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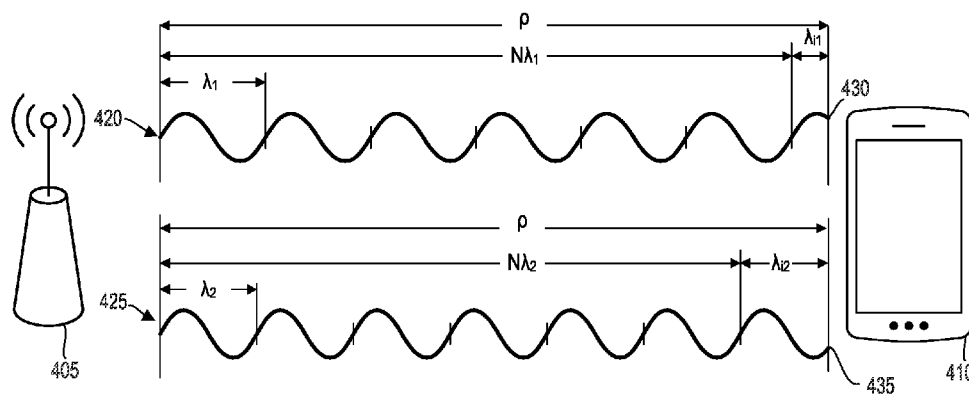


FIG. 4

(57) **Abstract:** Disclosed are systems, apparatuses, processes, and computer-readable media for wireless communications. For example, an example of a process includes receiving, at an apparatus (e.g., a user equipment (UE) or component of the UE), a plurality of resource blocks associated with a positioning reference signal (PRS). A comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks. The process includes transmitting a phase measurement report to a first network entity. The phase measurement report includes information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks. As described herein, a subcarrier set includes at least one subcarrier.

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REFERENCE SIGNALS FOR ENHANCED CARRIER PHASE MEASUREMENTS

FIELD

[0001] The present disclosure generally relates to carrier phase positioning. For example, aspects of the present disclosure relate to reference signals for enhanced carrier phase measurements for carrier phase positioning.

BACKGROUND

[0002] 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 networks), a third-generation (3G) high speed data, Internet-capable wireless service, and a fourth-generation (4G) service (e.g., Long-Term Evolution (LTE), 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 communication (GSM), etc.

[0003] A fifth generation (5G) mobile standard calls for higher data transfer speeds, greater numbers of connections, and better coverage, among other improvements. The 5G standard (also referred to as “New Radio” or “NR”), 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, for example, a gigabit connection speeds to tens of users in a common location, such as 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/LTE standard. Furthermore, signaling efficiencies should be enhanced and latency should be substantially reduced compared to current standards.

SUMMARY

[0004] Systems and techniques are described herein that provide reference signals for enhanced carrier phase measurements for carrier phase positioning with wireless communication systems. In one illustrative example, a process for wireless communications at a user equipment (UE) is provided. The process includes: receiving, at the UE, a plurality of resource blocks associated with a positioning reference signal (PRS), wherein a comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks; and transmitting a phase measurement report to a first network entity, the phase measurement report including information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks, wherein a subcarrier set includes at least one subcarrier.

[0005] In another example, an apparatus (e.g., a UE or a component of the UE) for wireless communications is provided that includes a memory (e.g., configured to store data, such as virtual content data, one or more images, etc.) and one or more processors (e.g., implemented in circuitry) coupled to the memory. The one or more processors are configured to and can: receive, at the UE, a plurality of resource blocks associated with a positioning reference signal (PRS), wherein a comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks; and transmit a phase measurement report to a first network entity, the phase measurement report including information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks, wherein a subcarrier set includes at least one subcarrier.

[0006] In another example, a non-transitory computer-readable medium of a UE is provided that has stored thereon instructions that, when executed by one or more processors, cause the one or more processors to: receive, at the UE, a plurality of resource blocks associated with a positioning reference signal (PRS), wherein a comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks; transmit a phase measurement report to a first network entity, the phase measurement report including information associated

with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks, wherein a subcarrier set includes at least one subcarrier.

[0007] In another example, an apparatus (e.g., a UE or a component of the UE) for wireless communications is provided. The apparatus includes: means for receiving a plurality of resource blocks associated with a positioning reference signal (PRS), wherein a comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks; and means for transmitting a phase measurement report to a first network entity, the phase measurement report including information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks, wherein a subcarrier set includes at least one subcarrier.

[0008] According to another example, a process is provided for wireless communications at a first network entity. The process includes: transmitting, to a second network entity, a message including a configuration for a plurality of resource blocks associated with a positioning reference signal (PRS), wherein, based on the configuration, a comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks; and receiving, from a user equipment (UE), a phase measurement report, the phase measurement report including information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks.

[0009] In another example, an apparatus (e.g., a first network entity or a component of the first network entity) for wireless communications is provided that includes a memory (e.g., configured to store data, such as virtual content data, one or more images, etc.) and one or more processors (e.g., implemented in circuitry) coupled to the memory. The one or more processors are configured to and can: transmit, to a second network entity, a message including a configuration for a plurality of resource blocks associated with a positioning reference signal (PRS), wherein, based on the configuration, a comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks; receive, from a user equipment (UE), a phase measurement report, the phase measurement report including information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks.

[0010] In another example, a non-transitory computer-readable medium of a first network entity is provided that has stored thereon instructions that, when executed by one or more processors, cause the one or more processors to: transmit, to a second network entity, a message including a configuration for a plurality of resource blocks associated with a positioning reference signal (PRS), wherein, based on the configuration, a comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks; receive, from a user equipment (UE), a phase measurement report, the phase measurement report including information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks.

[0011] In another example, an apparatus (e.g., a first network entity or a component of the first network entity) for wireless communications is provided. The apparatus includes: means for transmitting, to a second network entity, a message including a configuration for a plurality of resource blocks associated with a positioning reference signal (PRS), wherein, based on the configuration, a comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks; and means for receiving, from a user equipment (UE), a phase measurement report, the phase measurement report including information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks.

[0012] In some aspects, the apparatus is, is part of, and/or includes a wearable device, an extended reality device (e.g., a virtual reality (VR) device, an augmented reality (AR) device, or a mixed reality (MR) device), a head-mounted display (HMD) device, a wireless communication device, a mobile device (e.g., a mobile telephone and/or mobile handset and/or so-called “smart phone” or other mobile device), a camera, a personal computer, a laptop computer, a server computer, a vehicle or a computing device or component of a vehicle, another device, or a combination thereof. In some aspects, the apparatus includes a camera or multiple cameras for capturing one or more images. In some aspects, the apparatus further includes a display for displaying one or more images, notifications, and/or other displayable data. In some aspects, the apparatuses described above can include one or more sensors (e.g., one or more inertial measurement units (IMUs), such as one or more gyroscopes, one or more gyrometers, one or more accelerometers, any combination thereof, and/or other sensor).

[0013] This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used in isolation to determine the scope of the claimed subject matter. The subject matter should be understood by reference to appropriate portions of the entire specification of this patent, any or all drawings, and each claim.

[0014] The foregoing, together with other features and aspects, will become more apparent upon referring to the following specification, claims, and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] Illustrative aspects of the present application are described in detail below with reference to the following figures:

[0016] FIG. 1 is a diagram illustrating an example wireless communications system, in accordance with some aspects of the present disclosure.

[0017] FIGS. 2A and 2B are diagrams illustrating example wireless network structures, in accordance with some aspects of the present disclosure.

[0018] FIG. 3 is a diagram of a user equipment (UE) in a wireless communication system that determines a location based on distances from terrestrial transmitting devices, according to some aspects of the present disclosure.

[0019] FIG. 4 is an illustration of a phase measurement to determine a distance between a transmitting device and a receiving device based on a phase measurement combination, according to some aspects of the present disclosure.

[0020] FIG. 5 is a graph that illustrates the equivalent wavelengths of subcarrier pairs based on subcarrier spacing of an orthogonal frequency division multiplexing (OFDM) system, according to some aspects of the present disclosure.

[0021] FIG. 6 is a diagram illustrating an example of a resource block.

[0022] FIG. 7 is a diagram illustrating examples of existing comb structures for reference signals.

[0023] FIG. 8A is a diagram illustrating an example of a group of resource blocks with a regular resource element structure (having a 1-resource block boundary), according to some aspects of the present disclosure.

[0024] FIG. 8B and FIG. 8C are diagrams illustrative examples of resource blocks with irregular resource element structures (having an X-resource block boundary), according to some aspects of the present disclosure.

[0025] FIG. 9A illustrates an example of a resource block with eight consecutive symbols for four subcarriers, according to some aspects of the present disclosure.

[0026] FIG. 9B illustrates an example of a resource block with twelve consecutive symbols for three subcarriers, according to some aspects of the present disclosure.

[0027] FIG. 10A is a diagram illustrating an example of a resource block with resource elements assigned to four reference signal resources from four sources, according to some aspects of the present disclosure.

[0028] FIG. 10B illustrates an example of combining resource elements of the four reference signal resources of FIG. 10A, according to some aspects of the present disclosure.

[0029] FIG. 10C is a diagram illustrating an example of frequency domain muting on the combined reference signal resources of FIG. 10B, according to some aspects of the present disclosure.

[0030] FIG. 11 is a flow chart illustrating an example of a process for wireless communications, according to some aspects of the present disclosure.

[0031] FIG. 12 is a flow chart illustrating another example of a process for wireless communications, according to some aspects of the present disclosure.

[0032] FIG. 13 illustrates an example block diagram of a computing system of a UE, in accordance with some aspects of the present disclosure.

[0033] FIG. 14 illustrates an example computing system, according to aspects of the disclosure.

DETAILED DESCRIPTION

[0034] Certain aspects of this disclosure are provided below. Some of these aspects may be applied independently and some of them may be applied in combination as would be apparent to those of skill in the art. In the following description, for the purposes of explanation, specific details are set forth in order to provide a thorough understanding of aspects of the application. However, it will be apparent that various aspects may be practiced without these specific details. The figures and description are not intended to be restrictive.

[0035] The ensuing description provides example aspects only and is not intended to limit the scope, applicability, or configuration of the disclosure. Rather, the ensuing description of the example aspects will provide those skilled in the art with an enabling description for implementing an example aspect. It should be understood that various changes may be made in the function and arrangement of elements without departing from the spirit and scope of the application as set forth in the appended claims.

[0036] The ensuing description provides example aspects only, and is not intended to limit the scope, applicability, or configuration of the disclosure. Rather, the ensuing description of the exemplary aspects will provide those skilled in the art with an enabling description for implementing an aspect of the disclosure. It should be understood that various changes may be made in the function and arrangement of elements without departing from the spirit and scope of the application as set forth in the appended claims.

[0037] The terms “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.

[0038] As noted above, 5G mobile standard calls for higher data transfer speeds, greater numbers of connections, and better coverage, among other improvements. 5G is expected to

support several hundreds of thousands of simultaneous connections. Consequently, there is room to improve the spectral efficiency of 5G mobile communications by enhancing signaling efficiencies and reducing latency. One aspect where such signaling efficiency and reduction in latency can be achieved is the communication of various uplink and downlink reference signals between user equipment and their respective serving base stations.

[0039] Reference signals are predefined signals occupying specific resource elements within a time–frequency grid of a resource block and may be exchanged on one or both of downlink and uplink physical communication channels. Each reference signal has been defined by the 3rd Generation Partnership Project (3GPP) for a specific purpose, such as for channel estimation, phase-noise compensation, acquiring downlink/uplink channel state information, time and frequency tracking, among others.

[0040] Example reference signals include, but are not limited to, Positioning Reference Signal (PRS), Sounding Reference Signal (SRS), Channel State Information – Reference Signal (CSI-RS), De-Modulation Reference Signal (DMRS), among others. Some reference signals (e.g., PRS, CSI-RS, etc.) are downlink specific signals, while others such as DMRS are sent both on downlink and uplink communication channels. There are also uplink specific reference signals defined by the 3GPP.

[0041] Combination (comb) structures (also referred to as tone patterns) can be defined as specific arrangements of resource elements in a given resource block for transmission of a reference signal. Comb structures are currently pre-defined in the 3GPP communication standards (e.g., 5G/NR, 4G/LTE, etc.) and may be known to both the user equipment (UE) and corresponding network entity (e.g., base station or portion thereof). Currently-defined comb structures may not be optimized for all environments. For instance, the arrangement or combination of resource elements used for transmission of a PRS are defined for all of the PRS resource sets defined in a given positioning frequency layer (PFL). Existing comb structures provide symmetrical allocation of resource elements in the frequency domain. For example, for a comb2 structure, every alternate symbol of a resource block is given to the PRS resources. Existing comb structures also specify a regular (or consistent) arrangement of resource elements across all resource blocks. For instance, existing comb structures for PRSs have a

single resource block boundary, in which case all of the resource blocks for a PRS will have the same resource elements assigned to the PRS resources. Further, existing comb structures do not specify that consecutive symbols in a resource block can be assigned to a PRS resource. A regular comb structure with a single resource block boundary and/or non-consecutive symbols (per resource) may not be optimal for certain operations, such as for performing carrier phase positioning. Symmetrical allocation of resource elements in the frequency domain also may not be desirable for carrier phase positioning.

[0042] Systems, apparatuses, processes (also referred to as methods), and computer-readable media (collectively referred to herein as systems and techniques) are described herein for providing reference signals that can be more suitable for certain operations. For instance, comb structures (or tone patterns) and techniques for generating and supporting (e.g., through signaling) such comb structures are described herein that provide enhanced carrier phase measurements for carrier phase positioning.

[0043] In some aspects, resource blocks are defined with an irregular resource element structure. For instance, an X-resource block boundary (where X is an integer value greater than 1) is defined for resources of a reference signal, such as a PRS, SRS, or other reference signal that can be used for positioning. According to the X-resource block boundary, the comb structure for the reference signal (which specifies the arrangement of resource elements with resource blocks of the reference signal) is repeated a certain number of times every X-resource blocks. For instance, the X-resource block boundary can be a 4-resource block boundary, where the comb structure for the reference signal is repeated a certain number of times (e.g., one time, two times, or three times) every four resource blocks. For any resource block between resource blocks for which the comb pattern specifies resource elements for the reference signal, no resource elements will be assigned to the reference signal. Such an irregular resource element structure for position-based reference signals (e.g., PRSs, SRSs, etc.) can be useful for carrier phase positioning techniques, as compared to the regular resource element structures provided in existing comb structures.

[0044] In some additional or alternative aspects, resource blocks are defined that are non-uniform in the frequency domain and/or are continuous in the time domain. For example, a

consecutive number of symbols can be allocated to a resource or to multiple resources of a reference signal (e.g., PRS resources). Providing resource blocks with consecutive symbols assigned to a PRS allows a device (e.g., a UE) to more easily to measure phase information (for carrier phase positioning) of multiple symbols if the subcarrier index number for the multiple symbols is constant (indicating that the symbols are associated with the same frequency subcarrier). Allowing the frequency domain component (e.g., subcarriers) of the resource blocks to be non-uniform also allows a network entity (e.g., a location server such as a location management function (LMF) or a base station such as a gNodeB (gNB)) to specify to a user device (e.g., a UE) which subcarriers can be used in carrier phase positioning (e.g., for determining a phase difference between two subcarriers). In some cases, the network entity may transmit information (e.g., a bitmap) indicating particular resource elements (e.g., in the frequency domain) of the resource blocks that are assigned to the reference signal (e.g., PRS). For example, a network entity (e.g., a location server such as an LMF, a base station, etc.) can signal a bitmap (e.g., to another network entity, to a UE, etc.) that specifies the subcarriers in the resource block that are assigned to the reference signal.

[0045] In some additional or alternative aspects, the systems and techniques can combine reference signal resources (e.g., PRS resources) by combining resource elements of the reference signal resources. In some cases, the systems and techniques can perform frequency domain muting or suppression to remove certain resource elements from the combined reference signal resources.

[0046] The systems and techniques described herein can be applied to communications between a network entity (e.g., a base station, location server, etc.) and a user device (e.g., a UE) or to communications between user devices (e.g., between UEs, vehicles, etc.) using sidelink communications (e.g., a cellular based PC5 sidelink interface, 802.11p defined Dedicated Short Range Communication (DSRC) interface, or other direct interface).

[0047] The systems and techniques described herein can improve user device (e.g., UE) location estimates or positioning based on the enhanced reference signals described herein. For instance, as noted above, the comb structures described herein can provide enhanced carrier phase measurements for carrier phase positioning. As used herein, a location estimate may be

referred to by other names, such as a position estimate, location, location measurement, position, position fix, fix, or the like. A location estimate may be geodetic and may include coordinates (e.g., latitude, longitude, and possibly altitude) or may be civic and include a street address, postal address, or some other description of a location. A location estimate may further be defined relative to some other known location or defined in absolute terms (e.g., using latitude, longitude, and/or altitude). A location estimate may include an expected error or uncertainty (e.g., by including an area or volume within which the location is expected to be included with some specified or default level of confidence).

[0048] Additional aspects of the present disclosure are described in more detail below.

[0049] As used herein, the terms “user equipment” (UE) and “network entity” 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, and/or tracking device, etc.), wearable (e.g., smartwatch, smart-glasses, wearable ring, and/or an extended reality (XR) device such as a virtual reality (VR) headset, an augmented reality (AR) headset or glasses, or a mixed reality (MR) headset), vehicle (e.g., automobile, motorcycle, bicycle, etc.), and/or 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 IEEE 802.11 communication standards, etc.) and so on.

[0050] A network entity can be implemented in an aggregated or monolithic base station architecture, or alternatively, in a disaggregated base station architecture, and may include one

or more of a central unit (CU), a distributed unit (DU), a radio unit (RU), a Near-Real Time (Near-RT) RAN Intelligent Controller (RIC), or a Non-Real Time (Non-RT) RIC. A base station (e.g., with an aggregated/monolithic base station architecture or disaggregated base station architecture) 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 (NB), 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 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, or a forward traffic channel, etc.). The term traffic channel (TCH), as used herein, can refer to either an uplink, reverse or downlink, and/or a forward traffic channel.

[0051] The term “network entity” or “base station” (e.g., with an aggregated/monolithic base station architecture or disaggregated base station architecture) may refer to a single physical TRP or to multiple physical TRPs that may or may not be co-located. For example, where the term “network entity” or “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 “network entity” or “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 (or simply “reference

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.

[0052] In some implementations that support positioning of UEs, a network entity or 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).

[0053] 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. As used herein, an RF signal may also be referred to as a “wireless signal” or simply a “signal” where it is clear from the context that the term “signal” refers to a wireless signal or an RF signal.

[0054] According to various aspects, FIG. 1 illustrates an exemplary wireless communications system 100. The wireless communications system 100 (which may also be referred to as a wireless wide area network (WWAN)) can include various base stations 102 and various UEs 104. In some aspects, the base stations 102 may also be referred to as “network entities” or “network nodes.” One or more of the base stations 102 can be implemented in an aggregated or monolithic base station architecture. Additionally or alternatively, one or more of the base stations 102 can be implemented in a disaggregated base station architecture, and may include one or more of a central unit (CU), a distributed unit (DU), a radio unit (RU), a Near-Real Time (Near-RT) RAN Intelligent Controller (RIC), or a Non-Real Time (Non-RT) RIC. The base stations 102 can 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 a long term evolution (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.

[0055] 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 or 5GC) over backhaul links 134, which may be wired and/or wireless.

[0056] 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 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 addition, because a TRP is typically the physical

transmission point of a cell, the terms “cell” and “TRP” may be used interchangeably. 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.

[0057] 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 base station 102' may have a coverage area 110' that substantially overlaps with the 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).

[0058] 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).

