference signal using a second UL beam pair from the plurality of UL beam pairs according to the timing information for the second UL beam pair; and report, to a positioning entity, beam timings for the first UL beam pair and the second UL beam pair, wherein the measuring the first reference signal and the measuring the second reference signal, the reporting the beam timings, or both, are performed according to the timing information for the first UL beam pair and the second UL beam pair.
- [0314] Those of skill in the art will appreciate that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.
- [0315] Further, those of skill in the art will appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the aspects disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above

generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such aspect decisions should not be interpreted as causing a departure from the scope of the present disclosure.

- [0316] The various illustrative logical blocks, modules, and circuits described in connection with the aspects disclosed herein may be implemented or performed with a general purpose processor, a DSP, an ASIC, an FPGA, or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.
- [0317] The methods, sequences and/or algorithms described in connection with the aspects disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in random access memory (RAM), flash memory, read-only memory (ROM), erasable programmable ROM (EPROM), electrically erasable programmable ROM (EEPROM), registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An example storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a user terminal (e.g., UE). In the alternative, the processor and the storage medium may reside as discrete components in a user terminal.
- [0318] In one or more example aspects, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A storage media may be any available

media that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. Also, any connection is properly termed a computer-readable medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and Blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

[0319] While the foregoing disclosure shows illustrative aspects of the disclosure, it should be noted that various changes and modifications could be made herein without departing from the scope of the disclosure as defined by the appended claims. The functions, steps and/or actions of the method claims in accordance with the aspects of the disclosure described herein need not be performed in any particular order. Furthermore, although elements of the disclosure may be described or claimed in the singular, the plural is contemplated unless limitation to the singular is explicitly stated.

**CLAIMS**

What is claimed is:

1. A user equipment (UE), comprising:
  - a memory;
  - at least one transceiver; and
  - at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to:
    - maintain timing information for each of a plurality of beam pairs, each beam pair comprising a receive beam of the UE and a transmit beam of a base station or another UE;
    - measure a first reference signal using a first beam pair from the plurality of beam pairs;
    - measure a second reference signal using a second beam pair from the plurality of beam pairs; and
    - report, to a transmitting entity, beam timings for the first beam pair and the second beam pair,
- wherein measuring the first reference signal and measuring the second reference signal, reporting the beam timings, or both, are performed according to the timing information for the first beam pair and the second beam pair.
2. The UE of claim 1, wherein the at least one processor is further configured to at least one of:
  - report, to the transmitting entity, the timing information for the first beam pair and the timing information for the second beam pair; or
  - indicate, to the transmitting entity, that the UE has a capability to maintain timing information for each of the plurality of beam pairs.
3. The UE of claim 1, wherein the first reference signal comprises a positioning reference signal (PRS) beam and the second reference signal comprises the same PRS beam or a different PRS beam.

4. The UE of claim 1, wherein the transmit beam of the first beam pair is the same as the transmit beam of the second beam pair, and wherein the receive beam of the first beam pair is different from the receive beam of the second beam pair.
5. The UE of claim 4, wherein the receive beam of the first beam pair and the receive beam of the second beam pair are in different receive timing error groups.
6. The UE of claim 1, wherein measuring the first reference signal and measuring the second reference signal according to the timing information for the first beam pair and the second beam pair comprises calculating a time of arrival (ToA) of the respective reference signal based on the timing information of the respective beam pair.
7. The UE of claim 1, wherein reporting the beam timings according to the timing information for the first beam pair and the second beam pair comprises calculating a time difference of arrival (TDoA) of the first reference signal and the second reference signal based on a time of arrival (ToA) of the respective reference signal and the timing information of the respective beam pair.
8. The UE of claim 1, wherein maintaining timing information for each of the plurality of beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.
9. A user equipment (UE), comprising:
  - a memory;
  - at least one transceiver; and
  - at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to:
    - maintain timing information for each of a plurality of beam pairs, each beam pair comprising a transmit beam of the UE and a receive beam of a base station or another UE;
    - cause the at least one transceiver to transmit, to a receiving entity, a first reference signal using a first beam pair from the plurality of beam pairs; and

cause the at least one transceiver to transmit, to the receiving entity, a second reference signal using a second beam pair from the plurality of beam pairs, wherein the first reference signal and the second reference signal are transmitted to the receiving entity according to the timing information for the first beam pair and the second beam pair, respectively, or wherein the at least one processor is further configured to cause the at least one transceiver to transmit, to the receiving entity, the timing information for the first beam pair and the second beam pair.

10. The UE of claim 9, wherein the at least one processor is further configured to at least one of:

report, to the receiving entity, the timing information for the first beam pair and the timing information for the second beam pair; or

indicate, to the receiving entity, that the UE has a capability to maintain timing information for each of the plurality of beam pairs.

11. The UE of claim 9, wherein the first reference signal comprises a sounding reference signal (SRS) beam and the second reference signal comprises the same SRS beam or a different SRS beam.

12. The UE of claim 11, wherein the transmit beam of the first beam pair is the same as the transmit beam of the second beam pair, and wherein the receive beam of the first beam pair is different from the receive beam of the second beam pair.

13. The UE of claim 9, wherein maintaining timing information for each of the plurality of beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.

14. A base station (BS), comprising:  
a memory;  
at least one transceiver; and

at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to:

- maintain timing information for each of a plurality of beam pairs, each beam pair comprising a transmit beam of the base station and a receive beam of a user equipment (UE);

- cause the at least one transceiver to transmit a first reference signal using a first beam pair from the plurality of beam pairs;

- cause the at least one transceiver to transmit a second reference signal using a second beam pair from the plurality of beam pairs; and

- wherein the first reference signal and the second reference signal are transmitted according to the timing information for the first beam pair and the second beam pair, respectively; or

- wherein the at least one processor is further configured to:

- cause the at least one transceiver to transmit the timing information for the first beam pair and the second beam pair to the UE;

- cause the at least one transceiver to transmit the timing information for the first beam pair and the second beam pair to a positioning entity; or

- use the timing information for the first beam pair and the second beam pair to adjust a timing report received from the UE.

15. The BS of claim 14, wherein the at least one processor is further configured to at least one of:

- receive, from the UE, the timing information for the first beam pair and the timing information for the second beam pair; or

- receive, from the UE, an indication that the UE has a capability to maintain timing information for each of the plurality of beam pairs.

16. The BS of claim 14, wherein the first reference signal comprises a positioning reference signal (PRS) beam and the second reference signal comprises the same PRS beam or a different PRS beam.

17. The BS of claim 16, wherein the transmit beam of the first beam pair is the same as the transmit beam of the second beam pair, and wherein the receive beam of the first beam pair is different from the receive beam of the second beam pair.

18. The BS of claim 14, wherein maintaining timing information for each of the plurality of beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.

19. A base station (BS), comprising:  
a memory;  
at least one transceiver; and  
at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to:

maintain timing information for each of a plurality of beam pairs, each beam pair comprising a receive beam of the base station and a transmit beam of a user equipment (UE);

measure a first reference signal using a first beam pair from the plurality of beam pairs according to the timing information for the first beam pair; and

measure a second reference signal using a second beam pair from the plurality of beam pairs according to the timing information for the second beam pair; and

report, to a positioning entity, beam timings for the first beam pair and the second beam pair,

wherein measuring the first reference signal and measuring the second reference signal, the reporting the beam timings, or both, are performed according to the timing information for the first beam pair and the second beam pair.

20. The BS of claim 19, wherein the at least one processor is further configured to at least one of:

calculate a reference signal timing according to the timing information for the first beam pair and the second beam pair;

report, to the positioning entity, the timing information for the first beam pair and the timing information for the second beam pair; or

indicate, to the UE, that the base station has a capability to maintain timing information for each of the plurality of beam pairs.

21. The BS of claim 19, wherein the first reference signal comprises a sounding reference signal (SRS) beam and the second reference signal comprises the same SRS beam or a different SRS beam.

22. The BS of claim 19, wherein the transmit beam of the first beam pair is the same as the transmit beam of the second beam pair, and wherein the receive beam of the first beam pair is different from the receive beam of the second beam pair.

23. The BS of claim 22, wherein the receive beam of the first beam pair and the receive beam of the second beam pair are in different receive timing error groups.

24. The BS of claim 19, wherein measuring the first reference signal and measuring the second reference signal according to the timing information for the first beam pair and the second beam pair comprises calculating a time of arrival (ToA) of the respective reference signal based on the timing information of the respective beam pair.

25. The BS of claim 19, wherein reporting the beam timings according to the timing information for the first beam pair and the second beam pair comprises calculating a time difference of arrival (TDoA) of the first reference signal and the second reference signal based on a time of arrival (ToA) of the respective reference signal and the timing information of the respective beam pair.

26. The BS of claim 19, wherein maintaining timing information for each of the plurality of beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.

27. A method of wireless communication performed by a user equipment (UE), the method comprising:

- maintaining timing information for each of a plurality of beam pairs, each beam pair comprising a receive beam of the UE and a transmit beam of a base station or another UE;

- measuring a first reference signal using a first beam pair from the plurality of beam pairs;

- measuring a second reference signal using a second beam pair from the plurality of beam pairs; and

- reporting, to a transmitting entity, beam timings for the first beam pair and the second beam pair,

- wherein the measuring the first reference signal and the measuring the second reference signal, the reporting the beam timings, or both, are performed according to the timing information for the first beam pair and the second beam pair.

28. The method of claim 27, further comprising at least one of:

- reporting, to the transmitting entity, the timing information for the first beam pair and the timing information for the second beam pair; or

- indicating, to the transmitting entity, that the UE has a capability to maintain timing information for each of the plurality of beam pairs.

29. The method of claim 27, wherein the first reference signal comprises a positioning reference signal (PRS) beam and the second reference signal comprises the same PRS beam or a different PRS beam.

30. The method of claim 27, wherein the transmit beam of the first beam pair is the same as the transmit beam of the second beam pair, and wherein the receive beam of the first beam pair is different from the receive beam of the second beam pair.

31. The method of claim 30, wherein the receive beam of the first beam pair and the receive beam of the second beam pair are in different receive timing error groups.

32. The method of claim 27, wherein the measuring the first reference signal and the measuring the second reference signal according to the timing information for the first beam pair and the second beam pair comprises calculating a time of arrival (ToA) of the respective reference signal based on the timing information of the respective beam pair.

33. The method of claim 27, wherein reporting the beam timings according to the timing information for the first beam pair and the second beam pair comprises calculating a time difference of arrival (TDoA) of the first reference signal and the second reference signal based on a time of arrival (ToA) of the respective reference signal and the timing information of the respective beam pair.

34. The method of claim 27, wherein maintaining timing information for each of the plurality of beam pairs comprises maintaining separate timing per beam pair on a per band basis, on a per band combination basis, on a per carrier basis, or combinations thereof.

35. A method of wireless communication performed by a user equipment (UE), the method comprising:

- maintain timing information for each of a plurality of beam pairs, each beam pair comprising a transmit beam of the UE and a receive beam of a base station or another UE;

- transmitting, to a receiving entity, a first reference signal using a first beam pair from the plurality of beam pairs; and

- transmitting, to the receiving entity, a second reference signal using a second beam pair from the plurality of beam pairs,

- wherein the first reference signal and the second reference signal are transmitted to the receiving entity according to the timing information for the first beam pair and the second beam pair, respectively, or wherein the UE transmits, to the receiving entity, the timing information for the first beam pair and the second beam pair.

36. The method of claim 35, further comprising at least one of:

- reporting, to the receiving entity, the timing information for the first beam pair and the timing information for the second beam pair; or

indicating, to the receiving entity, that the UE has a capability to maintain timing information for each of the plurality of beam pairs.

37. The method of claim 35, wherein the first reference signal comprises a sounding reference signal (SRS) beam and the second reference signal comprises the same SRS beam or a different SRS beam.

38. A method of wireless communication performed by a base station (BS), the method comprising:

- maintaining timing information for each of a plurality of beam pairs, each beam pair comprising a transmit beam of the base station and a receive beam of a user equipment (UE);

- transmitting a first reference signal using a first beam pair from the plurality of beam pairs; and

- transmitting a second reference signal using a second beam pair from the plurality of beam pairs;

- wherein the first reference signal and the second reference signal are transmitted according to the timing information for the first beam pair and the second beam pair, respectively, or wherein the method further comprises at least one of:

- transmitting the timing information for the first beam pair and the second beam pair to the UE,

- transmitting the timing information for the first beam pair and the second beam pair to a positioning entity, or

- using the timing information for the first beam pair and the second beam pair to adjust a timing report received from the UE.

39. The method of claim 38, further comprising at least one of:

- receiving, from the UE, the timing information for the first beam pair and the timing information for the second beam pair; or

- receiving, from the UE, an indication that the UE has a capability to maintain timing information for each of the plurality of beam pairs.

40. The method of claim 38, wherein the first reference signal comprises a positioning reference signal (PRS) beam and the second reference signal comprises the same PRS beam or a different PRS beam.

41. A method of wireless communication performed by a base station (BS), the method comprising:

- maintaining timing information for each of a plurality of beam pairs, each beam pair comprising a receive beam of the base station and a transmit beam of a user equipment (UE);

- measuring a first reference signal using a first beam pair from the plurality of beam pairs according to the timing information for the first beam pair;

- measuring a second reference signal using a second beam pair from the plurality of beam pairs according to the timing information for the second beam pair; and

- reporting, to a positioning entity, beam timings for the first beam pair and the second beam pair,

- wherein measuring the first reference signal and measuring the second reference signal, the reporting the beam timings, or both, are performed according to the timing information for the first beam pair and the second beam pair.

42. The method of claim 41, further comprising at least one of:

- calculating a reference signal timing according to the timing information for the first beam pair and the second beam pair;

- reporting, to the positioning entity, the timing information for the first beam pair and the timing information for the second beam pair; or

- indicating, to the UE, that the base station has a capability to maintain timing information for each of the plurality of beam pairs.

43. The method of claim 41, wherein the first reference signal comprises a sounding reference signal (SRS) beam and the second reference signal comprises the same SRS beam or a different SRS beam.

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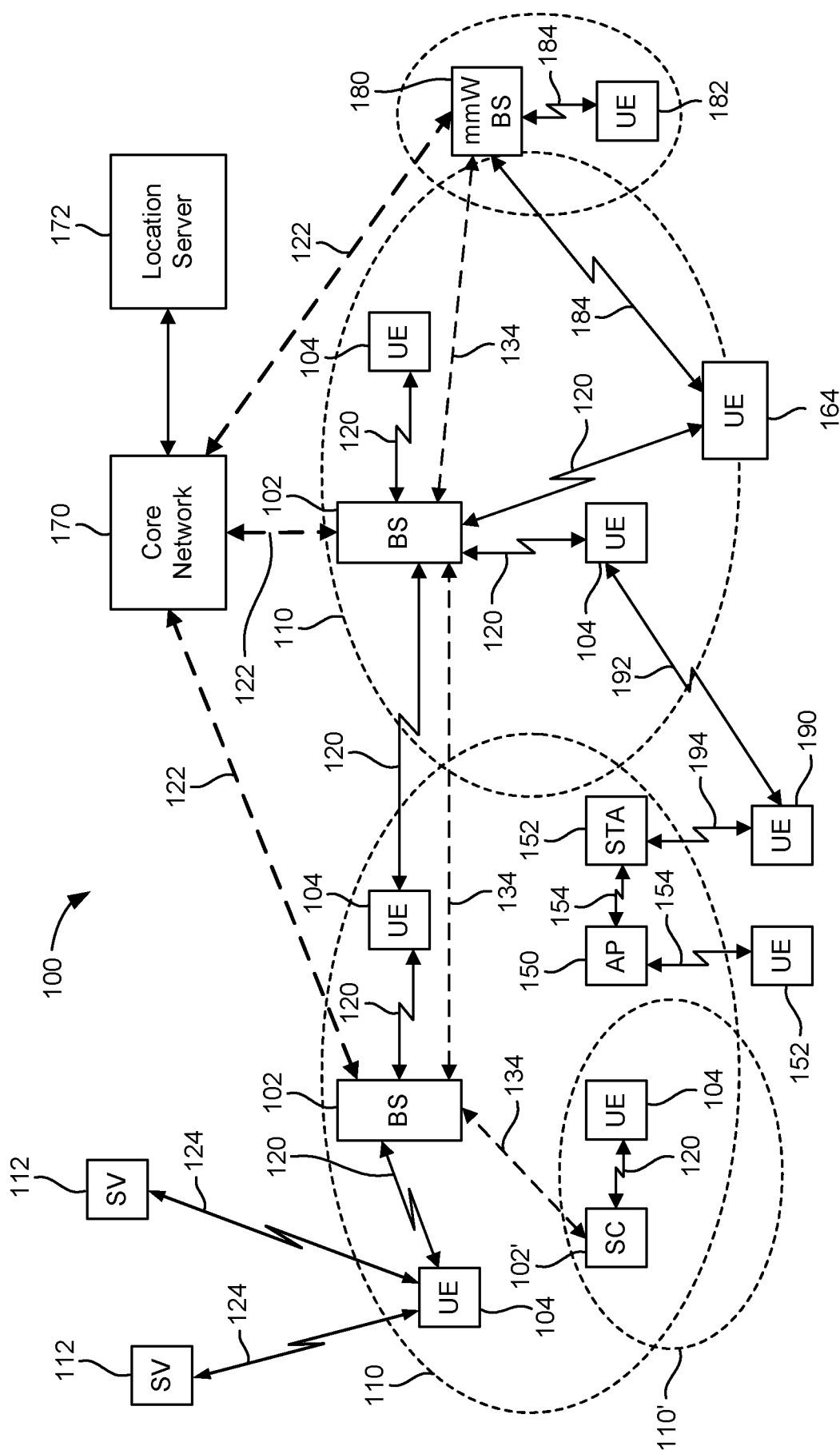


FIG. 1

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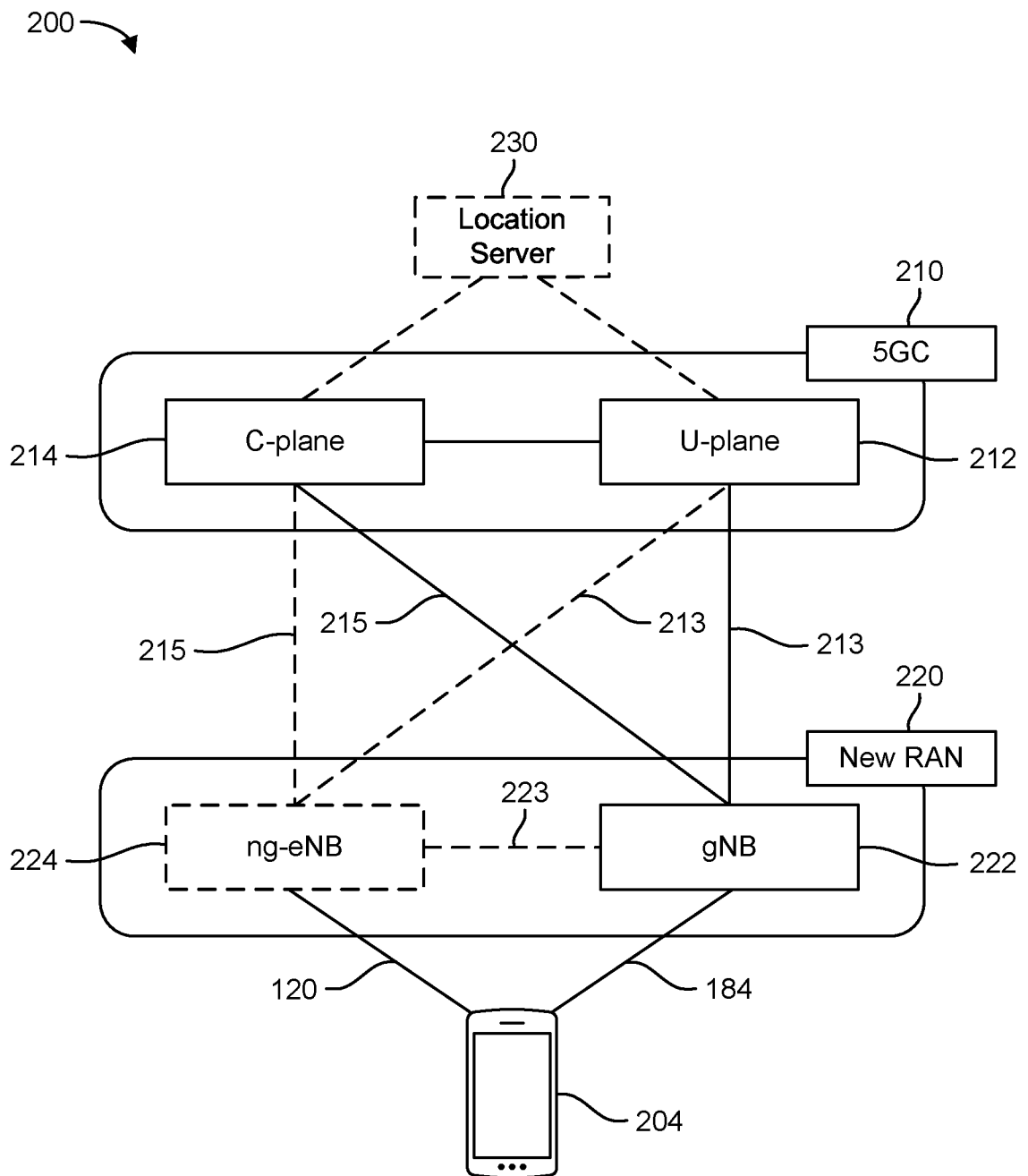