[0059] The wireless communications system 100 may further include a WLAN AP 150 in communication with WLAN stations (STAs) 152 via communication links 154 in an unlicensed frequency spectrum (e.g., 5 Gigahertz (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. In some examples, the wireless communications system 100 can include devices (e.g., UEs, etc.) that communicate with one or more UEs 104, base stations 102, APs 150, etc. utilizing the ultra-wideband (UWB) spectrum. The UWB spectrum can range from 3.1 to 10.5 GHz.

[0060] 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 and/or 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.

[0061] 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. The mmW base station 180 may be implemented in an aggregated or monolithic base station architecture, or alternatively, in a disaggregated base station architecture (e.g., including one or more of a CU, a DU, a RU, a Near-RT RIC, or a Non-RT RIC). 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 and/or 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 an 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.

[0062] Transmit beamforming is a technique for focusing an RF signal in a specific direction. Traditionally, when a network node or entity (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 canceling to suppress radiation in undesired directions.

[0063] Transmit beams may be quasi-collocated, 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 collocated. In NR, there are four types of quasi-collocation (QCL) relations. Specifically, a QCL relation of a given type means that certain parameters about a second reference RF signal on a second beam can be derived from information about a source reference RF signal on a source beam. Thus, 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 second 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 second 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 second 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 second reference RF signal transmitted on the same channel.

[0064] In receiving 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 of other 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.

[0065] 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 network node or entity (e.g., 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 network node or entity (e.g., a base station) based on the parameters of the receive beam.

[0066] 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 network node or entity (e.g., 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 network node or entity (e.g., 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.

[0067] In 5G, the frequency spectrum in which wireless network nodes or entities (e.g., base stations 102/180, UEs 104/182) operate is divided into multiple frequency ranges, FR1 (from 450 to 6000 Megahertz (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 and/or 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.

[0068] 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”). In carrier aggregation, the base stations 102 and/or the UEs 104 may use spectrum up to Y MHz (e.g., 5, 10, 15, 20, 100 MHz) bandwidth per carrier up to a total of Yx MHz (x component carriers) for transmission in each direction. The component carriers may or may not be adjacent to each other on the frequency spectrum. Allocation of carriers may be asymmetric with respect to the downlink and uplink (e.g., more or less carriers may be allocated for downlink than for uplink). 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.

[0069] In order to operate on multiple carrier frequencies, a base station 102 and/or a UE 104 is equipped with multiple receivers and/or transmitters. For example, a UE 104 may have two receivers, “Receiver 1” and “Receiver 2,” where “Receiver 1” is a multi-band receiver that can be tuned to band (i.e., carrier frequency) ‘X’ or band ‘Y,’ and “Receiver 2” is a one-band receiver tuneable to band ‘Z’ only. In this example, if the UE 104 is being served in band ‘X,’ band ‘X’ would be referred to as the PCell or the active carrier frequency, and “Receiver 1” would need to tune from band ‘X’ to band ‘Y’ (an SCell) in order to measure band ‘Y’ (and vice versa). In contrast, whether the UE 104 is being served in band ‘X’ or band ‘Y,’ because of the separate “Receiver 2,” the UE 104 can measure band ‘Z’ without interrupting the service on band ‘X’ or band ‘Y.’

[0070] 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 an 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.

[0071] 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), Wi-Fi Direct (Wi-Fi-D), Bluetooth®, and so on.

[0072] According to various aspects, 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).

[0073] 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 with a component of the core network, or alternatively may be external to the core network. In some examples, the location server 230 can be operated by a carrier or provider of the 5GC 210, a third party, an original equipment manufacturer (OEM), or other party. In some cases, multiple location servers can be provided, such as a location server for the carrier, a location server for an OEM of a particular device, and/or other location servers. In such cases, location assistance data can be received from the location server of the carrier and other assistance data can be received from the location server of the OEM.

[0074] According to various aspects, 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 network nodes or network entities (e.g., 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.

[0075] 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/or 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 access networks.

[0076] 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 and/or 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.

[0077] 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.

[0078] In some aspects, location and positioning functions can be aided by a Location Management Function (LMF) 270 that is configured for communication with the 5GC 260, e.g., 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).

[0079] In an aspect, the LMF 270 and/or the SLP 272 may be integrated with a network node or entity (e.g., base station), such as the gNB 222 and/or the ng-eNB 224. When integrated with the gNB 222 and/or the ng-eNB 224, the LMF 270 and/or the SLP 272 may be referred to as a “location management component,” or “LMC.” However, as used herein, references to the LMF 270 and the SLP 272 include both the case in which the LMF 270 and the SLP 272 are components of the core network (e.g., 5GC 260) and the case in which the LMF 270 and the SLP 272 are components of a network node or entity (e.g., base station).

[0080] As discussed herein, NR supports a number of cellular network-based positioning technologies, including downlink-based, uplink-based, and downlink-and-uplink-based positioning methods. For example, the LMF 270 can enable positioning based on location measurements computed for various positioning signal (PRS or SRS) resources. As used herein, “PRS resource set” is a set of PRS resources used for the transmission of PRS signals, where each PRS resource has a PRS resource identifier (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 (e.g., 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 (e.g., 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.

[0081] In some cases, a PRS resource ID in a PRS resource set is associated with a single beam (and/or beam ID) transmitted from a single TRP (where a TRP may transmit one or more beams). For example, each PRS resource of a PRS resource set may be transmitted on a

different beam, and as such, a “PRS resource,” or simply “resource,” can also 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.

[0082] A “PRS instance” or “PRS occasion” is one instance of a periodically repeated time window (e.g., a group of one or more consecutive slots) where PRS are expected to be transmitted. A PRS occasion may also 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.”

[0083] A “positioning frequency layer” (also referred to simply as a “frequency layer” or “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 (SCS) 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 and/or 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.

[0084] 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 network node or entity (e.g., a 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) network nodes or entities (e.g., 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.

[0085] Downlink-based location measurements can include observed time difference of arrival (OTDOA) in LTE, downlink time difference of arrival (DL-TDOA) in NR, and downlink angle-of-departure (DL-AoD) in NR. In an OTDOA or DL-TDOA positioning procedure, a UE measures the differences between the times of arrival (ToAs) of reference signals (e.g., PRS, TRS, NRS, CSI-RS, SSB, etc.) received from pairs of network nodes or entities (e.g., base stations), referred to as reference signal time difference (RSTD) or time difference of arrival (TDOA) measurements, and reports them to a positioning entity. More specifically, the UE receives the identifiers of a reference network node or entity (e.g., a serving base station) and multiple non-reference network nodes or entities (e.g., base stations) in assistance data. The UE then measures the RSTD between the reference network node or entity (e.g., reference base station) and each of the non-reference network nodes or entities (e.g., non-reference base stations). Based on the known locations of the involved network nodes/entities (e.g., base stations) and the RSTD measurements, the positioning entity (e.g., LMF 270) can estimate the UE's location. For DL-AoD positioning, a network node or entity (e.g., a base station such as gNB 222) measures the angle and other channel properties (e.g., signal strength) of the downlink transmit beam used to communicate with a UE to estimate the location of the UE.

[0086] Uplink-based positioning methods include uplink time difference of arrival (UL-TDOA) and uplink angle-of-arrival (UL-AoA). UL-TDOA is similar to DL-TDOA, but is based on uplink reference signals (e.g., SRS) transmitted by the UE. For UL-AoA positioning, a network node or entity (e.g., a base station) measures the angle and other channel properties (e.g., gain level) of the uplink receive beam used to communicate with a UE to estimate the location of the UE.

[0087] Downlink-and-uplink-based positioning methods include enhanced cell-ID (E-CID) positioning and multi-round-trip-time (RTT) positioning (also referred to as "multi-cell RTT or multi RTT"). In an RTT procedure, an initiator (a network node or entity, such as a base station, or a UE) transmits an RTT measurement signal (e.g., a PRS or SRS) to a responder (a UE or base station), which transmits an RTT response signal (e.g., an SRS or PRS) back to the initiator. The RTT response signal includes the difference between the ToA of the RTT measurement signal and the transmission time of the RTT response signal, referred to as the

reception-to-transmission (Rx-Tx) measurement. The initiator calculates the difference between the transmission time of the RTT measurement signal and the ToA of the RTT response signal, referred to as the “Tx-Rx” measurement. The propagation time (also referred to as the “time of flight”) between the initiator and the responder can be calculated from the Tx-Rx and Rx-Tx measurements. Based on the propagation time and the known speed of light, the distance between the initiator and the responder can be determined. For multi-RTT positioning, a UE performs an RTT procedure with multiple network nodes or entities (e.g., base stations) to enable its location to be determined (e.g., using multilateration) based on the known locations of the a network nodes (e.g., base stations). RTT and multi-RTT methods can be combined with other positioning techniques, such as UL-AoA and DL-AoD, to improve location accuracy.

[0088] To assist positioning operations, a location server (e.g., location server 230, LMF 270, or other location server) may provide assistance data to the UE. For example, the assistance data may include identifiers of the network nodes or entities (e.g., base stations or the cells and/or TRPs of the base stations) from which to measure reference signals, the reference signal configuration parameters (e.g., the number of consecutive positioning subframes, periodicity of positioning subframes, muting sequence, frequency hopping sequence, reference signal ID, reference signal bandwidth, etc.), and/or other parameters applicable to the particular positioning method. Alternatively, the assistance data may originate directly from the network nodes or entities (e.g., base stations) themselves, such as in periodically broadcasted overhead messages, etc. In some cases, the UE may be able to detect neighbor network nodes itself without the use of assistance data.

[0089] For DL-AoD, the UE 204 can provide DL-PRS beam RSRP measurements to the LMF 270, whereas the gNB 222 can provide the beam azimuth and elevation angle information. When using an UL AoA positioning method, the position of UE 204 is estimated based on UL SRS AoA measurements taken at different TRPs (not illustrated). For example, TRPs can report AoA measurements directly to LMF 270. Using angle information (e.g., AoD or AoA) together TRP co-coordinate information and beam configuration details, the LMF 270 can estimate a location of UE 204.

[0090] For multi-RTT location measurements, the LMF 270 can initiate a procedure whereby multiple TRPs (not illustrated) and a UE perform the gNB Rx-Tx and UE Rx-Tx measurements, respectively. For example, the gNB 222 and UE 204 can transmit a downlink positioning reference signal (DL-PRS) and uplink sounding reference signal (UL-SRS), respectively, whereby the gNB 222 configures UL-SRS to the UE 204 e.g., using the RRC protocol. In turn, the LMF 270 can provide the DL-PRS configuration to the UE 204. Resulting location measurements are reported to the LMF 270 by the UE 204 and/or gNB 222 to perform location estimation for the UE 204.

[0091] The 3rd Generation Partnership (3GPP) (e.g., Technical Specification (TS) TS22.261 and others) requires location measurements of devices (e.g., UEs) with sub-meter level performance. Conventional approaches to determining location measurements using terrestrial systems determine a distance using a “code-phase” or an RSTD measurement technique based on a time of arrival (ToA) of the signal. In one example of an RSTD measurement, a UE receives signals from several neighboring eNBs and the ToA from each eNB are subtracted from the ToA of a reference eNB to yield an observed time difference of arrival (ODToA) of each neighboring eNBs. Each ODToA determines a hyperbola based on a known function, and a point at which the hyperbolas intersect corresponds to the location of the UE. At least three different timing measurements from geographically dispersed eNBs with good geometry are needed to solve for two coordinates (e.g., latitude and longitude) of the UE. RSTD measurements cannot satisfy the requirement of location measurement with sub-meter level performance due to timing errors and location errors that propagate into each ODToA measurement and reduce the accuracy of the location measurement.

[0092] A terrestrial-based system may implement an angle of departure (AoD) method or a Zenith angle of departure (ZoD) method to provide better accuracy and resource utilization within a 3GPP system. There are contributions proposing the use of phase measurement for improving 5G/NR location measurements, however, the feasibility and performance of such proposals have not been sufficiently studied in 3GPP.

[0093] In some cases, phase measurement-based location measurements can be achieved using a non-terrestrial system, such as a Global Navigation Satellite System (GNSS), that

employs carrier phase positioning techniques to provide centimeter-level accuracy. Carrier phase positioning can be performed by determining timing and/or distance measurements using a wavelength of a subcarrier signal. In contrast to RSTD measurement techniques, carrier phase positioning estimate a phase of a subcarrier signal in the frequency domain.

[0094] One example of GNSS measurement techniques that provide sub-meter level performance use real-time kinematic positioning (RTK) to improve the accuracy of current satellite navigation (e.g., GNSS based) systems by configuring a network entity (e.g., a base station such as an eNB, a gNB, etc.) to measure the subcarrier signal and the network entity retransmits the measured phase of the carrier signal to a UE. The UE also measures the phase of the carrier signal from the satellite and compares the phase measurement at the UE and the phase measurement at the network entity to determine the distance of the mobile device from the network entity. While RTK positioning provides better accuracy over conventional GNSS measurement approaches, the accuracy is limited based on the accuracy of the network entity (e.g., the base station), line-of-sight to the satellite, and environmental conditions that can affect the measurements from the satellite system. For example, buildings can create reflections that increase phase error measured by the mobile device and cloudy conditions. RTK positioning is also limited to outdoor environments due to the receiver device requiring a line-of-sight to the satellites.

[0095] Bluetooth can also use carrier phase measurement for providing centimeter-level high accuracy positioning services but is limited to indoor environments due to the limited range of Bluetooth communication. Carrier phase measurement with Bluetooth may be inaccurate because the reference devices that transmit the carrier signals may not be fixed and inaccuracies in the location of the reference devices propagate into the carrier phase measurement.

[0096] FIG. 3 is a diagram of a UE 305 in a wireless communication system 300 that determines a location based on distances from terrestrial transmitting devices, according to some aspects of the present disclosure. Although FIG. 3 illustrates determining a location of the UE 305 in a wireless networking system relative to network entities 310, 315, and 320, this non-limiting illustration is for explanation purposes and the descriptions herein can be applied

to other systems. In another illustrative example, the UE 305 may be a vehicle that employs vehicle-to-everything (V2X) communications with other vehicles or UEs to determine locations relative to other vehicles or objects to perform various driving functions such as lane assist, blind-spot detection, autonomous driving functions, and the like.

[0097] As shown in FIG. 3, the wireless communication system 300 includes the UE 305 positioned relative to a network entity 310, a network entity 315, and a network entity 320. In some cases, one or more of the network entities 310, 315, and 320 can be implemented in an aggregated or monolithic base station architecture or in a disaggregated base station architecture (e.g., including one or more of a CU, a DU, a RU, a Near-RT RIC, or a Non-RT RIC). Each of the network entities 310, 315, and 320 transmits a carrier signal that is received by the UE 305. In particular, the network entity 310 transmits the carrier signal 322, the network entity 315 transmits the carrier signal 324, and the network entity 320 transmits the carrier signal 326. In some aspects, the UE 305 can be configured to measure a distance L1 to network entity 310, a distance L2 to network entity 315, and a distance L3 to network entity 320. In one illustrative example, the UE 305 can determine its location based on the distances L1, L2, and L3 and the locations of each of the network entities 310, 315, and 320. In other examples, the UE can measure a parameter such as a carrier phase and transmit the measured parameter to another device, such as a location server (e.g., an LMF), that determines the location of the UE.

[0098] In some aspects, the wireless communication system 300 is a system configured to transmit using subcarriers across various frequencies. For instance, the wireless communication system 300 may be an orthogonal frequency division multiplexing (OFDM) system configured to transmit in a licensed frequency band or an unlicensed frequency band using subcarriers that are spaced across the frequency band.

[0099] FIG. 4 is an illustration of a transmitting device 405 communicating with a receiving device 410 via signal 420 and a signal 425. The signals 420 and 425 may be subcarrier signals. The transmitting device or the receiving device 410 may be configured to determine a carrier phase measurement that can be used to determine a distance between the transmitting device 405 and the receiving device 410 based on a phase measurement combination. In some

aspects, the transmitting device 405 or the receiving device 410 can determine the carrier phase measurement and/or the distance. For instance, the receiving device 410 may determine the carrier phase measurement and may transmit the carrier phase measurement to the transmitting device 405. In another example, the receiving device 410 may determine the carrier phase measurement and may transmit the carrier phase measurement to another network entity, such as a location server (e.g., an LMF). The location server may receive the carrier phase measurement and determine the distance between the transmitting device 405 and the receiving device 410 using the carrier phase measurement. In some examples, the location server may receive distances between one or more other receiving devices and the transmitting device 405. The location server can use the distance determined for the receiving device 410 and the distances between one or more other receiving devices and the transmitting device 405 to determine a location of the receiving device 410 and/or the other receiving devices (e.g., by performing triangulation using the locations).

[00100] The signal 420 and the signal 425 are sinusoidal signals. The signal 420 has a wavelength denoted as λ_1 in FIG. 4 and the signal 422 has a wavelength denoted as λ_2 . There are an integer number of wavelength cycles for each of the signals (e.g., subcarrier signals), including an integer number $N\lambda_1$ for the signal 420 and an integer number $N\lambda_2$ for the signal 425, as shown in FIG. 4. The receiving device 410 can measure the phase 430 of the signal 420 when the signal 420 is received and can measure the phase 435 of the signal 425 when the signal 425 is received. As shown, there is a fractional wavelength (shown as fractional wavelength λ_{i1} for the signal 420 and λ_{i2} for the signal 425) between the beginning of the last period or wavelength and when the signal is received by the receiving device 410. The receiving device 410 can perform carrier phase measurements by first determining the phase at which a signal is received (e.g., the phase 430 of the signal 420) and how many integer number (e.g., $N\lambda_1$ or $N\lambda_2$) of wavelengths have passed. For instance, the distance ρ between the transmitting device 405 and the receiving device 410 can be determined based on the integer number (e.g., $N\lambda_1$ or $N\lambda_2$) of wavelength cycles of a signal (e.g., the signal 420 and/or the signal 425) and the fractional wavelength (e.g., λ_{i1} or λ_{i2}). In one illustrative example, if the wavelength λ_1 is 10 centimeters (cm) and the integer number $N\lambda_1$ of wavelength cycles is 1000, then the distance ρ between the transmitting device 405 and a receiving device 410 can be

determined as 10 meters (m) (based on 0.01 m x 1000) plus a distance associated with the fractional wavelength λ_{i1} .

[00101] As noted above, the general concept of carrier phase measurements (e.g., for carrier/subcarrier-based positioning) is that any distance ρ between a transmitting device 405 (e.g., an eNB, a gNB, etc.) and a receiving device 410 (e.g., a UE) can be represented in terms of N full wavelengths λ and the residual fractional wavelength λ_i of the subcarrier signal. In mathematical terms, the principle of estimating distance (ρ , also referred to as d) using a carrier phase can be given as follows:

$$\rho = N\lambda + \frac{\phi}{2\pi}\lambda \quad (\text{Equation 1})$$

[00102] where $N\lambda$ is the integer number of wavelength cycles and $\frac{\phi}{2\pi}\lambda$ is the residual fractional wavelength λ_i of the subcarrier signal (where the phase ϕ is divided by 2π if the phase is in radians). The wavelength λ of a signal can be determined based $\frac{c}{f}$, where c is the speed of light (299,792,458 meters per second) and f is the frequency of the signal. For example, a frequency of 3 gigahertz (GHz) has a wavelength of 10 centimeters (cm) and a frequency of 500 kilohertz (kHz) has a wavelength of 600 meters. The fractional wavelength (e.g., λ_{i1} in FIG. 4 or $\frac{\phi}{2\pi}\lambda$ in Equation (1)) can be determined using a carrier phase measurement.

[00103] Measuring the phase ϕ of the received subcarrier signal will only provide the fractional wavelength λ_i because the carrier phase is periodic. As noted above, the distance ρ between the transmitting device 405 and the receiving device 410 can be determined based on the integer number (e.g., $N\lambda_1$ or $N\lambda_2$) of wavelength cycles of a signal (e.g., the signal 420 and/or the signal 425) and a distance associated with the fractional wavelength (e.g., λ_{i1} or λ_{i2}). However, typical carrier-phase measurements of a signal can only be used to determine the fractional phase term, as the term N is ambiguous (and cannot be directly measured) because the carrier phase is periodic. For example, a signal may be received by the receiving device 410 with a carrier phase of 0.5π (e.g., 90°), or a length of 2.5 cm for a 3 GHz signal, but the signal may have traveled 2.5 cm, 12.5 cm, or 102.5 cm. The receiving device 410 receives the signal 420 with a fractional wavelength λ_{i1} and receives the signal 425 with a fractional

wavelength λ_{i2} that is greater than fractional wavelength λ_{i1} (e.g., based on the signal 425 having a higher frequency than the signal 420, based on being transmitted at different times, etc.). Therefore, an estimation or an inference is required (e.g., via different cycle count techniques) to determine N and thus to determine the distance ρ from the transmitting device 405 to the receiving device 410.

[00104] In some aspects, the number of integer cycles N can be inferred and an unknown distance to the receiving device 410 can be determined based on a carrier phase measurement using terrestrial transmitting devices (e.g., a gNB, a beacon, etc.). If the receiving device 410 receives and determines distances to at least two terrestrial transmitting devices that have a known location, the receiving device 410 may be able to determine the location of the receiving device 410 without non-terrestrial sources (e.g., satellites). As noted above, systems and techniques described herein can be used to determine an unknown distance between a transmitting device and a receiving device using carrier phase measurements from terrestrial devices in both indoor and outdoor environments. In some aspects, the systems and techniques disclosed herein can be applied to other non-terrestrial devices in a licensed band or an unlicensed band.

[00105] As noted above, the received phase ϕ_i of the i^{th} carrier or subcarrier signal (e.g., the phase 430 of the signal 420 shown in FIG. 4) can be measured at the receiving device 410. In particular, the carrier phase can be determined based on Equation 2 below.

$$\phi_i = \frac{2\pi(\rho - N_i\lambda_i)}{\lambda_i} + e_{\phi_i} \quad (\text{Equation 2})$$

[00106] In equation 2, N_i is an ambiguous integer of wavelength cycles (as noted above), ρ is the distance between the transmitting device 405 and the receiving device 410, λ_i is the wavelength of the i^{th} carrier or subcarrier signal, and e_{ϕ_i} is the noise in the phase measurement. In some aspects, the received frequency domain resource elements (REs) of an OFDM-based reference signal (e.g., PRS, SRS, etc.) channel with a simple delay can be modeled by Equation 3 below:

$$R_k = D_k e^{-\frac{j2\pi k \Delta f \rho}{c}} + W_k \quad (\text{Equation 3})$$

[00107] In Equation 3, k corresponds to a subcarrier according to the following:

$$k = -\frac{N_{RB}}{2}, \dots, -1, 0, 1, \dots, \frac{N_{RB}}{2},$$

[00108] where N_{RB} is the number of resource blocks (RBs). The term k can be considered a subcarrier index that identifies a frequency of the signal. The term R_k in Equation 3 above is the frequency domain RE transmitted on carrier k , D_k is the time domain representation of the symbol transmitted on carrier k , and W_k is the noise at the subcarrier k . Equation 3 can be further simplified into Equation 4 below.

$$R_k = D_k e^{-\frac{j2\pi k\rho}{\lambda_\Delta}} + W_k, \text{ where } \lambda_\Delta = \frac{c}{\Delta f} \quad (\text{Equation 4})$$

[00109] In Equation 4, λ_Δ is the wavelength difference of two subcarrier frequencies. After a descrambling operation, the frequency domain PRS REs can be represented by Equations 5 and 6 below.

$$R'_k = \|D_k\|^2 e^{-\frac{j2\pi k\rho}{\lambda_\Delta}} + D_k^* W_k \quad (\text{Equation 5})$$

$$R'_k = e^{-\frac{j2\pi k\rho}{\lambda_\Delta}} + W'_k \quad (\text{Equation 6})$$

[00110] The carrier phase of a k^{th} subcarrier can be determined based on the arctangent of the imaginary part of the frequency domain PRS RE divided by the real part of frequency domain PRS RE as identified in Equation 7 below.

$$\phi_k = -\tan^{-1} \left(\frac{\text{Im}\{R'_k\}}{\text{Re}\{R'_k\}} \right) = \frac{2\pi k\rho}{\lambda_\Delta} - 2\pi N_k \quad (\text{Equation 7})$$

[00111] In this case, $N_k \in \mathbb{Z}$ is an ambiguous number of full wavelength cycles that cannot be directly measured, and $\phi_k \in (-\pi, \pi)$ is the phase observation for the k^{th} sub-carrier.

[00112] In some aspects, by combining the carrier phase measurements ϕ of different subcarriers, the measuring device (e.g., the transmitting device 405, the receiving device 410, or another network entity such as an LMF) may remove the ambiguity of the integer number of cycles N . For example, instead of directly mapping a phase (e.g., the phase 430 of signal

420) to a distance, as described above, a device can subtract the received phases of a pair of subcarrier signals (denoted as $\phi_k - \phi_{k-m}$ below) or a pair of set of subcarriers. A subcarrier set includes at least one subcarrier. One example of a “set of subcarriers” is a set with a single subcarrier. In such an example, a pair of subcarriers would be two subcarriers (as each set would include a single subcarrier). In some examples, “X subcarriers” (e.g., consecutive subcarriers) can be included in a set of subcarriers. In such examples, the measuring device can derive a single phase measurement for the set of subcarriers including X subcarriers. The measuring device can also derive a single phase measurement (e.g., an effective, average, median, or other representative phase of the set of subcarriers) for a second set of subcarriers including the same number (X) of subcarriers or a different number (e.g., Y) of subcarriers. Using the two phase measurements, the measuring device can determine the difference (e.g., $\phi_k - \phi_{k-m}$ as described below with respect to equation 8, where the ϕ_k is effective, average, median, or other representative phase of the set of subcarriers) between the two phase measurements. The terms subcarrier pair (or pair of subcarriers) and subcarrier set pair (or pair of set of subcarriers) will be used interchangeably herein.

[00113] In one illustrative example, for a pair of subcarriers x_1, x_2 , the measuring device (e.g., UE) can derive two phases ϕ_1, ϕ_2 . For a pair of set of subcarriers $\{x_{1a}, x_{1b}, x_{1c}, \dots, x_{1w}\}, \{x_{2a}, x_{2b}, x_{2c}, \dots, x_{2w}\}$, the measuring device can derive two phases as follows: ϕ_1, ϕ_2 , where ϕ_1 is derived based on $\{x_{1a}, x_{1b}, x_{1c}, \dots, x_{1w}\}$ and ϕ_2 is derived based on $\{x_{2a}, x_{2b}, x_{2c}, \dots, x_{2w}\}$. Further details regarding phase differences (e.g., $\phi_k - \phi_{k-m}$) are as described below with respect to equation 8.

[00114] For two subcarriers that are close together in the frequency domain, the wavelengths of the two subcarriers are close together, in which case the number of cycles of the subcarriers between a transmitting device (e.g., transmitting device 405) and a receiving device (e.g., receiving device 410) will be similar. Subtracting the respective phases of the two close-by subcarriers (denoted as $\lambda_{\Delta}^m \Delta N_m$ below) will thus result in the number N of wavelength cycles being canceled out or reduced to a negligible value, as shown by the equations below. As a result, as shown in Equation (11) below, the phase difference between the sub-carriers can map directly to the distance d between a transmitting device and a receiving device (e.g., transmitting device 405 and receiving device 410). Such a technique can thus be performed to

determine a distance between a transmitting device and a receiving device even in view of the ambiguous number of cycles N . In some aspects, a pair of subcarriers (or pair of set of subcarriers) may be referred to as a “lane,” and the operation of determining the distance from the transmitting device and the receiving device based on the difference in the phase measurements of a subcarrier pair (or subcarrier set pair) can be referred to as a phase measurement combination or “wide-laning”. Examples of various subcarrier pairs/ subcarrier set pair and corresponding wavelengths are illustrated in FIG. 5. Mathematical details of phase measurement combining (or wide-laning) using different subcarrier pairs are further detailed below with reference to descriptions related to Equations 8 to 10.

[00115] In some aspects, an OFDM system transmits across a licensed or unlicensed frequency band (e.g., 5 GHz) that assigns each subcarrier a distinct center frequency with a fixed bandwidth, and the subcarriers are separated by a subcarrier spacing such as 30 kHz. A subcarrier is associated with a subcarrier index that identifies a distinct center frequency of each distinct subcarrier based on the subcarrier spacing. In some communication systems, subcarriers of a particular frequency band may also be separated by a guard interval to address potential interference from communication devices that are also communicating in that same frequency band. Equation 8 below illustrates how the carrier phase measurements of two different subcarriers, subcarrier k and subcarrier $k-m$ with corresponding carrier phases denoted as ϕ_k and ϕ_{k-m} , can be combined based on the carrier phase measurement from Equation 7.

$$\phi_k - \phi_{k-m} = 2\pi d \frac{k}{\lambda_\Delta} - 2\pi N_k - 2\pi d \frac{k-m}{\lambda_\Delta} + 2\pi N_{k-m} \quad (\text{Equation 8})$$

[00116] In some aspects, the number of cycles N_k and N_{k-m} may be equal or may be similar. The phase of the subcarrier pair (or subcarrier set pair), being separated by subcarrier difference m , can be compared to yield a phase measurement difference $\Delta\phi_m$ (as illustrated in Equation 9 below), which can be used to determine a distance d from the transmitting device 405 and receiving device 410 (as illustrated in Equation 10 below).

$$\phi_k - \phi_{k-m} = \Delta\phi_m = \frac{2\pi d}{\lambda_\Delta} + 2\pi(N_{k-m} - N_k) = \frac{2\pi d}{\lambda_\Delta^m} + 2\pi\Delta N_m \quad (\text{Equation 9})$$

[00117] Based on equation 9, , the phase measurement difference $\Delta\phi_m$ determined using Equation 9 can be used in Equation 10 below to determine a distance d from a transmitting device (e.g., transmitting device 405) to the receiving device (e.g., receiving device 410).

$$d = \lambda_{\Delta}^m \frac{\Delta\phi_m}{2\pi} + \lambda_{\Delta}^m \Delta N_m \quad (\text{Equation 10})$$

[00118] where λ_{Δ}^m is the equivalent wavelength of a subcarrier combination with sub-carrier separation of $m\Delta f$, m is the subcarrier difference, and Δf is the spacing between subcarriers.

[00119] In one illustrative example, a first subcarrier of the subcarrier pair (or subcarrier set pair) has an index value of 1, corresponding to a subcarrier frequency of 5000.03 MHz, and a second subcarrier of the subcarrier pair (or subcarrier set pair) has an index value of 2, corresponding to subcarrier frequency of 5000.06 MHz (e.g., a SCS of 30 kHz), with the subcarrier difference of 1. In this example, the subcarriers are spaced at 30 kHz intervals, and the equivalent wavelength λ_{Δ}^1 of the subcarrier pair is based on $\frac{c}{\Delta f} = \frac{299,792,458 \text{ m/s}}{(2-1) * 30 \text{ kHz}}$, or approximately 10 kilometers (km). The wavelengths of the subcarriers in this example are nearly equal based on the 30 kHz frequency difference. Because of the similar wavelength of the subcarrier frequencies, the subcarriers will need to travel a large distance before the number of cycles of the higher frequency subcarrier will increase and be different than the number of cycles of the lower frequency subcarrier.

[00120] In some aspects, a larger difference in frequencies between subcarrier pairs (or subcarrier set pair) will increase the difference in wavelengths (ΔN_m) between the subcarriers in each subcarrier pair (or subcarrier set pair). However, the value of ΔN_m does not need to be zero, since the value of ΔN_m for each subcarrier pair can be known.

[00121] In some cases, there may be a maximum number of resource blocks (RBs) that can be assigned to a particular signal (e.g., a positioning reference signal (PRS), sounding reference signal (SRS), demodulation reference signal (DMRS), Channel State Information Reference Signal (CSI-RS), etc.). For example, there may be a maximum of 272 RBs that are assignable to a PRS. In such an example, presuming a comb 1, symbol 1 RB structure with 12 assignable tones, there are $272 \times 12 = 3264$ different subcarrier assignments. Presuming that the largest

subcarrier distance is used (e.g., the first subcarrier having an index of 1 and the last subcarrier having an index value of 3264), the two subcarriers of the subcarrier pair (or subcarrier set pair) are separated by 3263 subcarriers, and the equivalent wavelength is $\frac{299,792,458 \text{ m/s}}{3263 \times 30 \text{ kHz}} = 3 \text{ m}$. If the shortest subcarrier distance is used (e.g., the first subcarrier having an index of 1 and the next subcarrier having an index of 2), then the two subcarriers of the subcarrier pair are separated by 3263 subcarriers, and the equivalent wavelength is $\frac{299,792,458 \text{ m/s}}{s \times 30 \text{ kHz}} = 9,931 \text{ m}$ (or 10 km).

[00122] In some aspects, there are more subcarrier pairs (or subcarrier set pairs) with a larger equivalent wavelength than subcarrier pairs with a shorter equivalent wavelength. For example, there is a single subcarrier pair combination that yields a subcarrier distance of 3263 (e.g., subcarrier pair [1, 3264]), and there are at 3263 subcarrier pairs having a subcarrier spacing of 1 (e.g., [1, 2], [2, 3], [3, 4], ..., [3263, 3264]). In some aspects, a narrow subcarrier pair (corresponding to a wide lane) refers to subcarriers that are relatively close together in frequency and have similar wavelengths, and a wide subcarrier pair (corresponding to a narrow lane) refers to subcarriers that are farther apart in frequency and have less similar wavelengths as compared to the narrow subcarrier pairs, which is illustrated herein with reference to FIG. 5.

[00123] Different subcarrier combinations may be used to identify an unknown location of a device because a narrow subcarrier pair or a wide subcarrier pair will not be able to produce accurate initial results for every case. For example, a narrow subcarrier group may be inaccurate because the receiving device may be close to the transmitting device (e.g., 200 m), in which case the phase differences of the narrow subcarrier pair may be outside of a measurement sensitivity of a phase measurement device on the receiving device and the measured phase will be dominated by noise (e.g., e_{ϕ_i}). In the case that phase of each subcarrier measurement is below the noise floor of the measurement (e.g., e_{ϕ_i}) and the difference in the subcarrier phase is zero, the measured phase yields a distance of zero from the transmitting device to the receiving device. In some aspects, a zero distance indicates that the transmitting device and the receiving device occupy the same physical space, which is not possible. In this case, the narrowest subcarrier group cannot be used to determine the distance between

transmitting device 405 and the receiving device 410. The widest subcarrier group also cannot determine the distance between transmitting device 405 and the receiving device 410 because the receiving device 410 is outside of the smallest equivalent wavelength of 3 m and there are an ambiguous number of cycles N .

[00124] In some aspects, the wide subcarrier pair can be used if an initial location is known and the number of cycles can be determined. For example, if a location of a receiving device is known within a 3 meter radius, the widest subcarrier pair identified (e.g., subcarrier pair [1, 3264]) above can be used to identify a location in units of centimeters within that 3 meter radius. In some aspects, narrow subcarrier pairs can be used to identify a coarse location within larger areas but with lower accuracy, and then different subcarrier pairs can be used to identify a location within a smaller area but with higher accuracy.

[00125] FIG. 5 is a graph that illustrates the wavelengths of subcarrier pairs based on subcarrier spacing of an OFDM system and wavelength differences of the subcarrier pairs, according to some aspects of the present disclosure. In FIG. 5, the equivalent wavelength of the subcarrier pairs are illustrated by reference numeral 505 and the wavelength differences are illustrated by reference numeral 510. As described above, narrower subcarrier pairs have large equivalent wavelengths based on the wavelength of their subcarriers being closer than wider subcarrier pairs.

[00126] As previously described, reference signals are predefined signals occupying specific resource elements within a time–frequency grid of a resource block (RB) (which can also referred to as a physical resource block (PRB)) and may be exchanged on one or both of downlink and uplink physical communication channels. Example reference signals include Positioning Reference Signal (PRS), Sounding Reference Signal (SRS), Channel State Information – Reference Signal (CSI-RS), De-Modulation Reference Signal (DMRS), among others. In some cases, a RB may be the smallest unit of resources that can be allocated for a communication.

[00127] FIG. 6 is a diagram illustrating an example of an RB 602 (or PRB 602). The RB 602 is arranged with the time domain on the horizontal (or x-) axis and the frequency domain on the vertical (or y-) axis. As shown, the RB 602 may be 180 kilohertz (kHz) wide in

frequency and one slot long in time (with a slot being 1 milliseconds (ms) in time). In some cases, the slot may include fourteen symbols (e.g., in a slot configuration 0). The RB 602 includes twelve subcarriers (along the y-axis) and fourteen symbols (along the x-axis). An intersection of a symbol and subcarrier can be referred to as a resource element (RE) or tone. For instance, a RE is 1 subcarrier x 1 symbol, and is the smallest discrete part of the subframe. A RE includes a single complex value representing data from a physical channel or signal.

[00128] Combination (comb) structures (also referred to as tone patterns) can be defined as specific arrangements of REs in a given resource block for transmission of a reference signal. Comb structures are currently pre-defined in the 3GPP communication standards (e.g., 5G/NR, 4G/LTE, etc.) and may be known to both the user equipment (UE) and corresponding network entity (e.g., base station or portion thereof).

[00129] Examples of comb structures for reference signals (e.g., a PRS, SRS, etc.) are shown in FIG. 7. For example, the comb structure 710 is a comb-2 structure with two symbols (denoted as a comb-2/2-symbol structure). According to the comb-2/2-symbol structure of the comb structure 710, every alternate symbol is assigned to the reference signal resources. The comb patterns in FIG. 7 are for one TRP. A summary of the comb structures 710, 712, 714, 716, 718, 720, 722, and 724 are provided in Table 1 below:

	2-Symbols	4-Symbols	6-Symbols	12-Symbols
Comb-2	{0,1}	{0,1,0,1}	{0,1,0,1,0,1}	{0,1,0,1,0,1,0,1,0,1,0,1}
Comb-4	N/A	{0,2,1,3}	N/A	{0,2,1,3,0,2,1,3,0,2,1,3}
Comb-6	N/A	N/A	{0,3,1,4,2,5}	{0,3,1,4,2,5,0,1,3,4,2,5}
Comb-12	N/A	N/A	N/A	{0,6,3,9,1,7,4,10,2,8,5,11}

[00130] The proposed bandwidth (with respect to a number of PRBs or RBs) for a PRS signal is defined by a dl-PRS-ResourceBandwidth field or parameter in 3GPP Technical Specification (TS) 37.355. The dl-PRS-ResourceBandwidth parameter can be included in assistance data (e.g., a NR-DL-PRS-AssistanceData message) transmitted by a user device (e.g., a UE) to a network entity (e.g., a location server such as an LMF or base station). As shown below in a NR-DL-PRS-PositioningFrequencyLayer-r16 field of the NR-DL-PRS-

AssistanceData message, the dl-PRS-ResourceBandwidth field or parameter can have a value of 1 to 63.

```
NR-DL-PRS-PositioningFrequencyLayer-r16 ::= SEQUENCE {
    dl-PRS-SubcarrierSpacing-r16      ENUMERATED {kHz15, kHz30,
    kHz60, kHz120, ...},
    dl-PRS-ResourceBandwidth-r16      INTEGER (1..63),
    dl-PRS-StartPRB-r16               INTEGER(0..2176),
    dl-PRS-PointA-r16                 ARFCN-ValueNR-r15,
    dl-PRS-CombSizeN-r16              ENUMERATED {n2, n4, n6, n12,
    ...},
    dl-PRS-CyclicPrefix-r16           ENUMERATED {normal,
    extended, ...},
    ...
}
```

[00131] The dl-PRS-ResourceBandwidth parameter can be defined as follows: this parameter indicates the number of physical resource blocks (PRBs) allocated for downlink (DL) PRS Resource (allocated DL PRS bandwidth). All DL PRS Resources of the DL PRS Resource Set have the same bandwidth. All DL PRS Resource Sets belonging to the same Positioning Frequency Layer have the same value of DL PRS Bandwidth and Start PRB. Value 1 equals 24 PRBs, value 2 equals to 28 PRBs, value 3 equals to 32 PRBs, and so on. Based on this definition, the range of the bandwidth for the PRS is equal to 24:4:272, where the minimum is 24 PRBs and the maximum is 272 PRB (based on multiplying 4 times 62 (=248) and adding 24, which is the minimum number of PRBs).