FIG. 2A

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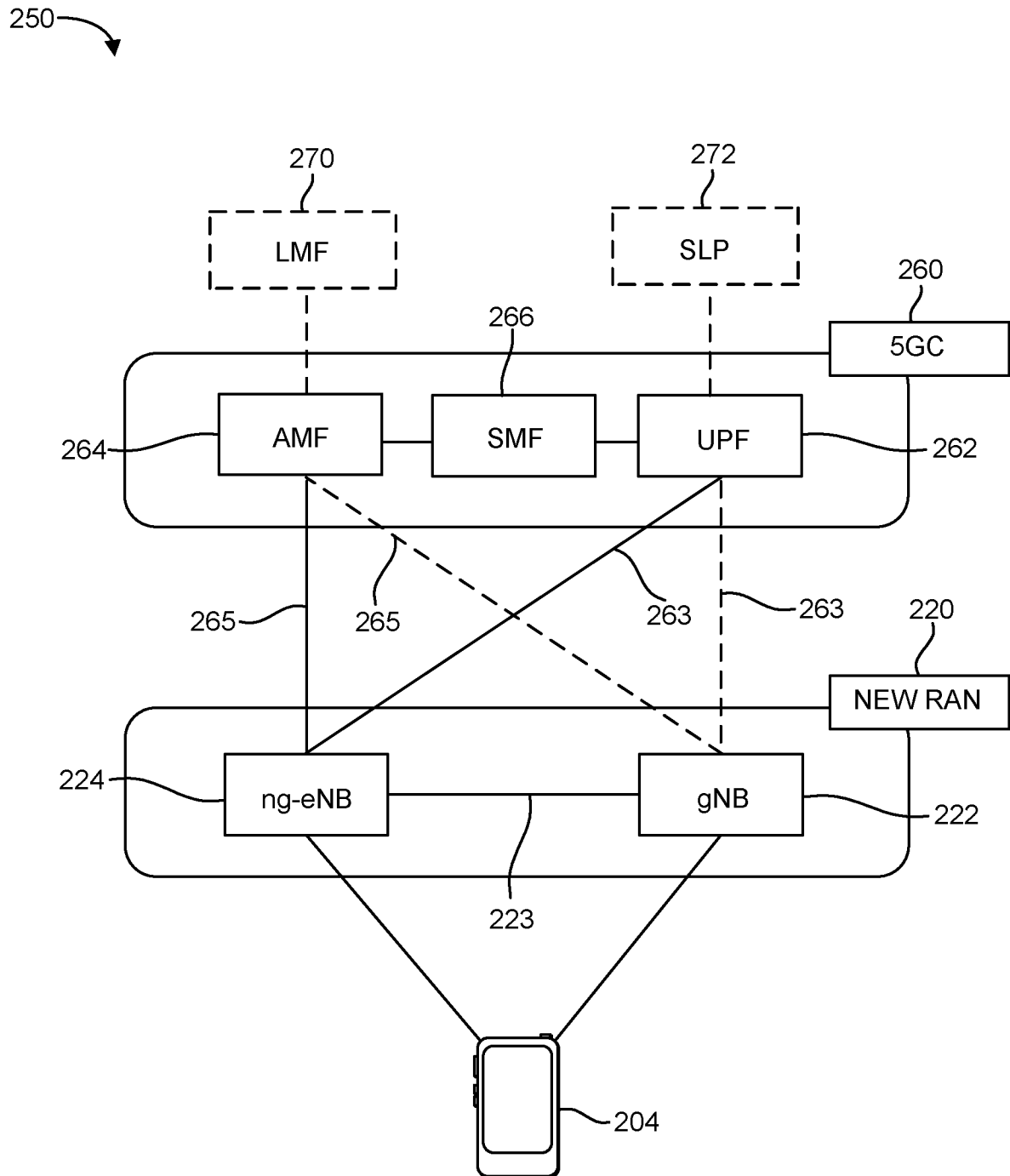


FIG. 2B

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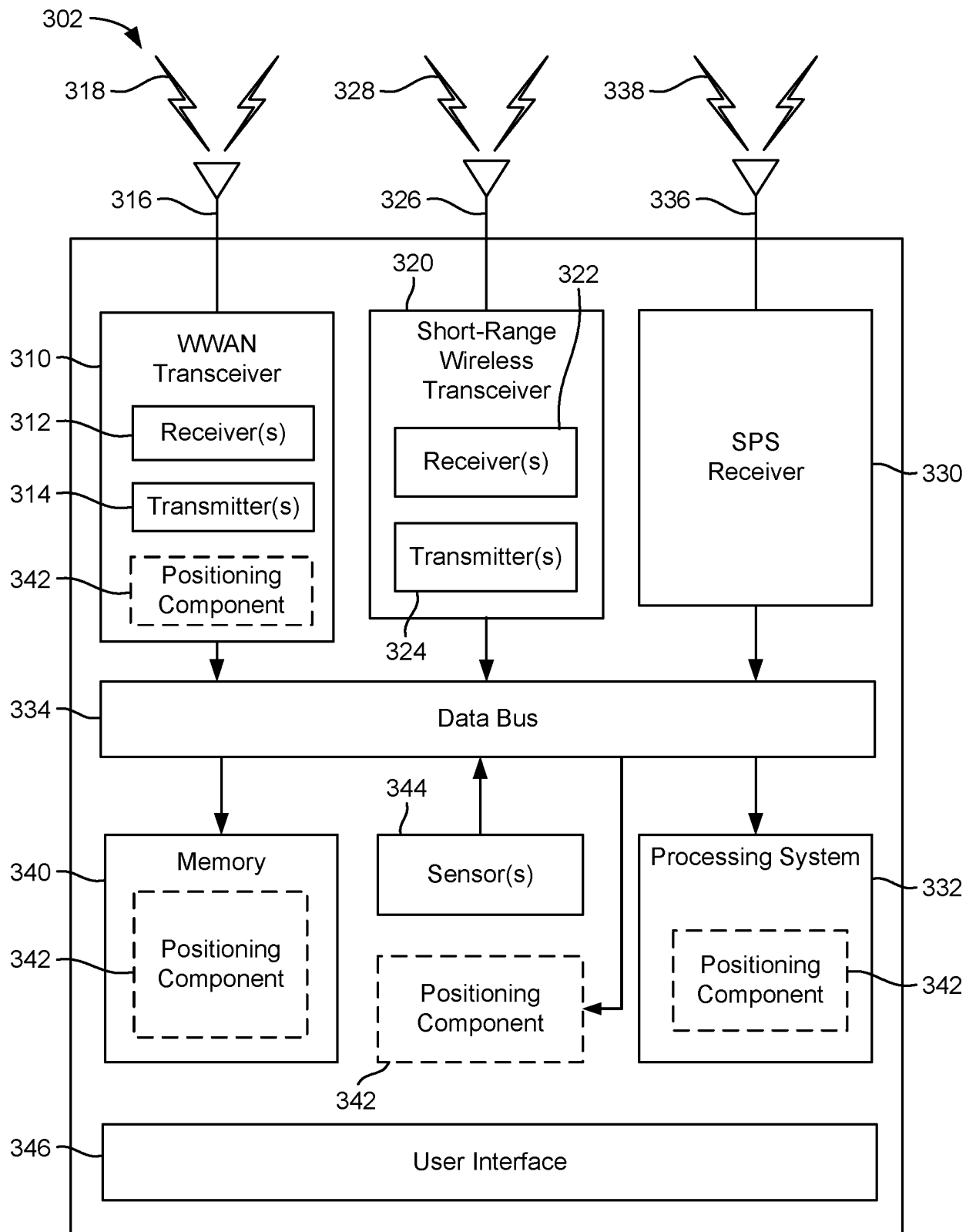