[00132] The dl-PRS-CombSizeN parameter in the NR-DL-PRS-AssistanceData message noted above indicates the RE spacing in each symbol of a downlink PRS resource and that all downlink PRS Resource Sets belonging to the same Positioning Frequency Layer (PFL) have the same value of combSize. As noted above, a PRS positioning frequency layer is defined as a collection of PRS resource sets with each PRS resource set defining a collection of PRS resources. For example, PRS can be transmitted by a network entity (e.g., one or more transmission-reception points (TRPs) of a base station or a portion thereof, such as one or more of a CU, a DU, a RU, a Near-RT RIC, or a Non-RT RIC) in multiple beams, where a PRS beam can be referred to as a PRS resource while the full set of PRS beams transmitted from the network entity (e.g., one or more TRPs of a base station or portion thereof) on the same frequency is referred to as a PRS resource set. Each PRS resource can have a PRS resource

identifier (ID). In some cases, the PRS resources in a PRS resource set can be associated with the same Transmission-Reception Point (TRP). In some aspects, a PRS resource set can be identified by a PRS resource set ID and can be associated with a specific TRP (identified by a TRP ID). In addition, the PRS resources in a PRS resource set can have the same periodicity, a common muting pattern configuration, and the same repetition factor (e.g., PRS-ResourceRepetitionFactor) across slots.

[00133] Existing comb structures may not be optimized for carrier phase positioning. For instance, the same comb size is defined for all of the PRS resource sets defined in a given PFL. Existing comb structures also provide symmetrical allocation of REs in the frequency domain. For example, for the comb2 structure shown in FIG. 7, every alternate symbol of an RB is given to the PRS resources.

[00134] Further, existing comb structures specify a regular (or consistent) arrangement of REs across all RBs. For example, existing comb structures for PRSs have a single RB boundary (denoted as a 1-RB boundary), in which case all of the RBs for a PRS will have the same REs assigned to the PRS resources (e.g., the comb structure will repeat every RB). Existing comb structures also do not specify that consecutive symbols in a RB can be assigned to a PRS resource.

[00135] The systems and techniques described herein provide reference signals that are optimal for determining carrier phase measurements for carrier phase positioning. FIG. 8A is a diagram 800 illustrating an example of a group of resource blocks (RBs) with a regular resource element (RE) structure according to an existing comb-2 structure (with a 1-resource block boundary). FIG. 8B and FIG. 8C are diagrams 805 and 810, respectively, illustrating examples of RBs with irregular RE structures (with an X-resource block boundary). The RBs in FIG. 8A – FIG. 8C illustrate resources for reference signals from two different sources, such as two TRPs (shown as TRP1 and TRP 2). The reference signals may include any reference signal that can be used for carrier phase positioning, such as a PRS, SRS, or the like. The RBs shown in FIG. 8A – FIG. 8C include a first resource block (RB1), a second resource block (RB2), a third resource block (RB3), a fourth resource block (RB4), a fifth resource block (RB5), a sixth resource block (RB6), a seventh resource block (RB7), and an eighth resource

block (RB8). The subcarriers associated with RBs in FIG. 8A – FIG. 8C increase in frequency in the vertical direction (e.g., RB1 has the lowest frequency subcarriers, followed by RB2, followed by RB3, and so on). The resource blocks RB1–RB8 are a portion of a total number of resource blocks for resources and/or resource sets of the reference signals from the two sources. For example, as noted above, the minimum bandwidth for a PRS is 24 RBs and the maximum bandwidth is 272 RBs.

[00136] Referring to FIG. 8A, the comb-2 structure of the RBs has a 1-RB boundary as described above. According to the 1-RB boundary, where the comb pattern is repeated four times per four RBs. As a result, the comb structure repeats and is thus the same in all RBs of the reference signal. In such cases, all of the RBs of the reference signal will have REs assigned to the PRS resources, and the same REs will be assigned in each RB.

[00137] The RBs of FIG. 8B and FIG. 8C are associated with a reference signal (e.g., a PRS, SRS, or other reference signal that can be used for carrier phase positioning) having an X-resource block boundary, where X is an integer value greater than 1. The X-resource block boundary indicates that a comb structure (the arrangement of REs with the RBs of the reference signal) for the reference signal is repeated a certain number of times (e.g., one time, two times, or three times) every X-resource blocks. With the X-resource block boundary, some RBs may not include data for or be assigned to the reference signal. For example, for any RB between RBs for which the comb pattern specifies REs for the reference signal, no REs will be assigned to the reference signal.

[00138] In one illustrative example, the X-resource block boundary can be a 4-resource block boundary. FIG. 8B and FIG. 8C illustrate examples of RBs of a reference signal (e.g., a PRS, etc.) having a 4-resource block boundary. In general, based on the 4-resource block boundary, the comb structure for the reference signal is repeated one time, two times, or three times every four RBs. In FIG. 8B, the comb structure 807 (or pattern) is repeated once every four RBs. In particular, the comb structure 807 is repeated in RB2 and RB6, but not in RB1, RB3, RB4, RB5, RB7, or RB8. In FIG. 8C, the comb structure 811 (or pattern) is repeated twice every four RBs. As shown, the comb structure 811 is repeated in RB1, RB4, RB5, and RB8, but not in RB2, RB3, RB6, or RB7.

[00139] The irregular resource element structure provided by an X-resource block boundary for a reference signal (e.g., PRSs, SRSs, etc.) can be useful for carrier phase positioning techniques (as compared to the regular resource element structures provided in existing comb structures) and can also save bandwidth by transmitting less resources for the reference signal. For example, the resource structure of FIG. 8B may be specified or signaled by a network entity (e.g., a location server, a base station or a portion thereof) when the network entity wants the device (e.g., the UE) receiving the subcarrier signals to use subcarrier pairs (or subcarrier set pairs) that are further apart (e.g., narrower lanes). In such cases, fewer consecutive subcarriers need to be signaled, as the subcarrier pairs (or subcarrier set pairs) that are to be signaled are farther apart from one another. Referring to FIG. 8B, data is signaled in the REs of RB2 and RB6 for the reference signal (e.g., the PRS) according to the comb pattern so that the device can compute phase measurements (e.g., phase measurement difference $\Delta\phi_m$) for subcarrier pairs (or subcarrier set pairs) associated with the assigned REs in RB2 and RB6, while data is not signaled in any of the REs of RB1, RB3, RB4, RB5, RB7, and RB8 for the reference signal.

[00140] In another example, the resource structure of FIG. 8C may be specified or signaled by a network entity (e.g., a location server, a base station or a portion thereof) when the network entity wants the device (e.g., the UE) receiving the subcarrier signals to use subcarrier pairs (or subcarrier set pairs) that are closer together (e.g., wider lanes). For instance, subcarriers that are closer together (e.g., consecutive subcarriers) need to be signaled. In the example of FIG. 8C, data is signaled in the REs of RB1, RB4, RB5, RB8, and so on for the reference signal (e.g., the PRS) according to the comb pattern. The device can then compute phase measurements (e.g., phase measurement difference $\Delta\phi_m$) for subcarrier pairs (or subcarrier set pairs) associated with the assigned REs in RB1, RB4, RB5, RB8, etc. As shown, data is not signaled in any of the REs of RB2, RB3, RB6, or RB7 for the reference signal.

[00141] By signaling less data (due to some of the RBs not including data for a given reference signal), signaling overhead and bandwidth can be saved. Such an irregular comb structure can provide an opportunity for a network entity (e.g., a base station such as a gNB, or a portion thereof such as one or more of a CU, a DU, a RU, a Near-RT RIC, or a Non-RT RIC) to multiplex signaling from more TRPs or base stations.

[00142] In some aspects, resource blocks can be provided with patterns that are non-uniform in the frequency domain and/or continuous in the time domain. For example, a consecutive number of symbols for a non-uniform number of subcarriers in an RB can be allocated to a resource or to multiple resources of a reference signal (e.g., PRS resources). FIG. 9A illustrates an example of an RB 902 with eight consecutive symbols for four subcarriers (out of the twelve available subcarriers) assigned to resources of the reference signal (e.g., PRS resources). FIG. 9B illustrates an example of an RB 904 with twelve consecutive symbols for three subcarriers (out of the twelve available subcarriers) assigned to resources of the reference signal (e.g., PRS resources).

[00143] The RB 902 of FIG. 9A and the RB 904 of FIG. 9B provide reference signals resources (e.g., subcarriers) that are continuous in the time domain. Such as a block-type reference signal structure, such as a PRS structure, is advantageous for phase measurement as compared to the current staggered patterns currently defined for reference signals (e.g., the PRS structures shown in FIG. 7 and FIG. 8A). In one example, providing resource blocks with consecutive symbols assigned to a PRS or other reference signal allows a device (e.g., a UE) to more easily to measure phase information (for carrier phase positioning) of multiple symbols if the subcarrier index number for the multiple symbols is constant (indicating that the symbols are associated with the same frequency subcarrier). For instance, defining a structure for a PRS as shown in FIG. 9A or FIG. 9B (or similar structure with continuous REs in the time domain) allows a device to determine a simple sum of complex numbers in the same line of block symbols. However, when using a staggered pattern for a PRS or other reference signal, phase estimation may involve complex calculations to compensate for frequency bias or timing errors.

[00144] Furthermore, orthogonality problems due to sampling window mismatches can be avoided by using the block-type structure for a reference signal (e.g., a PRS), such as that shown in FIG. 9A and FIG. 9B. For example, when PRS signals from several neighboring gNBs arrive with different latency, signals from one or more gNBs that are farther away from the receiving device (e.g., the UE) may arrive after the other signals and only a fraction of the signal can be included in a fast Fourier transform (FFT) window that is used in the phase measurement process. As a result, subcarrier interference may occur for certain symbols (e.g.,

the first and last symbols) and cause corruption of the phase measurements. By repeating the data for a reference signal (e.g., PRS) in consecutive symbols several times in the time domain (e.g., as shown in FIG. 9A and FIG. 9B), the receiving device may discard the symbols with subcarrier interference (e.g., the first and last symbols), and may use only the intermediate symbols containing full length subcarrier waves.

[00145] Providing data in subcarriers consistently across time also provides more robustness with respect to Doppler. For instance, for the comb-2/symbol-12 structure 720 in FIG. 7, if a device determines a subcarrier pair or subcarrier set pair (e.g., a lane) using the subcarrier corresponding to the RE 730 in the third symbol minus the subcarrier corresponding to the RE 732 in fourth symbol, the data is included in different subcarriers at different times and thus is less robust to Doppler than if the device compares the same subcarrier continuously across time.

[00146] Allowing the frequency domain component (e.g., subcarriers) of the resource blocks to be non-uniform in the RBs also allows a network entity (e.g., a location server such as an LMF or a base station such as a gNB or portion thereof) to specify to the receiving device (e.g., a UE) which subcarriers can be used in carrier phase positioning (e.g., for determining a phase difference between two subcarriers). For instance, referring to FIG. 9A, the network entity can select which subcarrier pairs (or subcarrier set pairs or lanes) it wants the receive device to use for phase measurements. The network device can transmit signaling or messaging to the receiving device (e.g., directly or via a base station or other network entity) that indicates that data is assigned for a reference signal to REs corresponding to subcarriers 2, 5, 7, and 11 in the RB 902. An example of such signaling or messaging can include a frequency bin bitmap, which is described in more detail below. Such a mechanism can avoid the unnecessary overhead of having to transmit all of the subcarriers. Using existing comb structures, the network entity would have to use a comb-2 structure because it provides at least one set of subcarriers with a subcarrier distance (or gap or difference) of two and thus data in every other subcarrier. In the example of FIG. 9B, a first subcarrier pair or lane between subcarriers 9 and 10 (with a subcarrier distance of one), a second subcarrier pair or lane between subcarrier 9 and subcarrier 2 (with a subcarrier distance of seven), and a third subcarrier pair or lane between subcarrier 10 and subcarrier 2 (with a subcarrier distance of eight) can be used for

carrier phase positioning. Such a scenario is not supported using existing comb structures, as there is not a comb structure with two subcarriers that have a subcarrier distance of one. Using existing comb structures, the network entity would have to measure subcarriers across symbols, which would introduce Doppler issues that would reduce positioning accuracy.

[00147] In some examples, a network entity (e.g., a location server such as an LMF or a base station such as a gNB or portion thereof) can generate information that indicates specific REs in the frequency domain that are assigned to include data for resources of a reference signal (e.g., a PRS resource). For instance, the network entity may generate a frequency bin bitmap (also referred to as a bitmap) indicating particular subcarriers of an RB that are assigned to the reference signal (e.g., PRS). The network entity can signal the bitmap to another network entity or to the receiving device (e.g., the UE) to specify the subcarriers in the RB that are assigned to the reference signal. For example, if the bitmap is transmitted from a first network entity (e.g., a location server) to a second network entity that is configured to send the reference signal resources (e.g., a base station such as a gNB or portion thereof, such as one or more of a CU, a DU, a RU, a Near-RT RIC, or a Non-RT RIC), the bitmap can indicate to the second network entity that it is to include data for the reference signal in the subcarriers of the resource block specified in the bitmap. In another example, if the bitmap is transmitted from a network entity (e.g., a location server, base station, or portion thereof) to a UE, the bitmap can indicate to the UE that the subcarriers of the resource block specified in the bitmap include data for the reference signal.

[00148] A frequency bin bitmap for an RB can include a value of 0 or 1 for each available subcarrier for that RB (e.g., twelve total values in a bitmap for an RB with twelve available subcarriers). Referring to FIG. 9A as an illustrative example, a corresponding bitmap can be represented as 010010100010 for REs in frequency domain. The example bitmap for FIG. 9A indicates that subcarriers corresponding to REs 2, 5, 7, and 11 (along the Y-axis of Figure 9A) are assigned to the reference signal resource (e.g., to a particular PRS resource). An illustrative example of a bitmap corresponding to FIG. 9B can be specified as 010000001100 for REs in frequency domain, indicating that subcarriers corresponding to REs 2, 9, and 10 are given to the reference signal resource (e.g., to a particular PRS resource). In some examples, a frequency bin bitmap can be provided (e.g., signaled by a network entity, such as a location server, a base

station, or portion thereof) for each symbol index, which can indicate to the user device (e.g., UE) the symbol for which the bitmap applies. For instance, referring to the example of FIG. 9A, the bitmap 010010100010 can be signaled for symbol indices 3, 4, 5, 6, 7, 8, 9, and 10.

[00149] According to additional or alternative aspects described herein, a network entity (e.g., location server, base station, or portion thereof such as one or more of a CU, a DU, a RU, a Near-RT RIC, or a Non-RT RIC) or receiving device (e.g., UE) can combine reference signal resources (e.g., PRS resources) by combining resource elements of the reference signal resources. In some cases, the network entity can perform frequency domain muting or suppression to remove certain resource elements from the combined reference signal resources. For instance, to obtain an unsymmetrical structure, the network entity or receiving device can combine reference signal resources (e.g., PRS resources) and in some cases enable frequency domain muting on the combined resources.

[00150] In some examples, the receiving device (e.g., UE) can receive signaling (e.g., from a network entity, such as from the location server, base station, or portion thereof) indicating that the receiving device can or needs to combine the received signals across the reference signal resources (e.g., PRS resources). In some examples, a base station (e.g., a gNB or portion thereof) may receive signaling from another network entity (e.g., a location server, such as an LMF) indicating that the base station should or will perform a transmission of the reference signal resources (e.g., PRS resources) that allow the UE to combine the received reference signal measurements (e.g., PRS measurements).

[00151] In some aspects, to combine reference signal resources (e.g., PRS resources), the receiving device can coherently use all of the received signals across the reference signal resources (e.g., PRS resources) to derive phase measurements. In one illustrative example, two PRS resources having a comb-2/symbol-2 structure (e.g., as shown in FIG. 7) can be combined to make a comb-1/symbol-2 PRS configuration.

[00152] In some cases, frequency domain muting can then be enabled to obtain an unsymmetrical RB structure. A network entity (e.g., an LMF) can provide new signaling specifying to another network entity (e.g., a base station or portion thereof) to combine the PRS resources within a resource set and/or to perform the frequency domain muting. Similar

techniques can be performed for other reference signal resources, such as SRS resources or the like. Illustrative examples of such techniques are described below with respect to FIG. 10A – FIG. 10C.

[00153] FIG. 10A is a diagram illustrating an example of a resource block 1002 with REs assigned to four PRS resources from four sources, including a first TRP (TRP1), a second TRP (TRP2), a third TRP (TRP3), and a fourth TRP (TRP4). In FIG. 10A, the four PRS resources have a comb-2/symbol-2 configuration, spanning over four consecutive symbols. In FIG. 10B, a network entity (e.g., location server, base station, or portion thereof such as one or more of a CU, a DU, a RU, a Near-RT RIC, or a Non-RT RIC) combines the REs of the four PRS resources to create a comb-1/symbol-4 configuration. In some cases, assistance from a network entity (e.g., location server or LMF assistance) may be needed to combine the REs. For example, a location server can transmit configuration information to a base station (or portion thereof) indicating which REs of different RBs to combine into a common RB.

[00154] FIG. 10C is a diagram illustrating an example of frequency domain muting on combined reference signal resources (e.g., combined PRS resources). For example, referring to the RB 1004 of FIG. 10B, a network entity (e.g., a base station such as a gNB or portion thereof) can remove the REs corresponding to subcarriers 2, 3, 6, 7, 8, 10, and 11 to generate the RB 1006 of FIG. 10C. In particular, the RE bins {2,3 6,7,8,10,11} are muted. In some cases, assistance from a network entity (e.g., location server or LMF assistance) may be needed to perform the frequency domain muting of the REs. For example, a location server can transmit configuration information to a base station (or portion thereof) indicating which REs of different RBs to remove from the combined RB.

[00155] While examples are described herein based on signaling between network entities (e.g., location servers, base stations or portions thereof, etc.) and user devices (e.g., UEs, etc.), the systems and techniques described herein can be applied to direct communications between devices (e.g., between UEs, vehicles, etc.) using sidelink communications (e.g., a cellular based PC5 sidelink interface, 802.11p defined Dedicated Short Range Communication (DSRC) interface, or other direct interface).

[00156] FIG. 11 is a flow chart illustrating an example of a process 1100 for wireless communications. The process 1100 can be performed by a computing device or apparatus, such as a wireless communications device (e.g., a UE), or a component or system (e.g., a chipset) of the wireless communication device. The operations of the process 1100 may be implemented as software components that are executed and run on one or more processors (e.g., processor(s) 1384 of FIG. 13, processor 1412 of FIG. 14, or other processor(s)). Further, the transmission and reception of signals by the wireless communications device in the process 1100 may be enabled, for example, by one or more antennas (e.g., antenna 1387 of FIG. 13) and/or one or more transceivers (e.g., wireless transceiver(s) 1378 of FIG. 13).

[00157] At block 1102, the wireless communication device (or component thereof) receives a plurality of resource blocks associated with a positioning reference signal (PRS). A comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks. For instance, according to the comb structure, a first subset of resource blocks from the plurality of resource blocks includes data for the PRS. In some cases, according to the comb structure, a second subset of resource blocks from the plurality of resource blocks does not include data for the PRS. In some illustrative examples, the comb structure of the PRS may be repeated across the plurality of resource blocks as shown in FIG. 8B or FIG. 8C, where some resource blocks include data for the PRS and some resource blocks do not include data for the PRS. The repetition may be based on an X-resource block boundary for the PRS, where the comb structure of the PRS is repeated once in every four consecutive resource blocks of the plurality of resource blocks, twice in every four consecutive resource blocks of the plurality of resource blocks, etc. In one illustrative example, as shown in FIG. 8B, the comb structure 807 is repeated in RB2 and RB6 (which include data for the reference signal, such as a PRS), but not in RB1, RB3, RB4, RB5, RB7, or RB8 (which do not include data for the reference signal, such as a PRS). In another illustrative example, as shown in FIG. 8C, the comb structure 811 is repeated in RB1, RB4, RB5, and RB8 (which include data for the reference signal, such as a PRS), but not in RB2, RB3, RB6, or RB7 (which do not include data for the reference signal, such as a PRS).

[00158] In some aspects, the plurality of resource blocks are received from the first network entity. In some aspects, the plurality of resource blocks are received from a second network

entity, which is different from the first network entity. In one illustrative example, the first network entity is a location server (e.g., an LMF) and the second network entity is a base station (e.g., an eNB, a gNB, or portion thereof, such as one or more of a CU, a DU, a RU, a Near-RT RIC, or a Non-RT RIC).

[00159] In some aspects, the wireless communication device (or component thereof) receives, from the first network entity, information indicating resource elements of the plurality of resource blocks that include data associated with the PRS. For instance, as described herein, the information may include a bitmap. The bitmap may also be referred to as a frequency bin bitmap, and can include a value of 0 or 1 for each available subcarrier for a particular RB. In one illustrative example, referring to FIG. 9A, a bitmap can be represented as 010010100010 for REs in frequency domain, indicating that subcarriers corresponding to REs 2, 5, 7, and 11 (along the Y-axis of Figure 9A) are assigned to the reference signal resource (e.g., to a particular PRS resource).

[00160] In some examples, a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS. In some cases, the plurality of consecutive symbols is associated with a common subcarrier index. Each resource block from the plurality of resource blocks may include a set of non-uniform subcarriers including data associated with the PRS. For example, as shown in FIG. 9A, eight consecutive symbols for the non-uniform set of subcarriers 2, 5, 7, 11, and 12 (out of the twelve available subcarriers for the resource block 902) are assigned to resources of the corresponding reference signal (e.g., PRS resources).

[00161] In some cases, the wireless communication device (or component thereof) receives a message indicating that resource elements of a first resource block associated with a first PRS resource of the PRS are to be combined with resource elements of a second resource block associated with a second PRS resource of the PRS. Based on the message, the wireless communication device (or component thereof) can combine the resource elements of the first resource block with the resource elements of the second resource block. In one illustrative example, the wireless communication device (or component thereof) can combine the resource elements of the first resource block and the resource elements of the second resource block by

coherently using all of the received signals across the reference signal PRS resources to derive the phase measurements. In some cases, one or more resource elements from the resource elements of the first resource block combined with the resource elements of the second resource block are removed (e.g., prior to the combining). For instance, the wireless communication device (or component thereof) can remove the one or more resource elements or a network entity (e.g., the first network entity or the second network entity).

[00162] At block 1104, the wireless communication device (or component thereof) transmits a phase measurement report to a first network entity. The phase measurement report includes information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks. As described above, a subcarrier set includes at least one subcarrier. For instance, as noted above, one example of a “set of subcarriers” is a set with a single subcarrier. In such cases, a pair of subcarriers includes two subcarriers (as each set would include a single subcarrier). In some examples, “X subcarriers” (e.g., consecutive subcarriers) can be included in a set of subcarriers, in which case the wireless communication device can derive a single phase measurement for the set of subcarriers including X subcarriers. The measurement report can include the measured phase difference(s) between the at least one subcarrier set pair or can include the measured phases (in which case the first network entity or other network entity can determine the phase difference(s)).

[00163] In some aspects, the wireless communication device (or component thereof) receives, from the first network entity (e.g., a location server or other network entity), a carrier phase measurement request for reporting phase measurements for one or more subcarrier set pairs of the plurality of resource blocks. In some cases, the wireless communication device (or component thereof) measures, based on the carrier phase measurement request, the phase difference between the at least one subcarrier set pair of the one or more subcarrier set pairs of subcarriers. The wireless communication device (or component thereof) may then transmit the phase measurement report to the first network entity based on the carrier phase measurement request from the first network entity.

[00164] FIG. 12 is a flow chart illustrating an example of a process 1200 for wireless communications. The process 1200 can be performed by a first network entity (e.g., an eNB, a

gNB, a location server such as an LMF, or a portion thereof, such as one or more of a CU, a DU, a RU, a Near-RT RIC, or a Non-RT RIC.) or by a component or system (e.g., a chipset) of the network entity. The operations of the process 1200 may be implemented as software components that are executed and run on one or more processors (e.g., processor 1412 of FIG. 14 or other processor(s)). Further, the transmission and reception of signals by the wireless communications device in the process 1200 may be enabled, for example, by one or more antennas and/or one or more transceivers (e.g., wireless transceiver(s)).

[00165] At block 1202, the first network entity (or component thereof) transmits, to a second network entity, a message including a configuration for a plurality of resource blocks associated with a positioning reference signal (PRS). In some cases, the first network entity is a location server (e.g., an LMF) and the second network entity is a base station (e.g., an eNB, a gNB, or portion thereof, such as one or more of a CU, a DU, a RU, a Near-RT RIC, or a Non-RT RIC). In some aspects, the plurality of resource blocks are transmitted from the first network entity to a user equipment (UE). In some aspects, the plurality of resource blocks are transmitted to the UE from the second network entity.

[00166] Based on the configuration for the plurality of resource blocks associated with the PRS, a comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks. For instance, according to the comb structure, a first subset of resource blocks from the plurality of resource blocks includes data for the PRS. In some cases, according to the comb structure, a second subset of resource blocks from the plurality of resource blocks does not include data for the PRS. In some illustrative examples, the comb structure of the PRS may be repeated across the plurality of resource blocks as shown in FIG. 8B or FIG. 8C, where some resource blocks include data for the PRS and some resource blocks do not include data for the PRS. The repetition may be based on an X-resource block boundary for the PRS, where the comb structure of the PRS is repeated once in every four consecutive resource blocks of the plurality of resource blocks, twice in every four consecutive resource blocks of the plurality of resource blocks, etc. In one illustrative example, as shown in FIG. 8B, the comb structure 807 is repeated in RB2 and RB6 (which include data for the reference signal, such as a PRS), but not in RB1, RB3, RB4, RB5, RB7, or RB8 (which do not include data for the reference signal, such as a PRS). In another illustrative example, as shown in FIG. 8C, the comb structure

811 is repeated in RB1, RB4, RB5, and RB8 (which include data for the reference signal, such as a PRS), but not in RB2, RB3, RB6, or RB7 (which do not include data for the reference signal, such as a PRS).

[00167] In some aspects, the first network entity (or component thereof) transmits, for receipt by the UE, information indicating resource elements of the plurality of resource blocks that include data associated with the PRS. For instance, as described herein, the information may include a bitmap. The bitmap may also be referred to as a frequency bin bitmap, and can include a value of 0 or 1 for each available subcarrier for a particular RB. In one illustrative example, referring to FIG. 9B, a bitmap can be specified as 010000001100 for REs in frequency domain, indicating that subcarriers corresponding to REs 2, 9, and 10 (along the Y-axis of Figure 9B) are given to the reference signal resource (e.g., to a particular PRS resource).

[00168] In some examples, a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS. In some cases, the plurality of consecutive symbols is associated with a common subcarrier index. Each resource block from the plurality of resource blocks may include a set of non-uniform subcarriers including data associated with the PRS. For example, as shown in FIG. 9A, eight consecutive symbols for the non-uniform set of subcarriers 2, 5, 7, 11, and 12 (out of the twelve available subcarriers for the resource block 902) are assigned to resources of the corresponding reference signal (e.g., PRS resources).

[00169] In some cases, the first network entity (or component thereof) transmits a message indicating that resource elements of a first resource block associated with a first PRS resource of the PRS are to be combined with resource elements of a second resource block associated with a second PRS resource of the PRS. Based on the message, the UE (or component thereof) can combine the resource elements of the first resource block with the resource elements of the second resource block. In some cases, the message further indicates that one or more resource elements from the resource elements of the first resource block combined with the resource elements of the second resource block are to be removed (e.g., prior to the combining). For instance, the wireless communication device (or component thereof) can remove the one or

more resource elements or a network entity (e.g., the first network entity or the second network entity).

[00170] At block 1204, the first network entity (or component thereof) receives, from the UE, a phase measurement report. The phase measurement report includes information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks. In some aspects, the first network entity (or component thereof) transmits, for receipt by the UE, a carrier phase measurement request for reporting phase measurements for one or more subcarrier set pairs of the plurality of resource blocks.

[00171] FIG. 13 illustrates an example of a computing system 1370 of a user equipment (UE) 1307. In some examples, the UE 1307 can include a mobile phone, router, tablet computer, laptop computer, tracking device, wearable device (e.g., a smart watch, glasses, an XR device, etc.), Internet of Things (IoT) device, and/or other device used by a user to communicate over a wireless communications network. The computing system 1370 includes software and hardware components that can be electrically coupled via a bus 1389 (or may otherwise be in communication, as appropriate). For example, the computing system 1370 includes one or more processors 1384. The one or more processors 1384 can include one or more CPUs, ASICs, FPGAs, APs, GPUs, VPUs, NSPs, microcontrollers, dedicated hardware, any combination thereof, and/or other processing device or system. The bus 1389 can be used by the one or more processors 1384 to communicate between cores and/or with the one or more memory devices 1386.

[00172] The computing system 1370 may also include one or more memory devices 1386, one or more digital signal processors (DSPs) 1382, one or more subscriber identity modules (SIMs) 1374, one or more modems 1376, one or more wireless transceivers 1378, an antenna 1387, one or more input devices 1372 (e.g., a camera, a mouse, a keyboard, a touch sensitive screen, a touch pad, a keypad, a microphone, and/or the like), and one or more output devices 1380 (e.g., a display, a speaker, a printer, and/or the like). As used herein, the one or more wireless transceivers 1378 can include one or more receiving devices (e.g., receivers) and/or one or more transmitting devices (e.g., transmitters).

[00173] The one or more wireless transceivers 1378 can transmit and receive wireless signals (e.g., signal 1388) via antenna 1387 to and from one or more other devices, such as one or more other UEs, network nodes or entities (e.g., base stations such as eNBs and/or gNBs, WiFi routers, etc.), cloud networks, and/or the like. As described herein, the one or more wireless transceivers 1378 can include a combined transmitter/receiver, discrete transmitters, discrete receivers, or any combination thereof. In some examples, the computing system 1370 can include multiple antennae. The wireless signal 1388 may be transmitted via a wireless network. The wireless network may be any wireless network, such as a cellular or telecommunications network (e.g., 3G, 4G, 5G, etc.), wireless local area network (e.g., a WiFi network), a BluetoothTM network, and/or other network. In some examples, the one or more wireless transceivers 1378 may include a radio frequency (RF) front end including one or more components, such as an amplifier, a mixer (also referred to as a signal multiplier) for signal down conversion, a frequency synthesizer (also referred to as an oscillator) that provides signals to the mixer, a baseband filter, an analog-to-digital converter (ADC), one or more power amplifiers, among other components. The RF front-end can generally handle selection and conversion of the wireless signals 1388 into a baseband or intermediate frequency and can convert the RF signals to the digital domain.

[00174] In some cases, the computing system 1370 can include a coding-decoding device (or CODEC) configured to encode and/or decode data transmitted and/or received using the one or more wireless transceivers 1378. In some cases, the computing system 1370 can include an encryption-decryption device or component configured to encrypt and/or decrypt data (e.g., according to the AES and/or DES standard) transmitted and/or received by the one or more wireless transceivers 1378.

[00175] The one or more SIMs 1374 can each securely store an International Mobile Subscriber Identity (IMSI) number and a related key assigned to the user of the UE 1307. The IMSI and the key can be used to identify and authenticate the subscriber when accessing a network provided by a network service provider or operator associated with the one or more SIMs 1374. The one or more modems 1376 can modulate one or more signals to encode information for transmission using the one or more wireless transceivers 1378. The one or more modems 1376 can also demodulate signals received by the one or more wireless transceivers

1378 in order to decode the transmitted information. In some examples, the one or more modems 1376 can include a 4G (or LTE) modem, a 5G (or NR) modem, a Bluetooth™ modem, a modem configured for vehicle-to-everything (V2X) communications, and/or other types of modems. In some examples, the one or more modems 1376 and the one or more wireless transceivers 1378 can be used for communicating data for the one or more SIMs 1374.

[00176] The computing system 1370 can also include (and/or be in communication with) one or more non-transitory machine-readable storage media or storage devices (e.g., one or more memory devices 1386), which can include, without limitation, local and/or network accessible storage, a disk drive, a drive array, an optical storage device, a solid-state storage device such as a RAM and/or a ROM, which can be programmable, flash-updateable and/or the like. Such storage devices may be configured to implement any appropriate data storage, including without limitation, various file systems, database structures, and/or the like.

[00177] In various aspects, functions may be stored as one or more computer-program products (e.g., instructions or code) in memory device(s) 1386 and executed by the one or more processor(s) 1384 and/or the one or more DSPs 1382. The computing system 1370 can also include software elements (e.g., located within the one or more memory devices 1386), including, for example, an operating system, device drivers, executable libraries, and/or other code, such as one or more application programs, which may include computer programs implementing the functions provided by various aspects, and/or may be designed to implement methods and/or configure systems, as described herein.

[00178] In some aspects, the UE 1307 can include means for performing operations described herein. The means can include one or more of the components of the computing system 1370. For example, the means for performing operations described herein may include one or more of input device(s) 1372, SIM(s) 1374, modems(s) 1376, wireless transceiver(s) 1378, output device(s) (1380), DSP(s) 1382, processors (1384), memory device(s) 1386, and/or antenna(s) 1387.

[00179] In some aspects, the UE 1307 can include means for receiving resource configuration information, wherein the resource configuration information is based on a threshold associated with the apparatus, and wherein the resource configuration information

indicates a time-gap for transmission of Sounding Reference Signal (SRS) resources. In some aspects, the UE 1307 may further include means for transmitting one or more SRS resources based on the time-gap indicated by the resource configuration information.

[00180] In some examples, the means for receiving can include the one or more wireless transceivers 1378, the one or more modems 1376, the one or more SIMs 1374, the one or more processors 1384, the one or more DSPs 1382, the one or more memory devices 1386, any combination thereof, or other component(s) of the client device. In some examples, the means for determining can include the one or more processors 1384, the one or more DSPs 1382, the one or more memory devices 1386, any combination thereof, or other component(s) of the client device. In some examples, the means for transmitting can include the one or more wireless transceivers 1378, the one or more modems 1376, the one or more SIMs 1374, the one or more processors 1384, the one or more DSPs 1382, the one or more memory devices 1386, any combination thereof, or other component(s) of the client device.

[00181] In some cases, the computing device or apparatus may include various components, such as one or more input devices, one or more output devices, one or more processors, one or more microprocessors, one or more microcomputers, one or more cameras, one or more sensors, and/or other component(s) that are configured to carry out the steps of processes described herein. In some examples, the computing device may include a display, one or more network interfaces configured to communicate and/or receive the data, any combination thereof, and/or other component(s). The one or more network interfaces can be configured to communicate and/or receive wired and/or wireless data, including data according to the 3G, 4G, 5G, and/or other cellular standard, data according to the Wi-Fi (802.11x) standards, data according to the BluetoothTM standard, data according to the Internet Protocol (IP) standard, and/or other types of data.

[00182] The components of the computing device can be implemented in circuitry. For example, the components can include and/or can be implemented using electronic circuits or other electronic hardware, which can include one or more programmable electronic circuits (e.g., microprocessors, graphics processing units (GPUs), DSPs, central processing units (CPUs), and/or other suitable electronic circuits), and/or can include and/or be implemented

using computer software, firmware, or any combination thereof, to perform the various operations described herein.

[00183] FIG. 14 is a diagram illustrating an example of a system for implementing certain aspects of the present technology. In particular, FIG. 14 illustrates an example of computing system 1400, which can be for example any computing device making up internal computing system, a remote computing system, a camera, or any component thereof in which the components of the system are in communication with each other using connection 1405. Connection 1405 can be a physical connection using a bus, or a direct connection into processor 1410, such as in a chipset architecture. Connection 1405 can also be a virtual connection, networked connection, or logical connection.

[00184] In some aspects, computing system 1400 is a distributed system in which the functions described in this disclosure can be distributed within a datacenter, multiple data centers, a peer network, etc. In some aspects, one or more of the described system components represents many such components each performing some or all of the function for which the component is described. In some aspects, the components can be physical or virtual devices.

[00185] Example system 1400 includes at least one processing unit (CPU or processor) 1410 and connection 1405 that couples various system components including system memory 1415, such as read-only memory (ROM) 1420 and random-access memory (RAM) 1425 to processor 1410. Computing system 1400 can include a cache 1411 of high-speed memory connected directly with, in close proximity to, or integrated as part of processor 1410.

[00186] Processor 1410 can include any general-purpose processor and a hardware service or software service, such as services 1432, 1434, and 1436 stored in storage device 1430, configured to control processor 1410 as well as a special-purpose processor where software instructions are incorporated into the actual processor design. Processor 1410 may essentially be a completely self-contained computing system, containing multiple cores or processors, a bus, memory controller, cache, etc. A multi-core processor may be symmetric or asymmetric.

[00187] To enable user interaction, computing system 1400 includes an input device 1445, which can represent any number of input mechanisms, such as a microphone for speech, a

touch-sensitive screen for gesture or graphical input, keyboard, mouse, motion input, speech, etc. Computing system 1400 can also include output device 1435, which can be one or more of a number of output mechanisms. In some instances, multimodal systems can enable a user to provide multiple types of input/output to communicate with computing system 1400. Computing system 1400 can include communications interface 1440, which can generally govern and manage the user input and system output.

[00188] The communication interface may perform or facilitate receipt and/or transmission wired or wireless communications using wired and/or wireless transceivers, including those making use of an audio jack/plug, a microphone jack/plug, a universal serial bus (USB) port/plug, an Apple® Lightning® port/plug, an Ethernet port/plug, a fiber optic port/plug, a proprietary wired port/plug, a BLUETOOTH® wireless signal transfer, a BLUETOOTH® low energy (BLE) wireless signal transfer, an IBEACON® wireless signal transfer, a radio-frequency identification (RFID) wireless signal transfer, near-field communications (NFC) wireless signal transfer, dedicated short range communication (DSRC) wireless signal transfer, 802.11 Wi-Fi wireless signal transfer, WLAN signal transfer, Visible Light Communication (VLC), Worldwide Interoperability for Microwave Access (WiMAX), Infrared (IR) communication wireless signal transfer, Public Switched Telephone Network (PSTN) signal transfer, Integrated Services Digital Network (ISDN) signal transfer, 3G/4G/5G/long term evolution (LTE) cellular data network wireless signal transfer, ad-hoc network signal transfer, radio wave signal transfer, microwave signal transfer, infrared signal transfer, visible light signal transfer, ultraviolet light signal transfer, wireless signal transfer along the electromagnetic spectrum, or some combination thereof.