FIG. 3A

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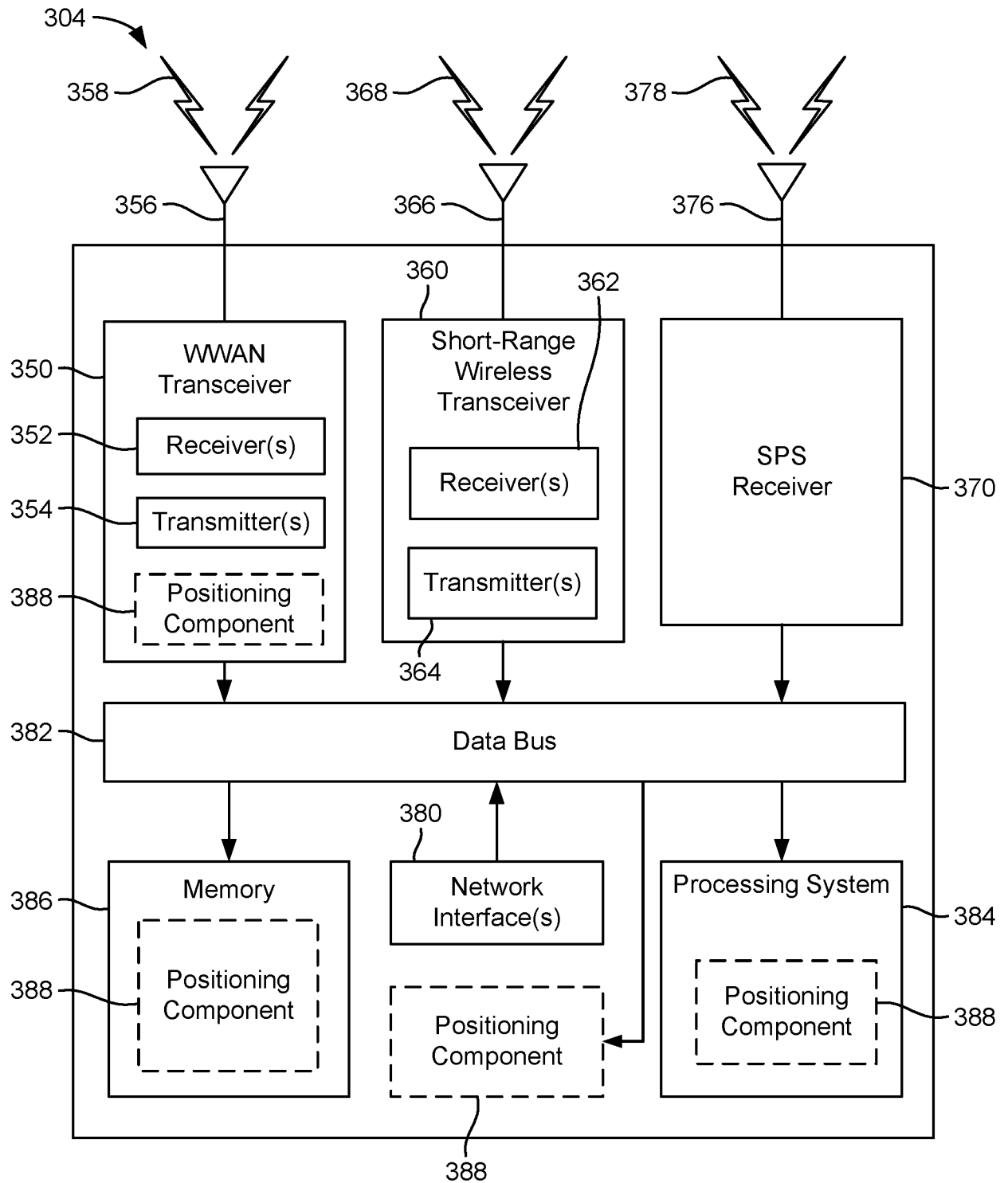


FIG. 3B

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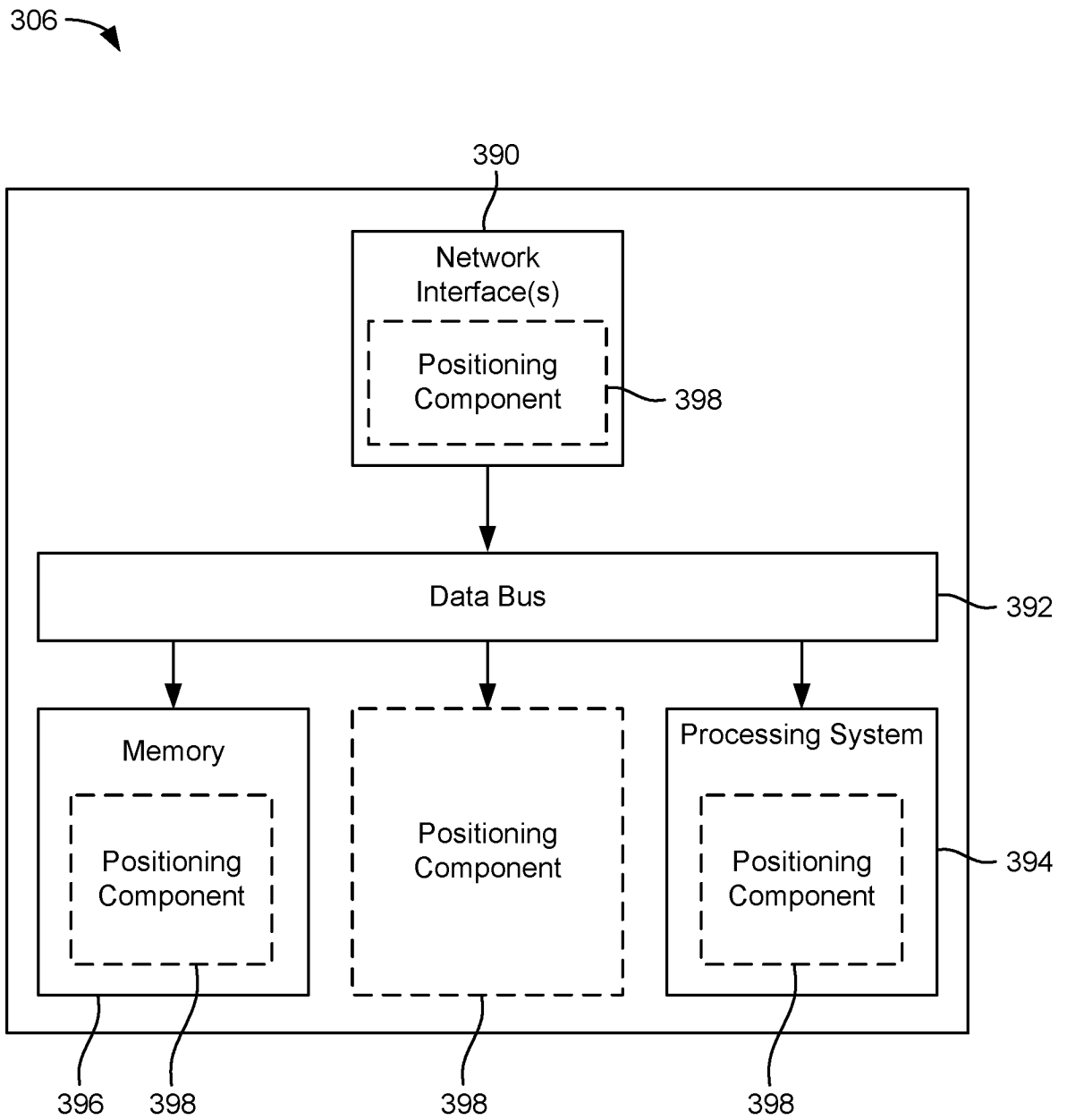