[00189] The communications interface 1440 may also include one or more GNSS receivers or transceivers that are used to determine a location of the computing system 1400 based on receipt of one or more signals from one or more satellites associated with one or more GNSS systems. GNSS systems include, but are not limited to, the US-based Global Positioning System (GPS), the Russia-based Global Navigation Satellite System (GLONASS), the China-based BeiDou Navigation Satellite System (BDS), and the Europe-based Galileo GNSS. There is no restriction on operating on any particular hardware arrangement, and therefore the basic

features here may easily be substituted for improved hardware or firmware arrangements as they are developed.

[00190] Storage device 1430 can be a non-volatile and/or non-transitory and/or computer-readable memory device and can be a hard disk or other types of computer readable media which can store data that are accessible by a computer, such as magnetic cassettes, flash memory cards, solid state memory devices, digital versatile disks, cartridges, a floppy disk, a flexible disk, a hard disk, magnetic tape, a magnetic strip/stripe, any other magnetic storage medium, flash memory, memristor memory, any other solid-state memory, a compact disc read only memory (CD-ROM) optical disc, a rewritable compact disc (CD) optical disc, digital video disk (DVD) optical disc, a blu-ray disc (BDD) optical disc, a holographic optical disc, another optical medium, a secure digital (SD) card, a micro secure digital (microSD) card, a Memory Stick® card, a smartcard chip, a Europay, Mastercard and Visa (EMV) chip, a subscriber identity module (SIM) card, a mini/micro/nano/pico SIM card, another integrated circuit (IC) chip/card, RAM, static RAM (SRAM), dynamic RAM (DRAM), ROM, programmable read-only memory (PROM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), flash EPROM (FLASHEPROM), cache memory (L1/L2/L3/L4/L5/L#), resistive random-access memory (RRAM/ReRAM), phase change memory (PCM), spin transfer torque RAM (STT-RAM), another memory chip or cartridge, and/or a combination thereof.

[00191] The storage device 1430 can include software services, servers, services, etc., that when the code that defines such software is executed by the processor 1410, it causes the system to perform a function. In some aspects, a hardware service that performs a particular function can include the software component stored in a computer-readable medium in connection with the necessary hardware components, such as processor 1410, connection 1405, output device 1435, etc., to carry out the function. The term “computer-readable medium” includes, but is not limited to, portable or non-portable storage devices, optical storage devices, and various other mediums capable of storing, containing, or carrying instruction(s) and/or data. A computer-readable medium may include a non-transitory medium in which data can be stored and that does not include carrier waves and/or transitory electronic signals propagating wirelessly or over wired connections.

[00192] As used herein, the term “computer-readable medium” includes, but is not limited to, portable or non-portable storage devices, optical storage devices, and various other mediums capable of storing, containing, or carrying instruction(s) and/or data. A computer-readable medium may include a non-transitory medium in which data can be stored and that does not include carrier waves and/or transitory electronic signals propagating wirelessly or over wired connections. Examples of a non-transitory medium may include, but are not limited to, a magnetic disk or tape, optical storage media such as CD or DVD, flash memory, memory or memory devices. A computer-readable medium may have stored thereon code and/or machine-executable instructions that may represent a procedure, a function, a subprogram, a program, a routine, a subroutine, a module, a software package, a class, or any combination of instructions, data structures, or program statements. A code segment may be coupled to another code segment or a hardware circuit by passing and/or receiving information, data, arguments, parameters, or memory contents. Information, arguments, parameters, data, etc. may be passed, forwarded, or transmitted using any suitable means including memory sharing, message passing, token passing, network transmission, or the like.

[00193] In some aspects the computer-readable storage devices, mediums, and memories can include a cable or wireless signal containing a bit stream and the like. However, when mentioned, non-transitory computer-readable storage media expressly exclude media such as energy, carrier signals, electromagnetic waves, and signals per se.

[00194] Specific details are provided in the description above to provide a thorough understanding of the aspects and examples provided herein. However, it will be understood by one of ordinary skill in the art that the aspects may be practiced without these specific details. For clarity of explanation, in some instances the present technology may be presented as including individual functional blocks including functional blocks comprising devices, device components, steps or routines in a method embodied in software, or combinations of hardware and software. Additional components may be used other than those shown in the figures and/or described herein. For example, circuits, systems, networks, processes, and other components may be shown as components in block diagram form in order not to obscure the aspects in unnecessary detail. In other instances, well-known circuits, processes, algorithms, structures,

and techniques may be shown without unnecessary detail in order to avoid obscuring the aspects.

[00195] Individual aspects may be described above as a process or method which is depicted as a flowchart, a flow diagram, a data flow diagram, a structure diagram, or a block diagram. Although a flowchart may describe the operations as a sequential process, many of the operations can be performed in parallel or concurrently. In addition, the order of the operations may be re-arranged. A process is terminated when its operations are completed but may have additional steps not included in a figure. A process may correspond to a method, a function, a procedure, a subroutine, a subprogram, etc. When a process corresponds to a function, its termination can correspond to a return of the function to the calling function or the main function.

[00196] Processes and methods according to the above-described examples can be implemented using computer-executable instructions that are stored or otherwise available from computer-readable media. Such instructions can include, for example, instructions and data which cause or otherwise configure a general purpose computer, special purpose computer, or a processing device to perform a certain function or group of functions. Portions of computer resources used can be accessible over a network. The computer executable instructions may be, for example, binaries, intermediate format instructions such as assembly language, firmware, source code, etc. Examples of computer-readable media that may be used to store instructions, information used, and/or information created during methods according to described examples include magnetic or optical disks, flash memory, USB devices provided with non-volatile memory, networked storage devices, and so on.

[00197] Devices implementing processes and methods according to these disclosures can include hardware, software, firmware, middleware, microcode, hardware description languages, or any combination thereof, and can take any of a variety of form factors. When implemented in software, firmware, middleware, or microcode, the program code or code segments to perform the necessary tasks (e.g., a computer-program product) may be stored in a computer-readable or machine-readable medium. A processor(s) may perform the necessary tasks. Typical examples of form factors include laptops, smart phones, mobile phones, tablet

devices or other small form factor personal computers, personal digital assistants, rackmount devices, standalone devices, and so on. Functionality described herein also can be embodied in peripherals or add-in cards. Such functionality can also be implemented on a circuit board among different chips or different processes executing in a single device, by way of further example.

[00198] The instructions, media for conveying such instructions, computing resources for executing them, and other structures for supporting such computing resources are example means for providing the functions described in the disclosure.

[00199] In the foregoing description, aspects of the application are described with reference to specific aspects thereof, but those skilled in the art will recognize that the application is not limited thereto. Thus, while illustrative aspects of the application have been described in detail herein, it is to be understood that the inventive concepts may be otherwise variously embodied and employed, and that the appended claims are intended to be construed to include such variations, except as limited by the prior art. Various features and aspects of the above-described application may be used individually or jointly. Further, aspects can be utilized in any number of environments and applications beyond those described herein without departing from the broader spirit and scope of the specification. The specification and drawings are, accordingly, to be regarded as illustrative rather than restrictive. For the purposes of illustration, methods were described in a particular order. It should be appreciated that in alternate aspects, the methods may be performed in a different order than that described.

[00200] One of ordinary skill will appreciate that the less than (“<”) and greater than (“>”) symbols or terminology used herein can be replaced with less than or equal to (“≤”) and greater than or equal to (“≥”) symbols, respectively, without departing from the scope of this description.

[00201] Where components are described as being “configured to” perform certain operations, such configuration can be accomplished, for example, by designing electronic circuits or other hardware to perform the operation, by programming programmable electronic circuits (e.g., microprocessors, or other suitable electronic circuits) to perform the operation, or any combination thereof.

[00202] The phrase “coupled to” refers to any component that is physically connected to another component either directly or indirectly, and/or any component that is in communication with another component (e.g., connected to the other component over a wired or wireless connection, and/or other suitable communication interface) either directly or indirectly.

[00203] Claim language or other language reciting “at least one of” a set and/or “one or more” of a set indicates that one member of the set or multiple members of the set (in any combination) satisfy the claim. For example, claim language reciting “at least one of A and B” or “at least one of A or B” means A, B, or A and B. In another example, claim language reciting “at least one of A, B, and C” or “at least one of A, B, or C” means A, B, C, or A and B, or A and C, or B and C, or A and B and C. The language “at least one of” a set and/or “one or more” of a set does not limit the set to the items listed in the set. For example, claim language reciting “at least one of A and B” or “at least one of A or B” can mean A, B, or A and B, and can additionally include items not listed in the set of A and B.

[00204] 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, firmware, or combinations thereof. 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 implementation decisions should not be interpreted as causing a departure from the scope of the present application.

[00205] The techniques described herein may also be implemented in electronic hardware, computer software, firmware, or any combination thereof. Such techniques may be implemented in any of a variety of devices such as general purposes computers, wireless communication device handsets, or integrated circuit devices having multiple uses including application in wireless communication device handsets and other devices. Any features described as modules or components may be implemented together in an integrated logic

device or separately as discrete but interoperable logic devices. If implemented in software, the techniques may be realized at least in part by a computer-readable data storage medium comprising program code including instructions that, when executed, performs one or more of the methods described above. The computer-readable data storage medium may form part of a computer program product, which may include packaging materials. The computer-readable medium may include memory or data storage media, such as RAM such as synchronous dynamic random access memory (SDRAM), ROM, non-volatile random access memory (NVRAM), EEPROM, flash memory, magnetic or optical data storage media, and the like. The techniques additionally, or alternatively, may be realized at least in part by a computer-readable communication medium that carries or communicates program code in the form of instructions or data structures and that can be accessed, read, and/or executed by a computer, such as propagated signals or waves.

[00206] The program code may be executed by a processor, which may include one or more processors, such as one or more DSPs, general purpose microprocessors, an application specific integrated circuits (ASICs), field programmable logic arrays (FPGAs), or other equivalent integrated or discrete logic circuitry. Such a processor may be configured to perform any of the techniques described in this disclosure. 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. Accordingly, the term “processor,” as used herein may refer to any of the foregoing structure, any combination of the foregoing structure, or any other structure or apparatus suitable for implementation of the techniques described herein.

[00207] Illustrative examples of the disclosure include:

[00208] Aspect 1: A method for wireless communications at a first user equipment (UE), comprising: receiving, at the UE, a plurality of resource blocks associated with a positioning reference signal (PRS), wherein a comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks; and transmitting a phase measurement report to a

first network entity, the phase measurement report including information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks, wherein a subcarrier set includes at least one subcarrier.

[00209] Aspect 2: The method of Aspect 1, wherein, according to the comb structure, a first subset of resource blocks from the plurality of resource blocks includes data for the PRS.

[00210] Aspect 3: The method of any of Aspects 1 to 2, wherein, according to the comb structure, a second subset of resource blocks from the plurality of resource blocks does not include data for the PRS.

[00211] Aspect 4: The method of any of Aspects 1 to 3, wherein the comb structure of the PRS is repeated once in every four consecutive resource blocks of the plurality of resource blocks.

[00212] Aspect 5: The method of any of Aspects 1 to 4, wherein the comb structure of the PRS is repeated twice in every four consecutive resource blocks of the plurality of resource blocks.

[00213] Aspect 6: The method of any of Aspects 1 to 5, further comprising: receiving, at the UE from the first network entity, information indicating resource elements of the plurality of resource blocks that include data associated with the PRS.

[00214] Aspect 7: The method of any of Aspects 1 to 6, wherein the information includes a bitmap.

[00215] Aspect 8: The method of any of Aspects 1 to 7, wherein a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS.

[00216] Aspect 9: The method of any of Aspects 1 to 8, wherein the plurality of consecutive symbols is associated with a common subcarrier index.

[00217] Aspect 10: The method of any of Aspects 1 to 9, wherein each resource block from the plurality of resource blocks includes a set of non-uniform subcarriers including data associated with the PRS.

[00218] Aspect 11: The method of any of Aspects 1 to 10, wherein a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS, and wherein each resource block from the plurality of resource blocks includes a set of non-uniform subcarriers including data associated with the PRS.

[00219] Aspect 12: The method of any of Aspects 1 to 11, further comprising: receiving, at the UE, a message indicating that resource elements of a first resource block associated with a first PRS resource of the PRS are to be combined with resource elements of a second resource block associated with a second PRS resource of the PRS; and combining, based on the message, the resource elements of the first resource block with the resource elements of the second resource block.

[00220] Aspect 13: The method of any of Aspects 1 to 12, wherein one or more resource elements from the resource elements of the first resource block combined with the resource elements of the second resource block are removed.

[00221] Aspect 14: The method of any of Aspects 1 to 13, wherein the plurality of resource blocks are received from the first network entity.

[00222] Aspect 15: The method of any of Aspects 1 to 14, wherein the first network entity is a location server.

[00223] Aspect 16: The method of any of Aspects 1 to 15, wherein the plurality of resource blocks are received from a second network entity, the second network entity being different from the first network entity.

[00224] Aspect 17: The method of any of Aspects 1 to 16, wherein the first network entity is a location server and the second network entity is a base station.

[00225] Aspect 18: The method of any of Aspects 1 to 17, further comprising: receiving, at the UE from the first network entity, a carrier phase measurement request for reporting phase measurements for one or more subcarrier set pairs of the plurality of resource blocks; and transmitting the phase measurement report to the first network entity based on the carrier phase measurement request.

[00226] Aspect 19: The method of any of Aspects 1 to 18, further comprising: measuring, at the UE based on the carrier phase measurement request, the phase difference between the at least one subcarrier set pair of the one or more subcarrier set pairs of subcarriers.

[00227] Aspect 20: A method for wireless communications at a first network entity, comprising: transmitting, to a second network entity, a message including a configuration for a plurality of resource blocks associated with a positioning reference signal (PRS), wherein, based on the configuration, a comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks; and receiving, from a user equipment (UE), a phase measurement report, the phase measurement report including information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks.

[00228] Aspect 21: The method of Aspect 20, wherein the first network entity is a location server and the second network entity is a base station.

[00229] Aspect 22: The method of any of Aspects 20 to 21, wherein, according to the comb structure, a first subset of resource blocks from the plurality of resource blocks includes data for the PRS.

[00230] Aspect 23: The method of any of Aspects 20 to 22, wherein, according to the comb structure, a second subset of resource blocks from the plurality of resource blocks does not include data for the PRS.

[00231] Aspect 24: The method of any of Aspects 20 to 23, wherein the comb structure of the PRS is repeated once in every four consecutive resource blocks of the plurality of resource blocks.

[00232] Aspect 25: The method of any of Aspects 20 to 24, wherein the comb structure of the PRS is repeated twice in every four consecutive resource blocks of the plurality of resource blocks.

[00233] Aspect 26: The method of any of Aspects 20 to 25, further comprising: transmitting, at the first network entity for receipt by the UE, information indicating resource elements of the plurality of resource blocks that include data associated with the PRS.

[00234] Aspect 27: The method of any of Aspects 20 to 26, wherein the information includes a bitmap.

[00235] Aspect 28: The method of any of Aspects 20 to 27, wherein a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS.

[00236] Aspect 29: The method of any of Aspects 20 to 28, wherein the plurality of consecutive symbols is associated with a common subcarrier index.

[00237] Aspect 30: The method of any of Aspects 20 to 29, wherein each resource block from the plurality of resource blocks includes a set of non-uniform subcarriers including data associated with the PRS.

[00238] Aspect 31: The method of any of Aspects 20 to 30, wherein a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS, and wherein each resource block from the plurality of resource blocks includes a set of non-uniform subcarriers including data associated with the PRS.

[00239] Aspect 32: The method of any of Aspects 20 to 31, further comprising: transmitting, at the first network entity, a message indicating that resource elements of a first resource block associated with a first PRS resource of the PRS are to be combined with resource elements of a second resource block associated with a second PRS resource of the PRS.

[00240] Aspect 33: The method of any of Aspects 20 to 32, wherein the message further indicates that one or more resource elements from the resource elements of the first resource block combined with the resource elements of the second resource block are to be removed.

[00241] Aspect 34: The method of any of Aspects 20 to 33, wherein the plurality of resource blocks are transmitted to the UE from the second network entity.

[00242] Aspect 35: The method of any of Aspects 20 to 34, further comprising: transmitting, at the first network entity for receipt by the UE, a carrier phase measurement request for reporting phase measurements for one or more subcarrier set pairs of the plurality of resource blocks.

[00243] Aspect 36: An apparatus for wireless communications, comprising: a memory; and one or more processors coupled to the memory, the one or more processors configured to: receive a plurality of resource blocks associated with a positioning reference signal (PRS), wherein a comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks; and transmit a phase measurement report to a first network entity, the phase measurement report including information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks, wherein a subcarrier set includes at least one subcarrier.

[00244] Aspect 37: The apparatus of Aspect 36, wherein, according to the comb structure, a first subset of resource blocks from the plurality of resource blocks includes data for the PRS.

[00245] Aspect 38: The apparatus of any of Aspects 36 to 37, wherein, according to the comb structure, a second subset of resource blocks from the plurality of resource blocks does not include data for the PRS.

[00246] Aspect 39: The apparatus of any of Aspects 36 to 38, wherein the comb structure of the PRS is repeated once in every four consecutive resource blocks of the plurality of resource blocks.

[00247] Aspect 40: The apparatus of any of Aspects 36 to 39, wherein the comb structure of the PRS is repeated twice in every four consecutive resource blocks of the plurality of resource blocks.

[00248] Aspect 41: The apparatus of any of Aspects 36 to 40, wherein the one or more processors are configured to: receive, at the UE from the first network entity, information indicating resource elements of the plurality of resource blocks that include data associated with the PRS.

[00249] Aspect 42: The apparatus of any of Aspects 36 to 41, wherein the information includes a bitmap.

[00250] Aspect 43: The apparatus of any of Aspects 36 to 42, wherein a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS.

[00251] Aspect 44: The apparatus of any of Aspects 36 to 43, wherein the plurality of consecutive symbols is associated with a common subcarrier index.

[00252] Aspect 45: The apparatus of any of Aspects 36 to 44, wherein each resource block from the plurality of resource blocks includes a set of non-uniform subcarriers including data associated with the PRS.

[00253] Aspect 46: The apparatus of any of Aspects 36 to 45, wherein a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS, and wherein each resource block from the plurality of resource blocks includes a set of non-uniform subcarriers including data associated with the PRS.

[00254] Aspect 47: The apparatus of any of Aspects 36 to 46, wherein the one or more processors are configured to: receive a message indicating that resource elements of a first resource block associated with a first PRS resource of the PRS are to be combined with resource elements of a second resource block associated with a second PRS resource of the PRS; and combine, based on the message, the resource elements of the first resource block with the resource elements of the second resource block.

[00255] Aspect 48: The apparatus of any of Aspects 36 to 47, wherein one or more resource elements from the resource elements of the first resource block combined with the resource elements of the second resource block are removed.

[00256] Aspect 49: The apparatus of any of Aspects 36 to 48, wherein the plurality of resource blocks are received from the first network entity.

[00257] Aspect 50: The apparatus of any of Aspects 36 to 49, wherein the first network entity is a location server.

[00258] Aspect 51: The apparatus of any of Aspects 36 to 50, wherein the plurality of resource blocks are received from a second network entity, the second network entity being different from the first network entity.

[00259] Aspect 52: The apparatus of any of Aspects 36 to 51, wherein the first network entity is a location server and the second network entity is a base station.