FIG. 3C

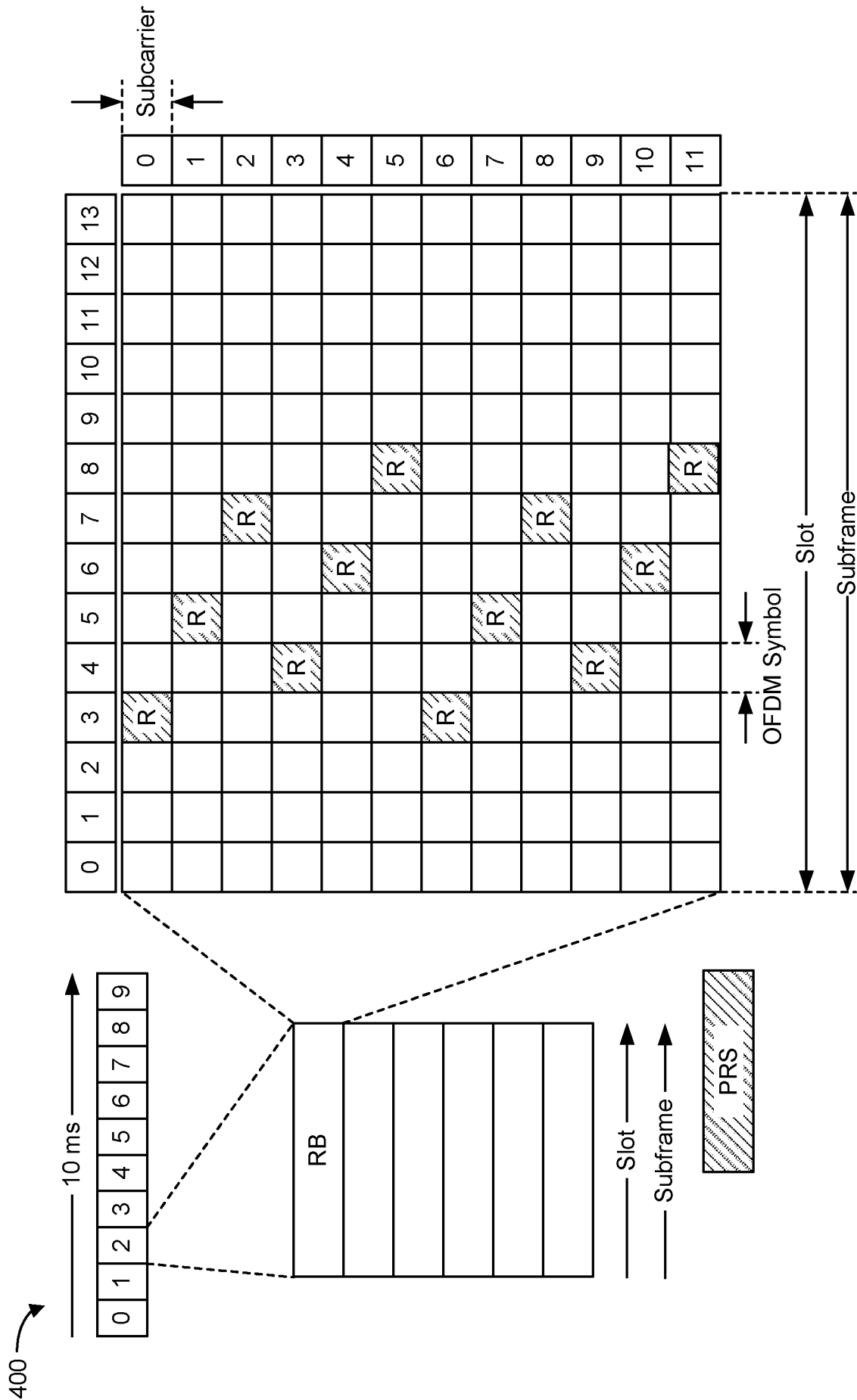


FIG. 4A

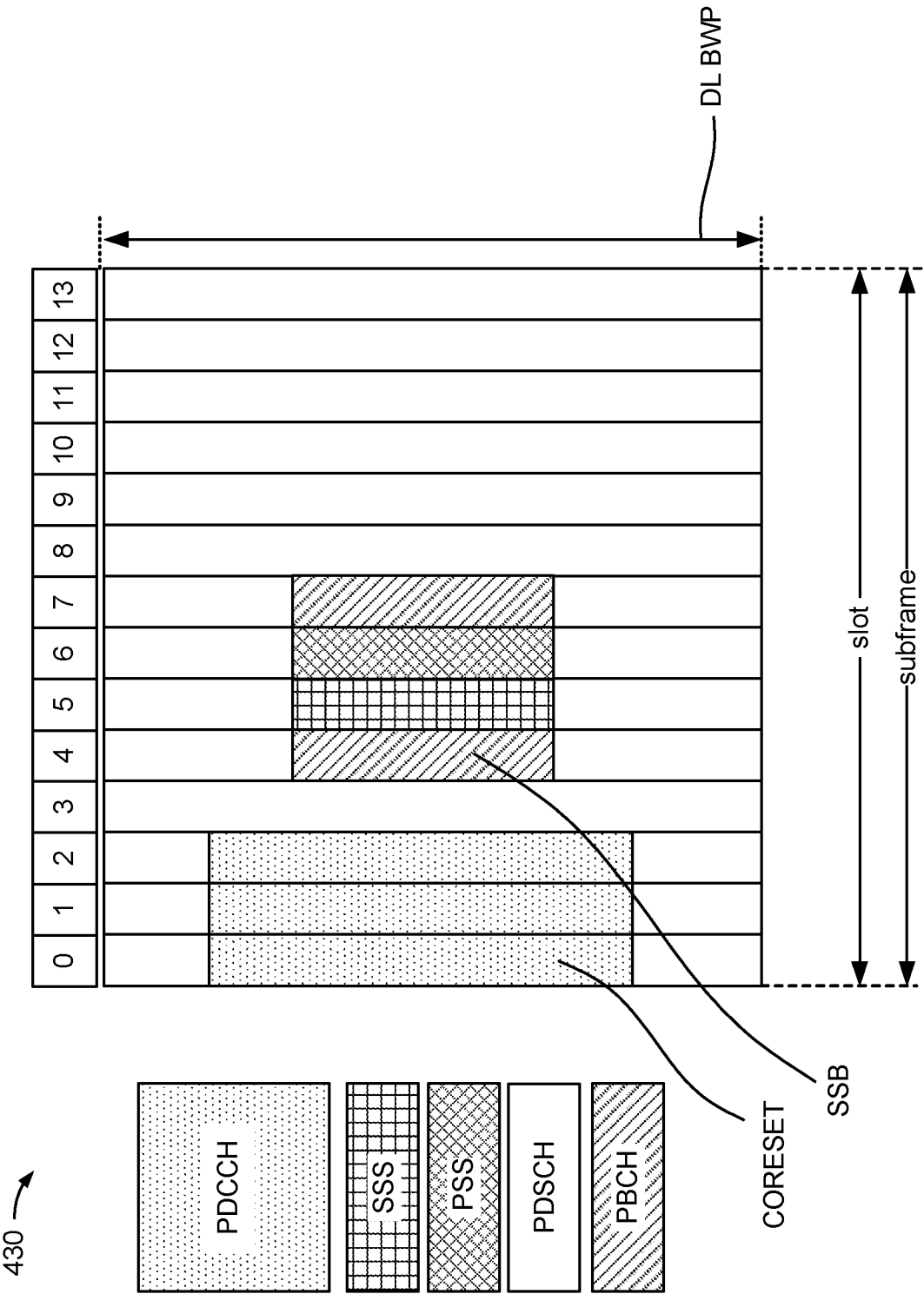


FIG. 4B

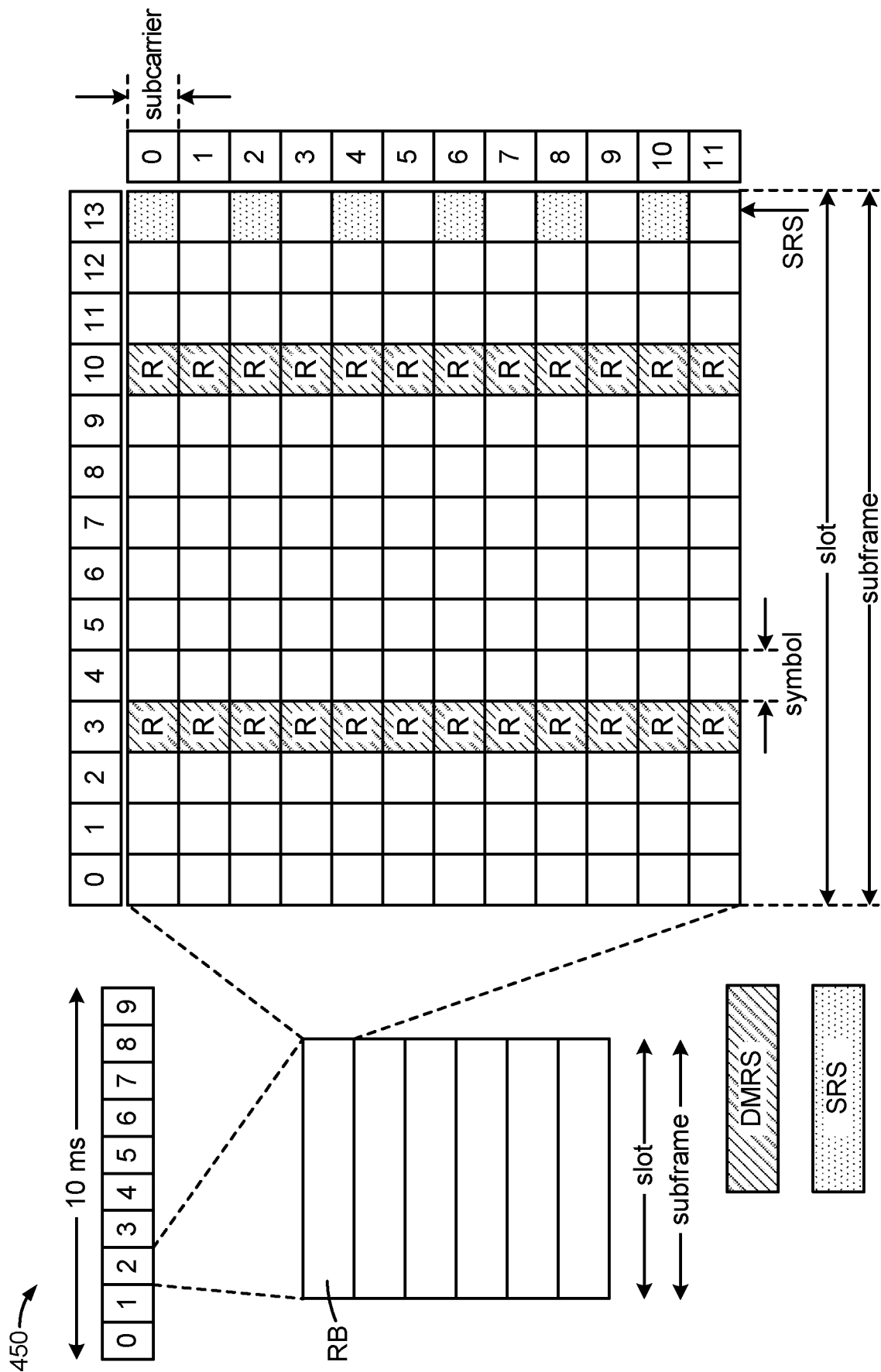


FIG. 4C

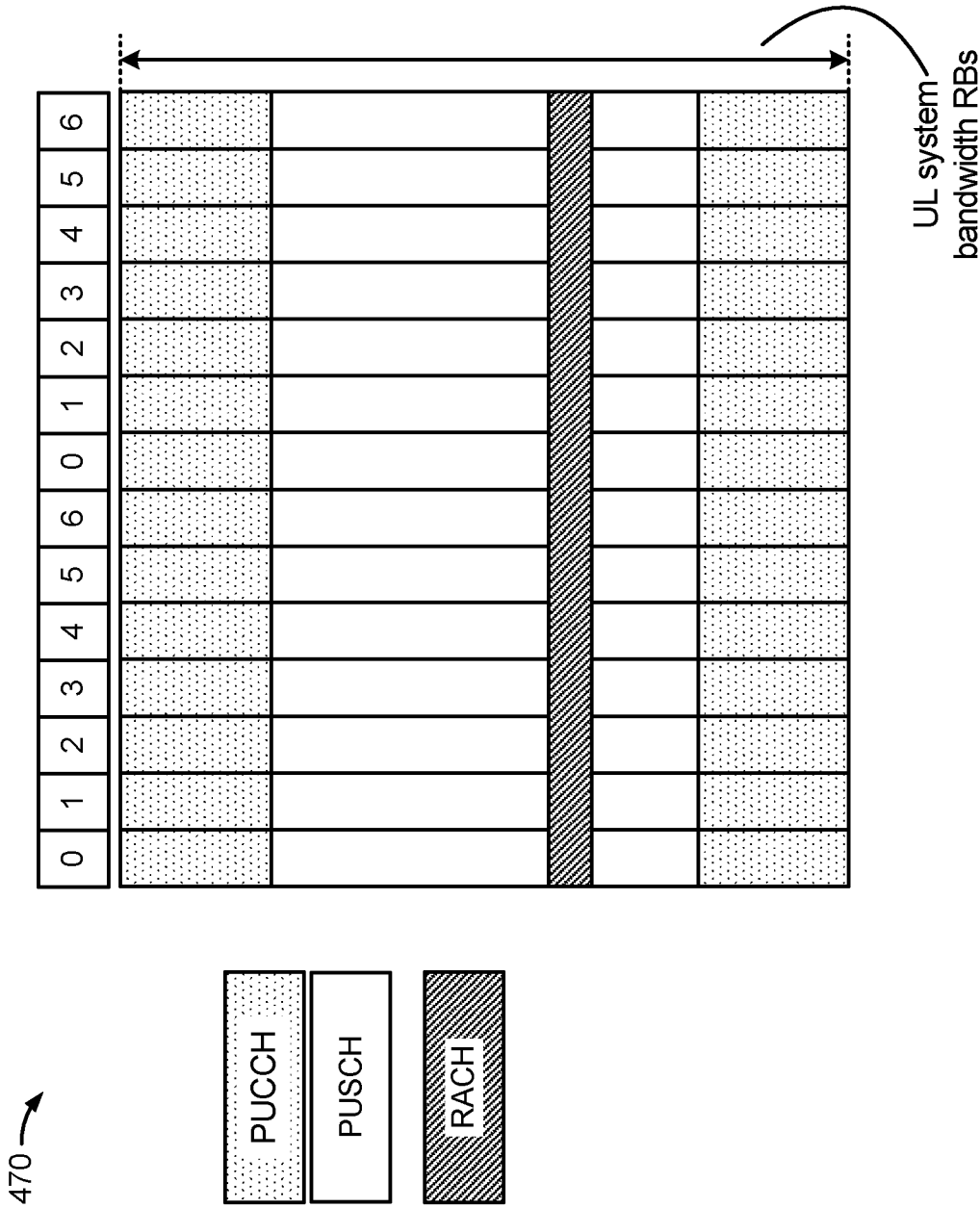


FIG. 4D

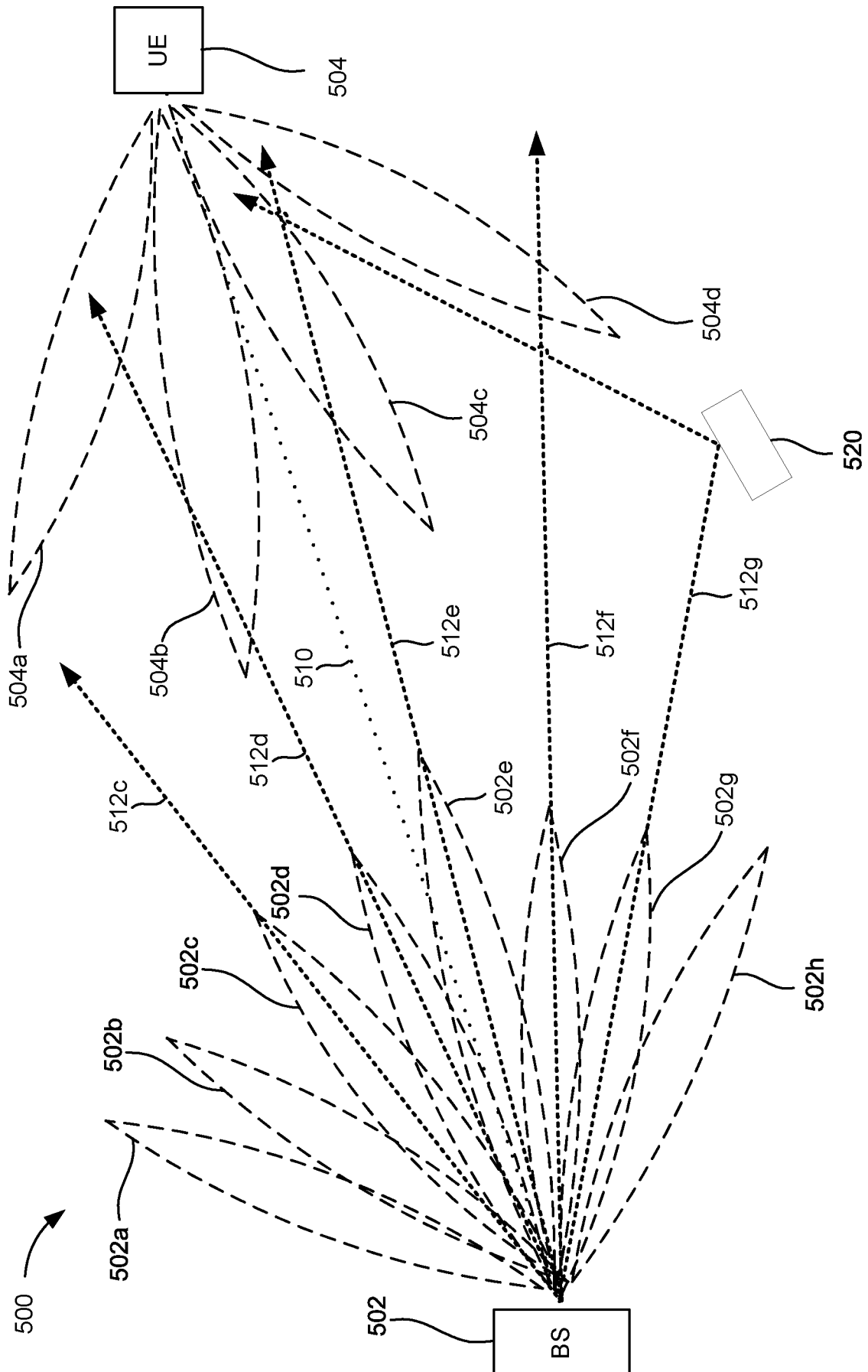


FIG. 5

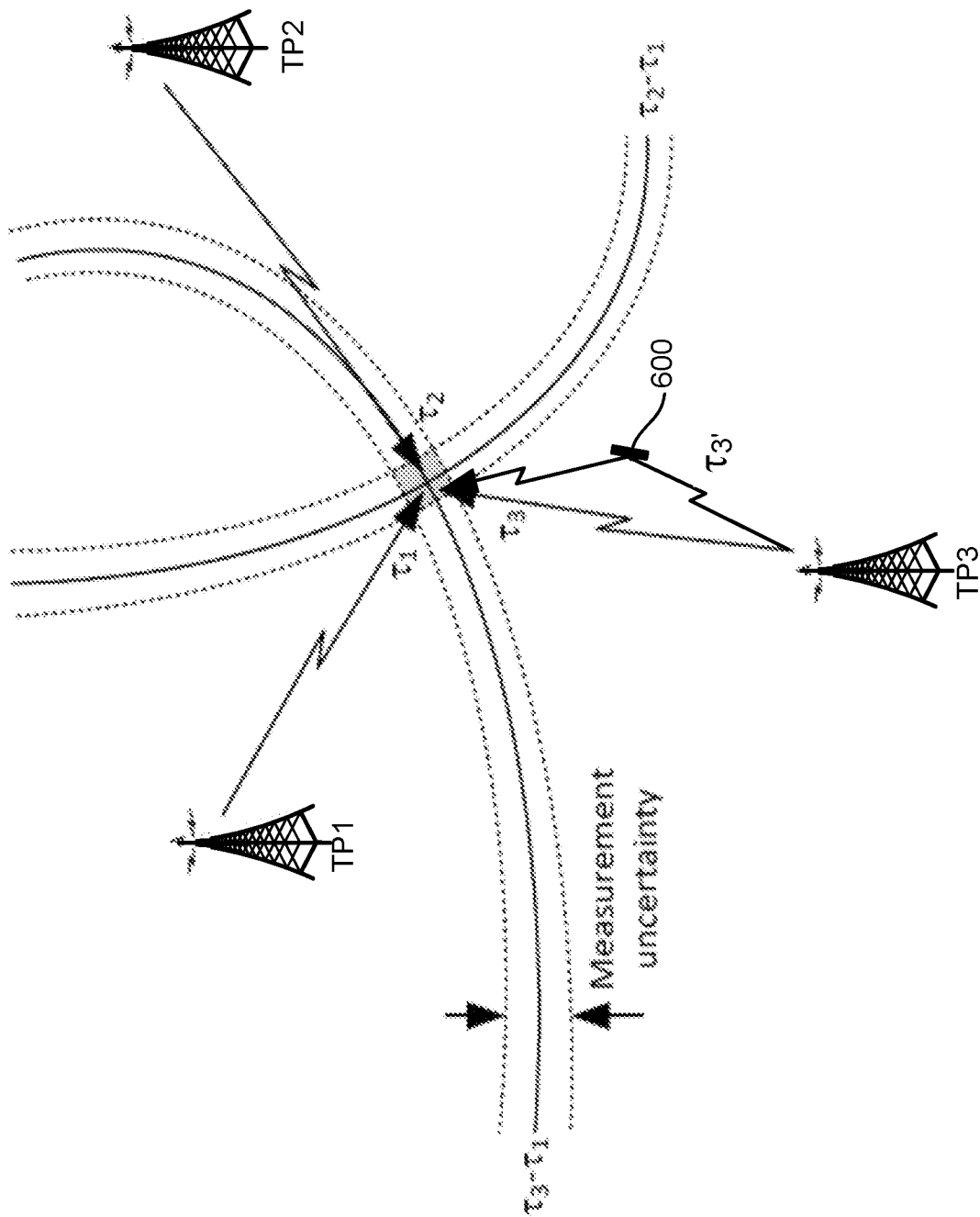


FIG. 6

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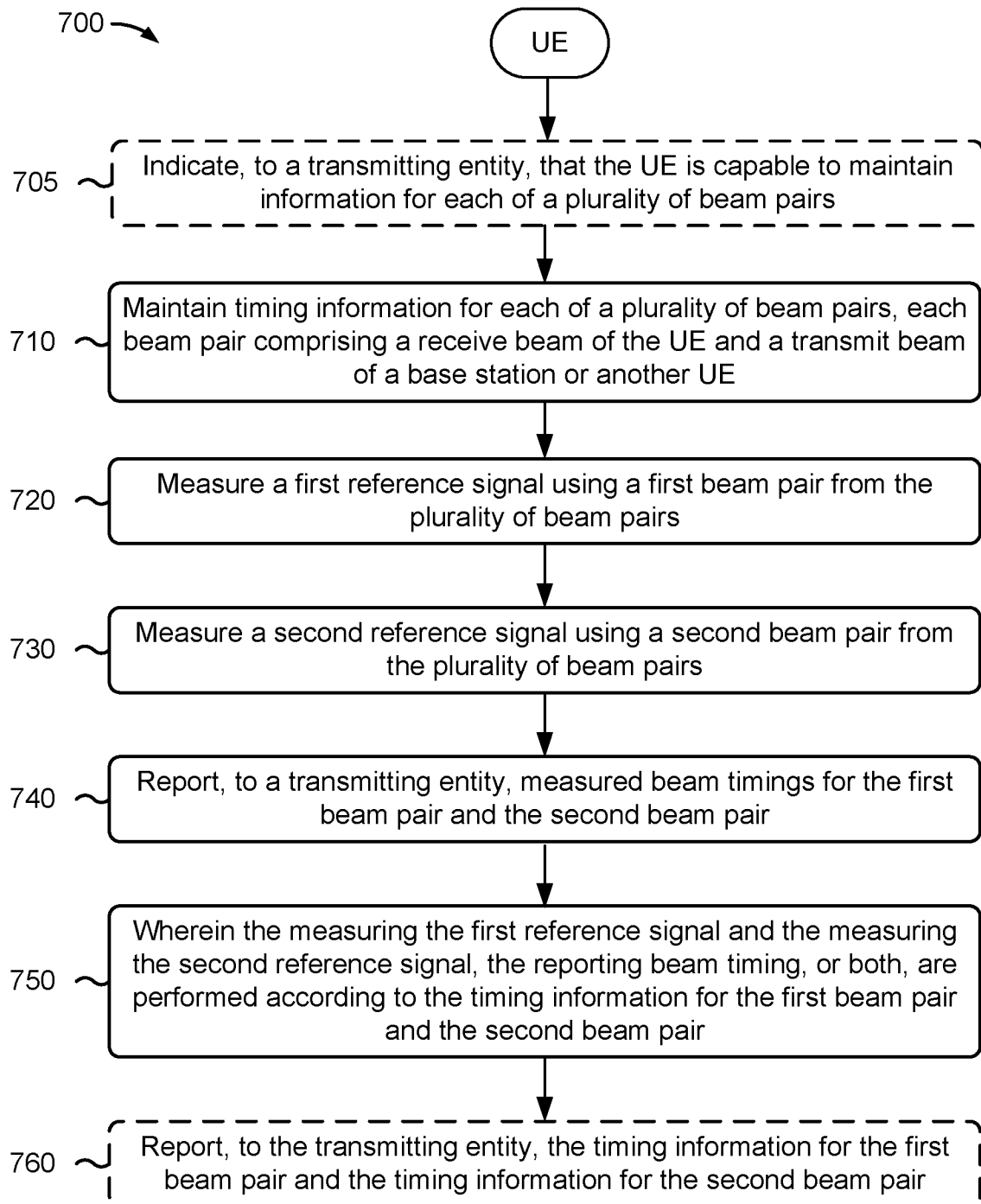