[00260] Aspect 53: The apparatus of any of Aspects 36 to 52, wherein the one or more processors are configured to: receive, from the first network entity, a carrier phase measurement request for report phase measurements for one or more subcarrier set pairs of the plurality of resource blocks; and transmit the phase measurement report to the first network entity based on the carrier phase measurement request.

[00261] Aspect 54: The apparatus of any of Aspects 36 to 53, wherein the one or more processors are configured to: measure, based on the carrier phase measurement request, the phase difference between the at least one subcarrier set pair of the one or more subcarrier set pairs of subcarriers.

[00262] Aspect 55: An apparatus for wireless communications, comprising: a memory; and one or more processors coupled to the memory, the one or more processors configured to: transmit, to a network entity, a message including a configuration for a plurality of resource blocks associated with a positioning reference signal (PRS), wherein, based on the configuration, a comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks; and receive, from a user equipment (UE), a phase measurement

report, the phase measurement report including information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks.

[00263] Aspect 56: The apparatus of Aspect 55, wherein the apparatus is implemented as a location server and the network entity is a base station.

[00264] Aspect 57: The apparatus of any of Aspects 55 to 56, wherein, according to the comb structure, a first subset of resource blocks from the plurality of resource blocks includes data for the PRS.

[00265] Aspect 58: The apparatus of any of Aspects 55 to 57, wherein, according to the comb structure, a second subset of resource blocks from the plurality of resource blocks does not include data for the PRS.

[00266] Aspect 59: The apparatus of any of Aspects 55 to 58, wherein the comb structure of the PRS is repeated once in every four consecutive resource blocks of the plurality of resource blocks.

[00267] Aspect 60: The apparatus of any of Aspects 55 to 59, wherein the comb structure of the PRS is repeated twice in every four consecutive resource blocks of the plurality of resource blocks.

[00268] Aspect 61: The apparatus of any of Aspects 55 to 60, wherein the one or more processors are configured to: transmit, for receipt by the UE, information indicating resource elements of the plurality of resource blocks that include data associated with the PRS.

[00269] Aspect 62: The apparatus of any of Aspects 55 to 61, wherein the information includes a bitmap.

[00270] Aspect 63: The apparatus of any of Aspects 55 to 62, wherein a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS.

[00271] Aspect 64: The apparatus of any of Aspects 55 to 63, wherein the plurality of consecutive symbols is associated with a common subcarrier index.

[00272] Aspect 65: The apparatus of any of Aspects 55 to 64, wherein each resource block from the plurality of resource blocks includes a set of non-uniform subcarriers including data associated with the PRS.

[00273] Aspect 66: The apparatus of any of Aspects 55 to 65, wherein a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS, and wherein each resource block from the plurality of resource blocks includes a set of non-uniform subcarriers including data associated with the PRS.

[00274] Aspect 67: The apparatus of any of Aspects 55 to 66, wherein the one or more processors are configured to: transmit a message indicating that resource elements of a first resource block associated with a first PRS resource of the PRS are to be combined with resource elements of a second resource block associated with a second PRS resource of the PRS.

[00275] Aspect 68: The apparatus of any of Aspects 55 to 67, wherein the message further indicates that one or more resource elements from the resource elements of the first resource block combined with the resource elements of the second resource block are to be removed.

[00276] Aspect 69: The apparatus of any of Aspects 55 to 68, wherein the plurality of resource blocks are transmitted to the UE from the network entity.

[00277] Aspect 70: The apparatus of any of Aspects 55 to 69, wherein the one or more processors are configured to: transmit, for receipt by the UE, a carrier phase measurement request for report phase measurements for one or more subcarrier set pairs of the plurality of resource blocks.

[00278] Aspect 71: At least one non-transitory computer-readable medium containing instructions which, when executed by one or more processors, cause the one or more processors to perform a method according to any of Aspects 1 to 19.

[00279] Aspect 72: An apparatus comprising means for performing a method according to any of Aspects 1 to 19.

[00280] Aspect 73: At least one non-transitory computer-readable medium containing instructions which, when executed by one or more processors, cause the one or more processors to perform a method according to any of Aspects 20 to 35.

[00281] Aspect 74: An apparatus comprising means for performing a method according to any of Aspects 20 to 35.

CLAIMS

What is claimed is:

1. A method for wireless communications at a user equipment (UE), comprising:
receiving, at the UE, a plurality of resource blocks associated with a positioning reference signal (PRS), wherein a comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks; and
transmitting a phase measurement report to a first network entity, the phase measurement report including information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks, wherein a subcarrier set includes at least one subcarrier.
2. The method of claim 1, wherein, according to the comb structure, a first subset of resource blocks from the plurality of resource blocks includes data for the PRS.
3. The method of claim 2, wherein, according to the comb structure, a second subset of resource blocks from the plurality of resource blocks does not include data for the PRS.
4. The method of claim 1, wherein the comb structure of the PRS is repeated once in every four consecutive resource blocks of the plurality of resource blocks.
5. The method of claim 1, wherein the comb structure of the PRS is repeated twice in every four consecutive resource blocks of the plurality of resource blocks.
6. The method of claim 1, further comprising:
receiving, at the UE from the first network entity, information indicating resource elements of the plurality of resource blocks that include data associated with the PRS.
7. The method of claim 6, wherein the information includes a bitmap.

8. The method of claim 1, wherein a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS.

9. The method of claim 8, wherein the plurality of consecutive symbols is associated with a common subcarrier index.

10. The method of claim 1, wherein each resource block from the plurality of resource blocks includes a set of non-uniform subcarriers including data associated with the PRS.

11. The method of claim 1, wherein a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS, and wherein each resource block from the plurality of resource blocks includes a set of non-uniform subcarriers including data associated with the PRS.

12. The method of claim 1, further comprising:
receiving, at the UE, a message indicating that resource elements of a first resource block associated with a first PRS resource of the PRS are to be combined with resource elements of a second resource block associated with a second PRS resource of the PRS; and
combining, based on the message, the resource elements of the first resource block with the resource elements of the second resource block.

13. The method of claim 12, wherein one or more resource elements from the resource elements of the first resource block combined with the resource elements of the second resource block are removed.

14. The method of claim 1, wherein the plurality of resource blocks are received from the first network entity.

15. The method of claim 1, wherein the first network entity is a location server.

16. The method of claim 1, wherein the plurality of resource blocks are received from a second network entity, the second network entity being different from the first network entity.

17. The method of claim 16, wherein the first network entity is a location server and the second network entity is a base station.

18. The method of claim 1, further comprising:
receiving, at the UE from the first network entity, a carrier phase measurement request for reporting phase measurements for one or more subcarrier set pairs of the plurality of resource blocks; and
transmitting the phase measurement report to the first network entity based on the carrier phase measurement request.

19. The method of claim 18, further comprising:
measuring, at the UE based on the carrier phase measurement request, the phase difference between the at least one subcarrier set pair of the one or more subcarrier set pairs of subcarriers.

20. A method for wireless communications at a first network entity, comprising:
transmitting, to a second network entity, a message including a configuration for a plurality of resource blocks associated with a positioning reference signal (PRS), wherein, based on the configuration, a comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks; and
receiving, from a user equipment (UE), a phase measurement report, the phase measurement report including information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks.

21. The method of claim 20, wherein the first network entity is a location server and the second network entity is a base station.

22. The method of claim 20, wherein, according to the comb structure, a first subset of resource blocks from the plurality of resource blocks includes data for the PRS.

23. The method of claim 22, wherein, according to the comb structure, a second subset of resource blocks from the plurality of resource blocks does not include data for the PRS.

24. The method of claim 20, wherein the comb structure of the PRS is repeated once in every four consecutive resource blocks of the plurality of resource blocks.

25. The method of claim 20, wherein the comb structure of the PRS is repeated twice in every four consecutive resource blocks of the plurality of resource blocks.

26. The method of claim 20, further comprising:
transmitting, at the first network entity for receipt by the UE, information indicating resource elements of the plurality of resource blocks that include data associated with the PRS.

27. The method of claim 26, wherein the information includes a bitmap.

28. The method of claim 20, wherein a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS.

29. The method of claim 28, wherein the plurality of consecutive symbols is associated with a common subcarrier index.

30. The method of claim 20, wherein each resource block from the plurality of resource blocks includes a set of non-uniform subcarriers including data associated with the PRS.

31. The method of claim 20, wherein a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS, and wherein each resource block from the plurality of resource blocks includes a set of non-uniform subcarriers including data associated with the PRS.

32. The method of claim 20, further comprising:
transmitting, at the first network entity, a message indicating that resource elements of a first resource block associated with a first PRS resource of the PRS are to be combined with resource elements of a second resource block associated with a second PRS resource of the PRS.

33. The method of claim 32, wherein the message further indicates that one or more resource elements from the resource elements of the first resource block combined with the resource elements of the second resource block are to be removed.

34. The method of claim 20, wherein the plurality of resource blocks are transmitted to the UE from the second network entity.

35. The method of claim 20, further comprising:
transmitting, at the first network entity for receipt by the UE, a carrier phase measurement request for reporting phase measurements for one or more subcarrier set pairs of the plurality of resource blocks.

36. An apparatus for wireless communications, comprising:
a memory; and
one or more processors coupled to the memory, the one or more processors configured to:

receive a plurality of resource blocks associated with a positioning reference signal (PRS), wherein a comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks, and

transmit a phase measurement report to a first network entity, the phase measurement report including information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks, wherein a subcarrier set includes at least one subcarrier.

37. The apparatus of claim 36, wherein, according to the comb structure, a first subset of resource blocks from the plurality of resource blocks includes data for the PRS.

38. The apparatus of claim 37, wherein, according to the comb structure, a second subset of resource blocks from the plurality of resource blocks does not include data for the PRS.

39. The apparatus of claim 36, wherein the comb structure of the PRS is repeated once in every four consecutive resource blocks of the plurality of resource blocks.

40. The apparatus of claim 36, wherein the comb structure of the PRS is repeated twice in every four consecutive resource blocks of the plurality of resource blocks.

41. The apparatus of claim 36, wherein the one or more processors are configured to:

receive, from the first network entity, information indicating resource elements of the plurality of resource blocks that include data associated with the PRS.

42. The apparatus of claim 41, wherein the information includes a bitmap.

43. The apparatus of claim 36, wherein a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS.

44. The apparatus of claim 43, wherein the plurality of consecutive symbols is associated with a common subcarrier index.

45. The apparatus of claim 36, wherein each resource block from the plurality of resource blocks includes a set of non-uniform subcarriers including data associated with the PRS.

46. The apparatus of claim 36, wherein a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS, and wherein each resource block from the plurality of resource blocks includes a set of non-uniform subcarriers including data associated with the PRS.

47. The apparatus of claim 36, wherein the one or more processors are configured to:

receive a message indicating that resource elements of a first resource block associated with a first PRS resource of the PRS are to be combined with resource elements of a second resource block associated with a second PRS resource of the PRS; and

combine, based on the message, the resource elements of the first resource block with the resource elements of the second resource block.

48. The apparatus of claim 47, wherein one or more resource elements from the resource elements of the first resource block combined with the resource elements of the second resource block are removed.

49. The apparatus of claim 36, wherein the plurality of resource blocks are received from the first network entity.

50. The apparatus of claim 36, wherein the first network entity is a location server.

51. The apparatus of claim 36, wherein the plurality of resource blocks are received from a second network entity, the second network entity being different from the first network entity.

52. The apparatus of claim 51, wherein the first network entity is a location server and the second network entity is a base station.

53. The apparatus of claim 36, wherein the one or more processors are configured to:

receive, from the first network entity, a carrier phase measurement request for report phase measurements for one or more subcarrier set pairs of the plurality of resource blocks; and

transmit the phase measurement report to the first network entity based on the carrier phase measurement request.

54. The apparatus of claim 53, wherein the one or more processors are configured to:

measure, based on the carrier phase measurement request, the phase difference between the at least one subcarrier set pair of the one or more subcarrier set pairs of subcarriers.

55. An apparatus for wireless communications, comprising:
a memory; and
one or more processors coupled to the memory, the one or more processors configured to:

transmit, to a network entity, a message including a configuration for a plurality of resource blocks associated with a positioning reference signal (PRS), wherein, based on the configuration, a comb structure of the PRS is repeated in less than all resource blocks of the plurality of resource blocks, and

receive, from a user equipment (UE), a phase measurement report, the phase measurement report including information associated with a measured phase difference between at least one subcarrier set pair of the plurality of resource blocks.

56. The apparatus of claim 55, wherein the apparatus is implemented as a location server and the network entity is a base station.

57. The apparatus of claim 55, wherein, according to the comb structure, a first subset of resource blocks from the plurality of resource blocks includes data for the PRS.

58. The apparatus of claim 57, wherein, according to the comb structure, a second subset of resource blocks from the plurality of resource blocks does not include data for the PRS.

59. The apparatus of claim 55, wherein the comb structure of the PRS is repeated once in every four consecutive resource blocks of the plurality of resource blocks.

60. The apparatus of claim 55, wherein the comb structure of the PRS is repeated twice in every four consecutive resource blocks of the plurality of resource blocks.

61. The apparatus of claim 55, wherein the one or more processors are configured to:

transmit, for receipt by the UE, information indicating resource elements of the plurality of resource blocks that include data associated with the PRS.

62. The apparatus of claim 61, wherein the information includes a bitmap.

63. The apparatus of claim 55, wherein a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS.

64. The apparatus of claim 63, wherein the plurality of consecutive symbols is associated with a common subcarrier index.

65. The apparatus of claim 55, wherein each resource block from the plurality of resource blocks includes a set of non-uniform subcarriers including data associated with the PRS.

66. The apparatus of claim 55, wherein a plurality of consecutive symbols of a resource block from the plurality of resource blocks include data associated with the PRS, and wherein each resource block from the plurality of resource blocks includes a set of non-uniform subcarriers including data associated with the PRS.

67. The apparatus of claim 55, wherein the one or more processors are configured to:

transmit a message indicating that resource elements of a first resource block associated with a first PRS resource of the PRS are to be combined with resource elements of a second resource block associated with a second PRS resource of the PRS.

68. The apparatus of claim 67, wherein the message further indicates that one or more resource elements from the resource elements of the first resource block combined with the resource elements of the second resource block are to be removed.

69. The apparatus of claim 55, wherein the plurality of resource blocks are transmitted to the UE from the network entity.

70. The apparatus of claim 55, wherein the one or more processors are configured to:

transmit, for receipt by the UE, a carrier phase measurement request for report phase measurements for one or more subcarrier set pairs of the plurality of resource blocks.