FIG. 7

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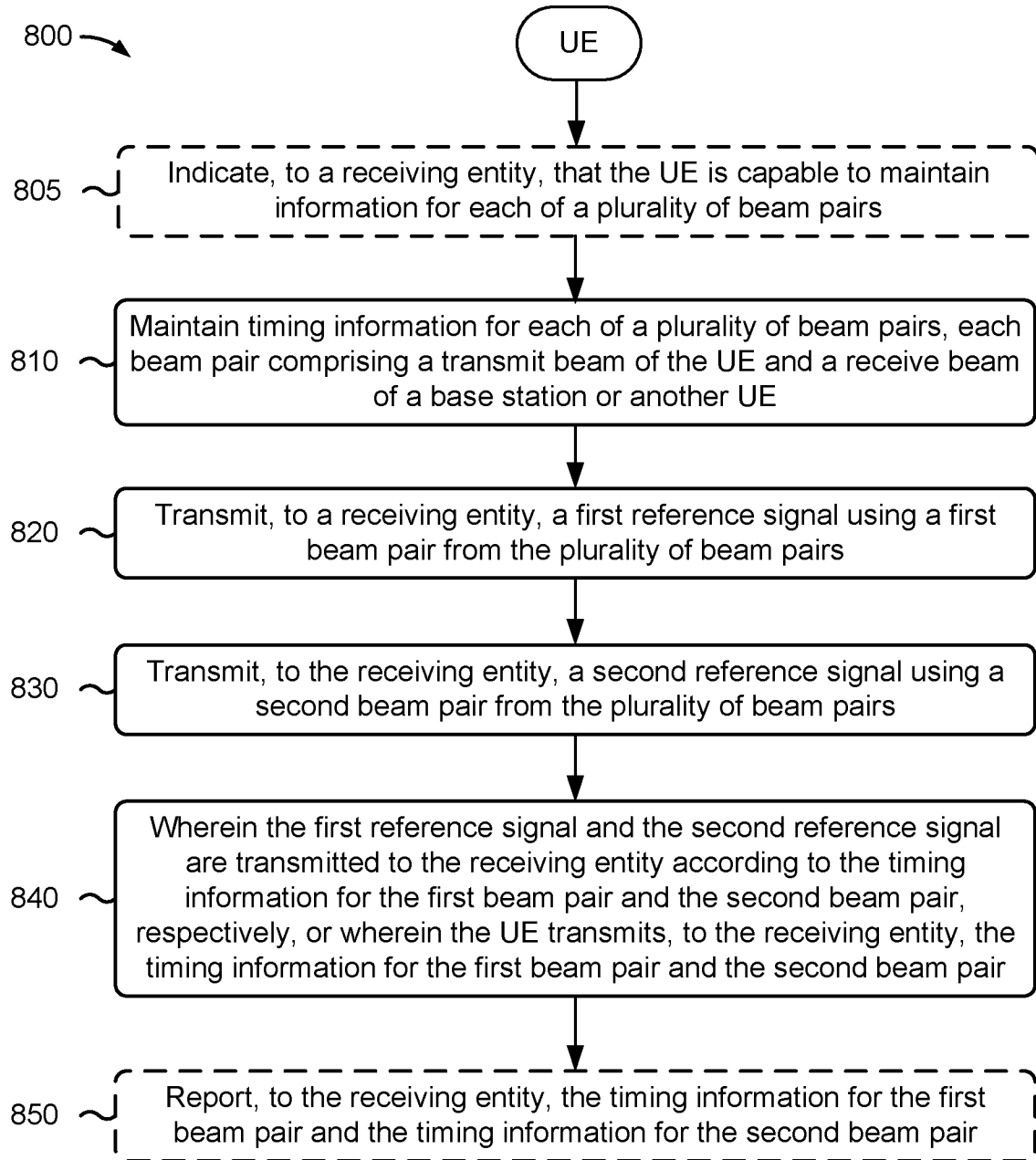


FIG. 8

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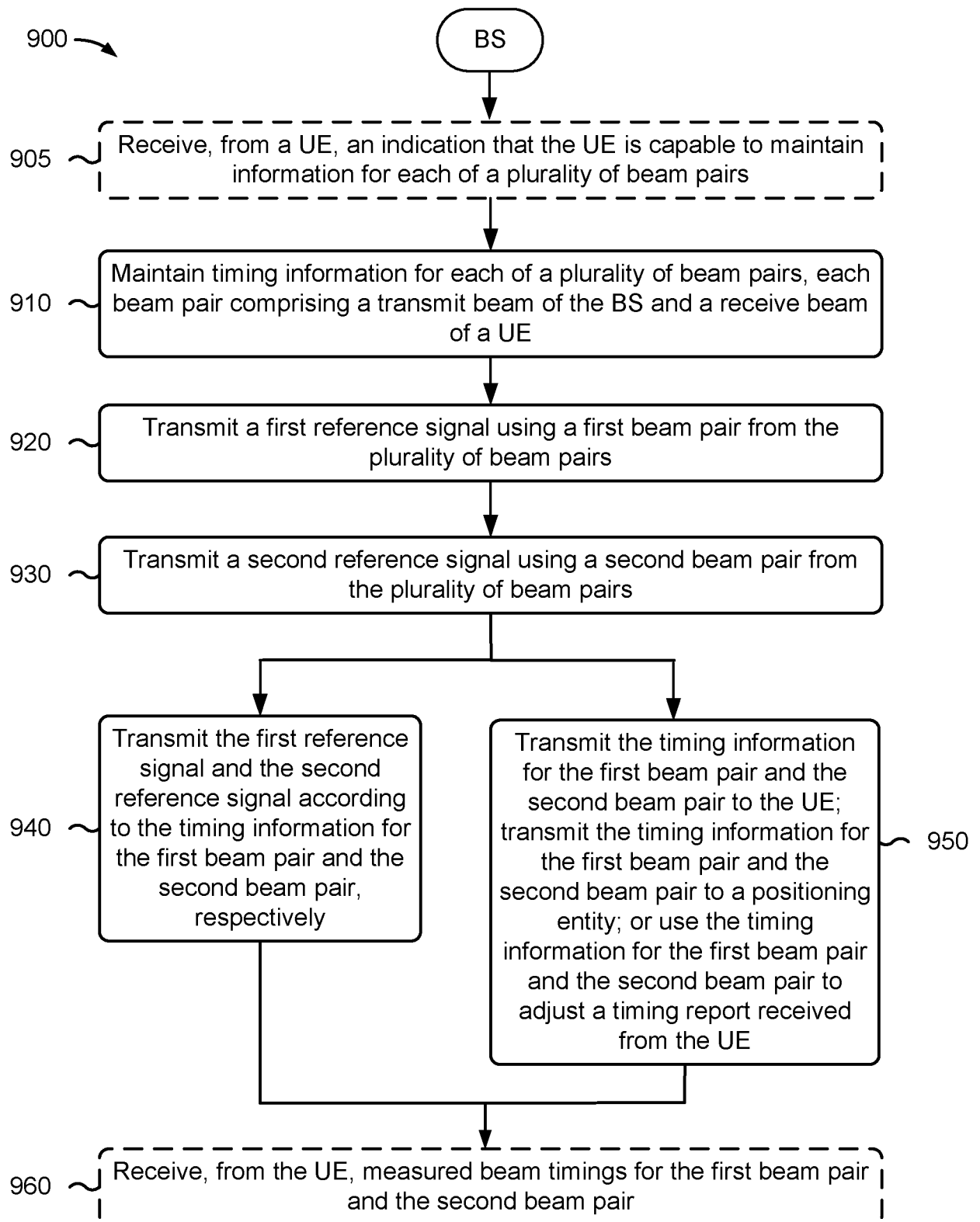


FIG. 9

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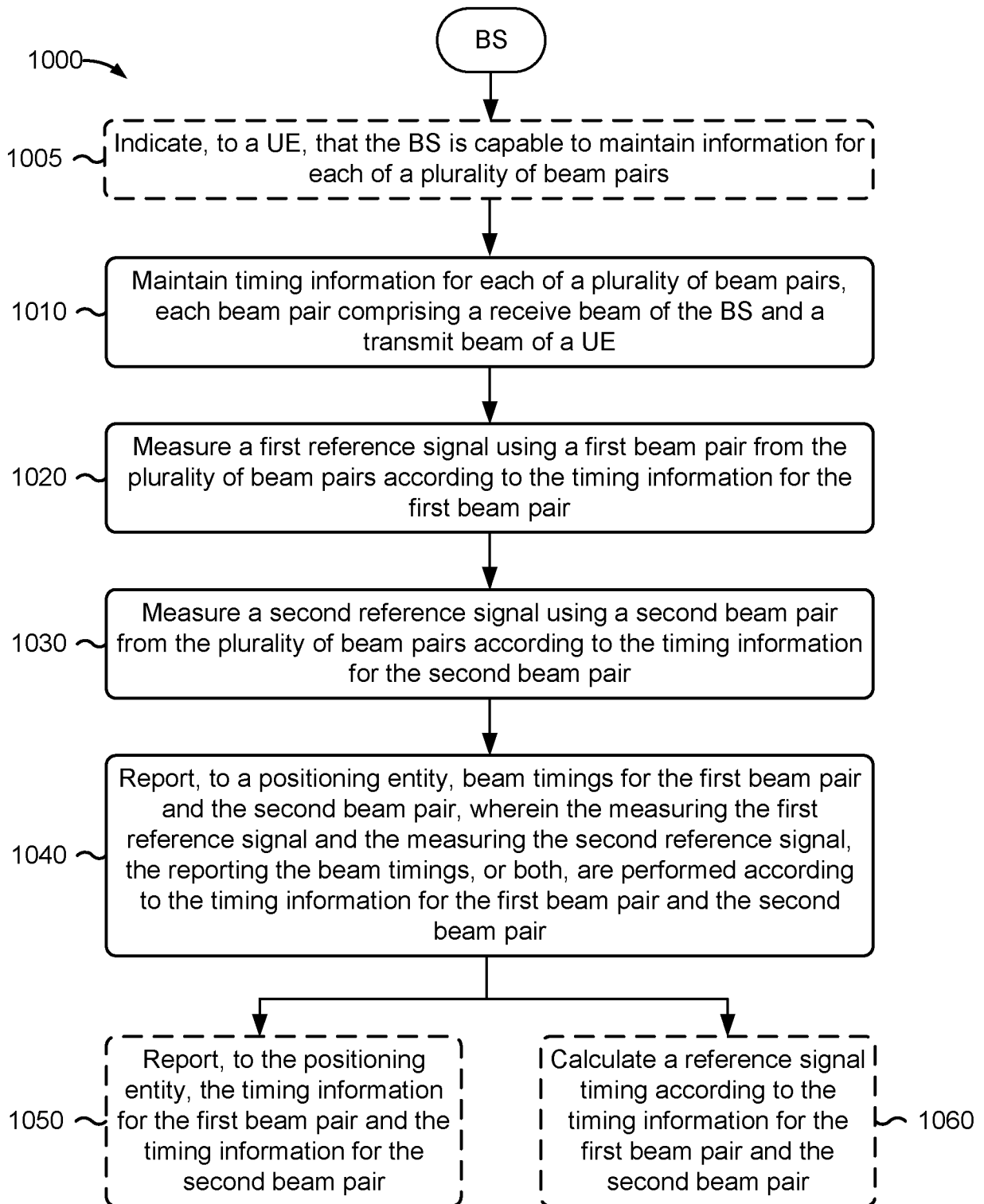


FIG. 10

# INTERNATIONAL SEARCH REPORT

International application No  
**PCT/US2022/070166**

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|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|
| <b>A. CLASSIFICATION OF SUBJECT MATTER</b><br><b>INV. H04B17/27 G01S5/10 H04W64/00</b><br><b>ADD.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                              |                                                                    |
| According to International Patent Classification (IPC) or to both national classification and IPC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                              |                                                                    |
| <b>B. FIELDS SEARCHED</b><br>Minimum documentation searched (classification system followed by classification symbols)<br><b>H04B H04W G01S</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                              |                                                                    |
| Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                              |                                                                    |
| Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)<br><br><b>EPO-Internal, WPI Data</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                              |                                                                    |
| <b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                              |                                                                    |
| Category*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                                                                           | Relevant to claim No.                                              |
| <b>X</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | <b>US 2017/374637 A1 (AKKARAKARAN SONY [US] ET AL) 28 December 2017 (2017-12-28)</b>                                                                                                                                                                                                                         | <b>1-3, 6, 7, 9-11, 14-16, 19-21, 24, 25, 27-29, 32, 33, 35-43</b> |
| <b>A</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | <b>abstract</b><br><b>paragraph [0026] - paragraph [0029]</b><br><b>paragraph [0109]</b><br><b>paragraph [0116]</b><br><b>paragraph [0137] - paragraph [0142]</b><br><b>paragraph [0155]</b><br><div style="text-align: center; margin-top: 10px;">             -----<br/>             -/--           </div> | <b>4, 5, 8, 12, 13, 17, 18, 22, 23, 26, 30, 31, 34</b>             |
| <div style="display: flex; justify-content: space-between;"> <div> <input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C.         </div> <div> <input checked="" type="checkbox"/> See patent family annex.         </div> </div>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                              |                                                                    |
| <div style="display: flex;"> <div style="flex: 1;"> <p>* Special categories of cited documents :</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="flex: 1;"> <p>"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</p> <p>"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</p> <p>"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</p> <p>"&amp;" document member of the same patent family</p> </div> </div> |                                                                                                                                                                                                                                                                                                              |                                                                    |
| Date of the actual completion of the international search                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Date of mailing of the international search report                                                                                                                                                                                                                                                           |                                                                    |
| <b>13 April 2022</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <b>29/04/2022</b>                                                                                                                                                                                                                                                                                            |                                                                    |
| Name and mailing address of the ISA/<br>European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Authorized officer<br><br><b>López Márquez, T</b>                                                                                                                                                                                                                                                            |                                                                    |

## INTERNATIONAL SEARCH REPORT

International application No

PCT/US2022/070166

| C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                                                                                                                              |                                                                                                                                          |
|------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| Category*                                            | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                           | Relevant to claim No.                                                                                                                    |
| <b>X</b>                                             | <b>WO 2019/226655 A1 (QUALCOMM INC [US])</b><br><b>28 November 2019 (2019-11-28)</b>                                                                                                         | <b>1, 9, 14,</b><br><b>19, 27,</b><br><b>35, 38, 41</b>                                                                                  |
| <b>A</b>                                             | <b>abstract</b><br><b>paragraph [0011] - paragraph [0018]</b><br><b>paragraph [0089] - paragraph [0096]</b>                                                                                  | <b>2-8,</b><br><b>10-13,</b><br><b>15-18,</b><br><b>20-26,</b><br><b>28-34,</b><br><b>36, 37,</b><br><b>39, 40,</b><br><b>42, 43</b>     |
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| <b>X,P</b>                                           | <b>US 2021/410103 A1 (ZHANG XIAOXIA [US] ET</b><br><b>AL) 30 December 2021 (2021-12-30)</b>                                                                                                  | <b>1-3, 6, 7,</b><br><b>9-11,</b><br><b>14-16,</b><br><b>19-21,</b><br><b>24, 25,</b><br><b>27-29,</b><br><b>32, 33,</b><br><b>35-43</b> |
| <b>A,P</b>                                           | <b>abstract</b><br><b>paragraph [0006] - paragraph [0010]</b><br><b>paragraph [0034]</b><br><b>paragraph [0082]</b><br><b>paragraph [0090]</b><br><b>paragraph [0099] - paragraph [0110]</b> | <b>4, 5, 8,</b><br><b>12, 13,</b><br><b>17, 18,</b><br><b>22, 23,</b><br><b>26, 30,</b><br><b>31, 34</b>                                 |
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| <b>A,P</b>                                           | <b>abstract</b><br><b>paragraph [0082] - paragraph [0083]</b><br><b>paragraph [0090] - paragraph [0103]</b>                                                                                  | <b>4, 5, 8,</b><br><b>12, 13,</b><br><b>17, 18,</b><br><b>22, 23,</b><br><b>26, 30,</b><br><b>31, 34</b>                                 |
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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

International application No

**PCT/US2022/070166**

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
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