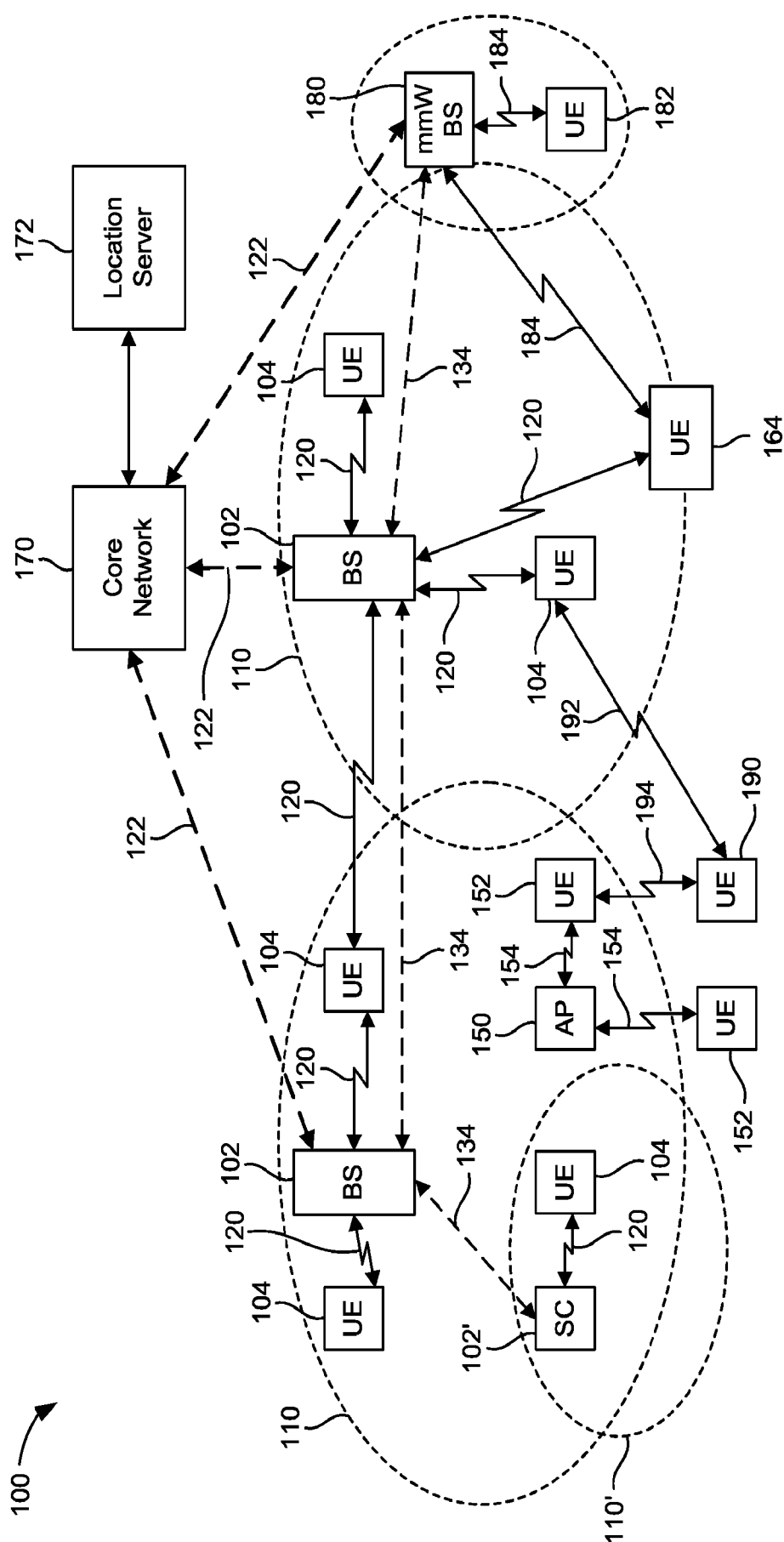


FIG. 1

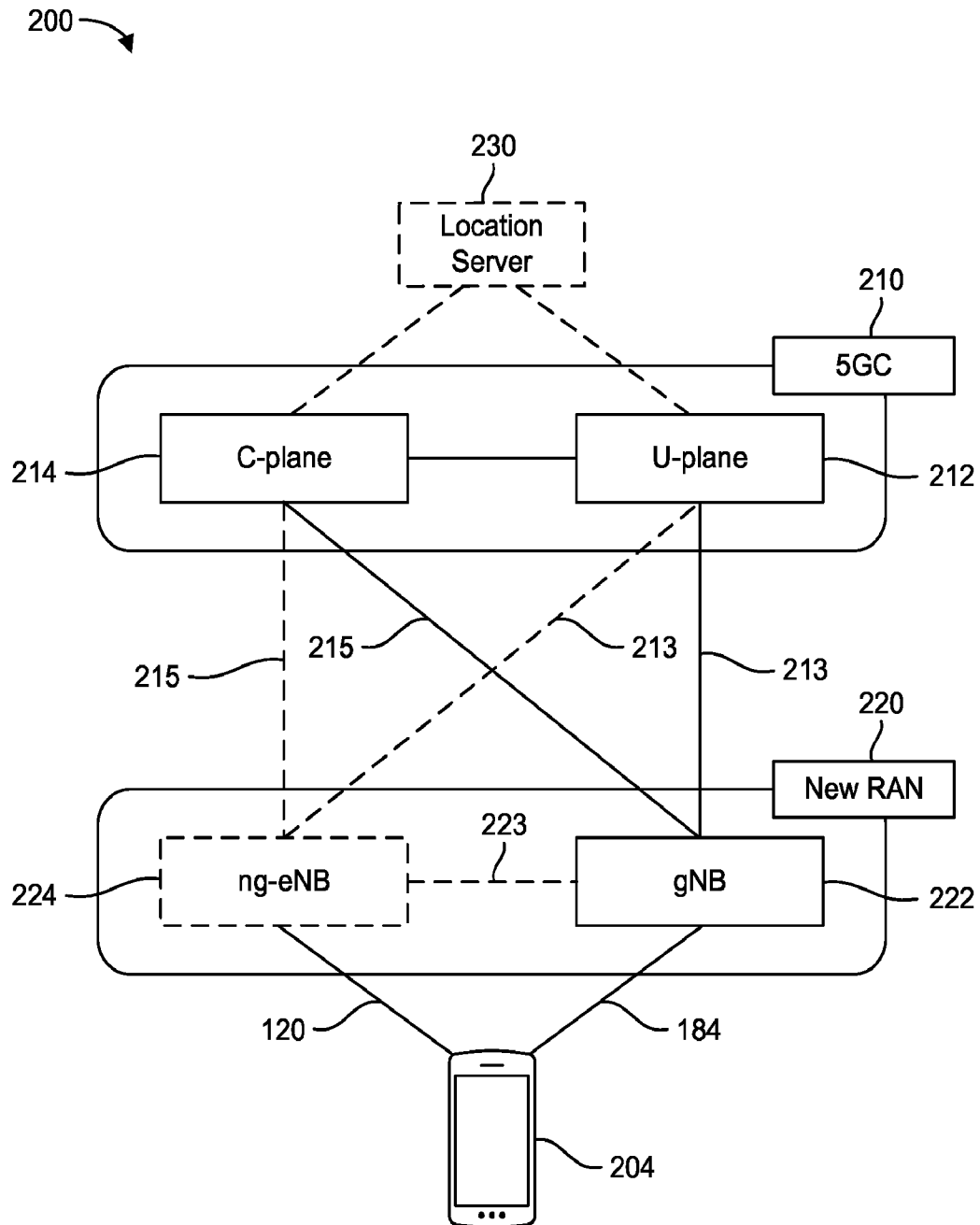


FIG. 2A

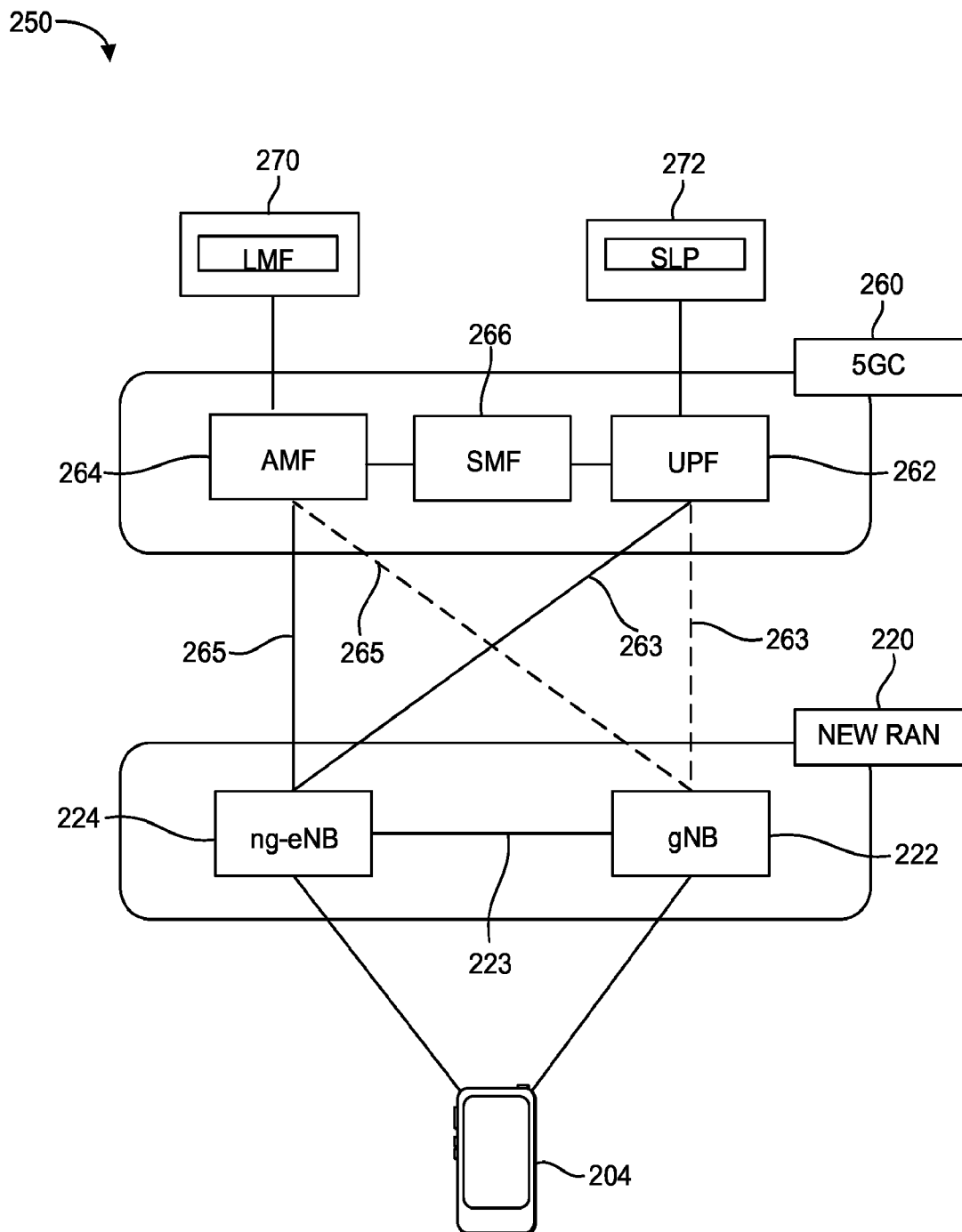


FIG. 2B

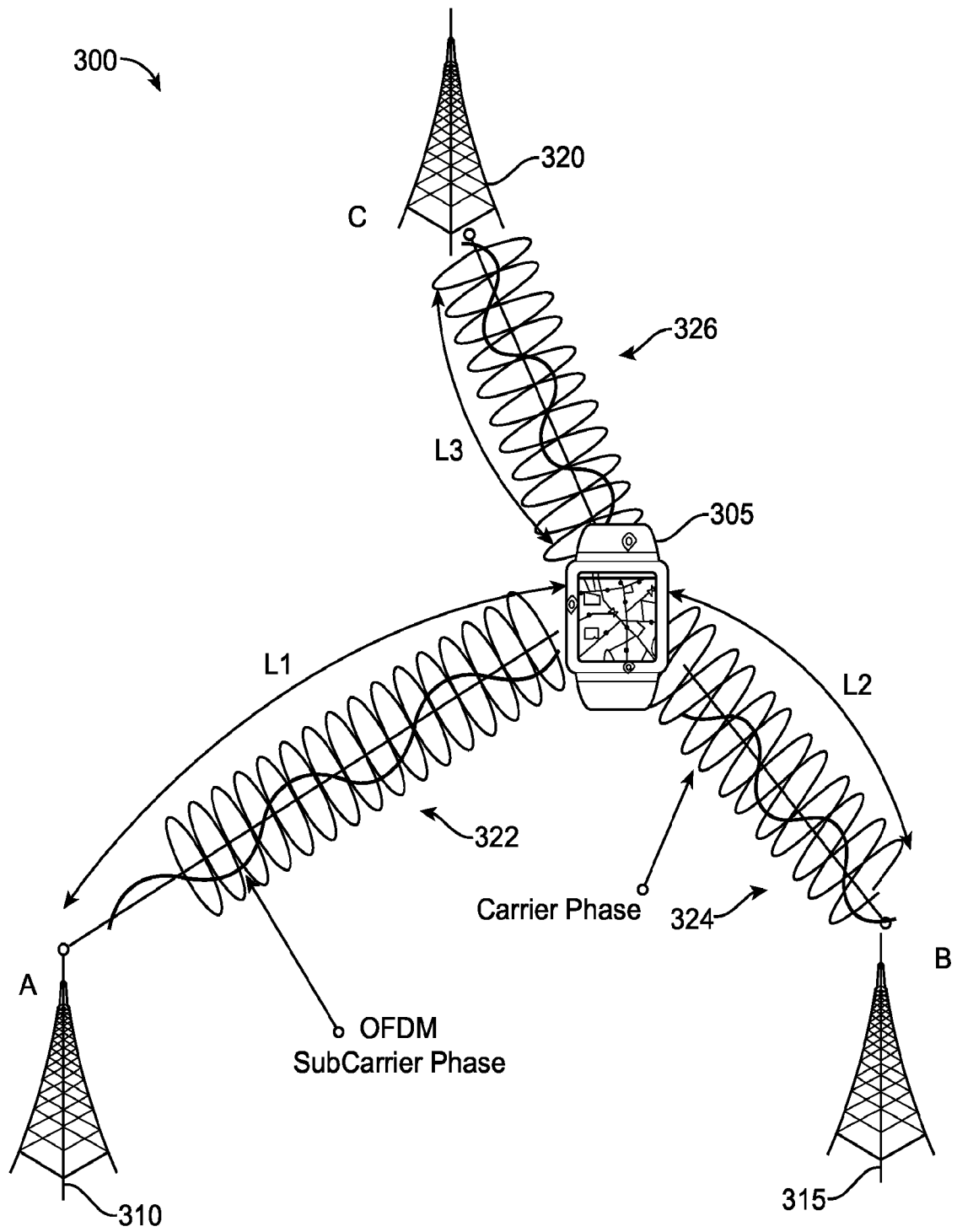


FIG. 3

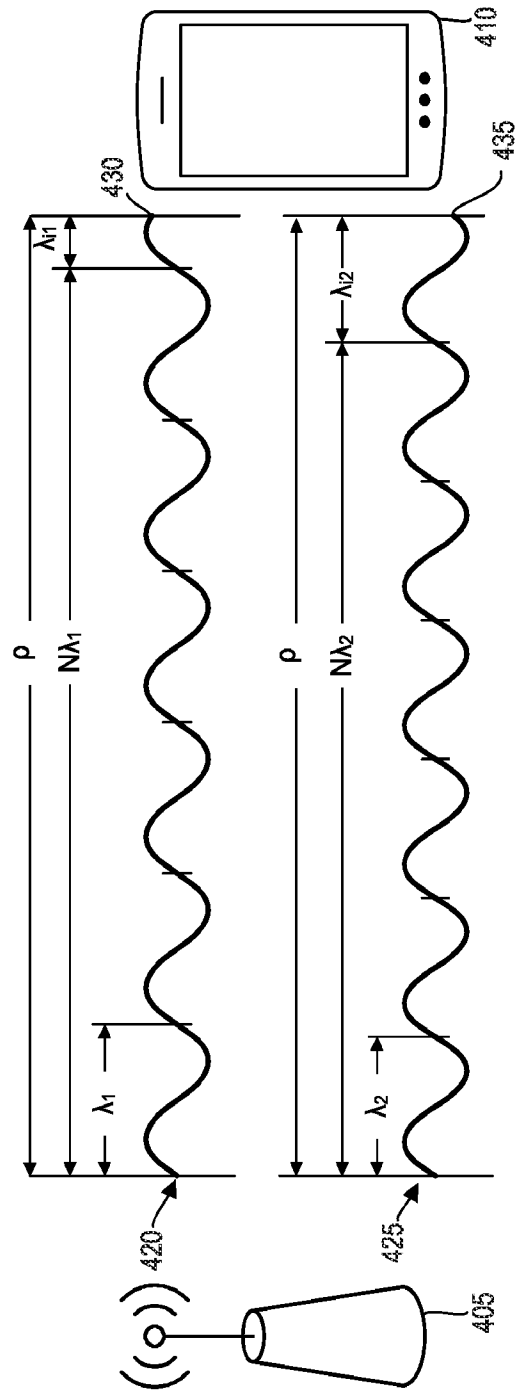


FIG. 4

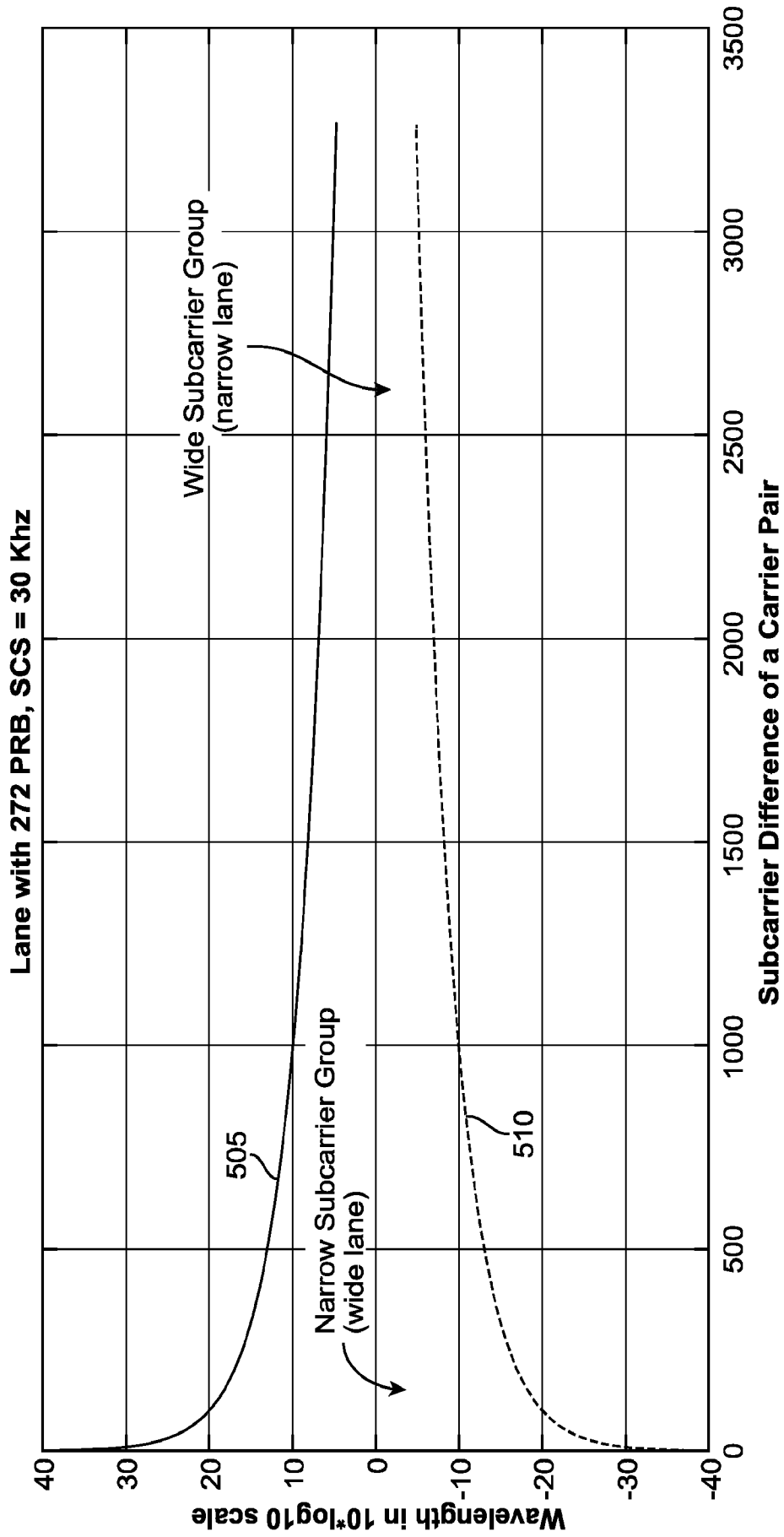


FIG. 5

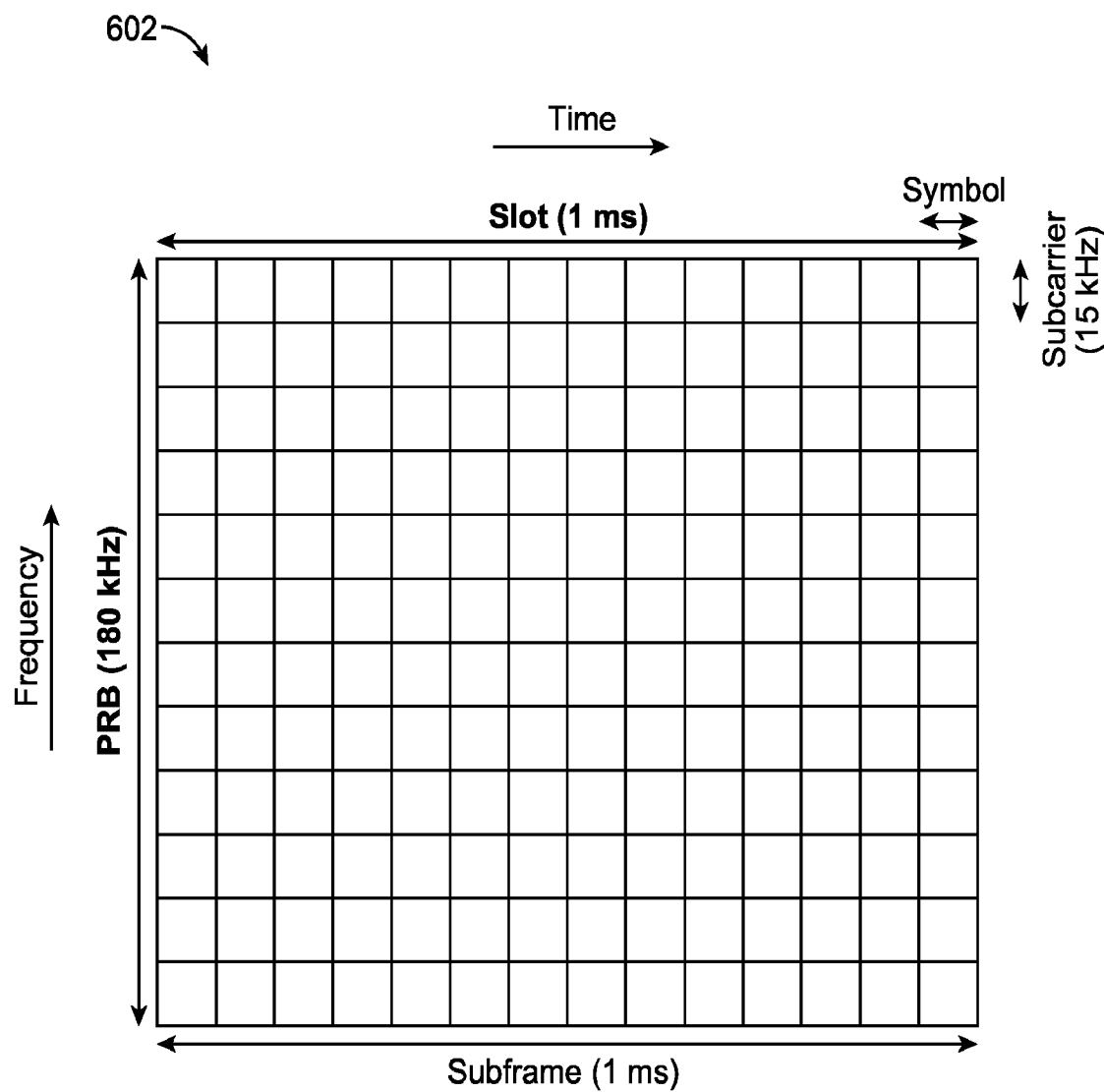


FIG. 6

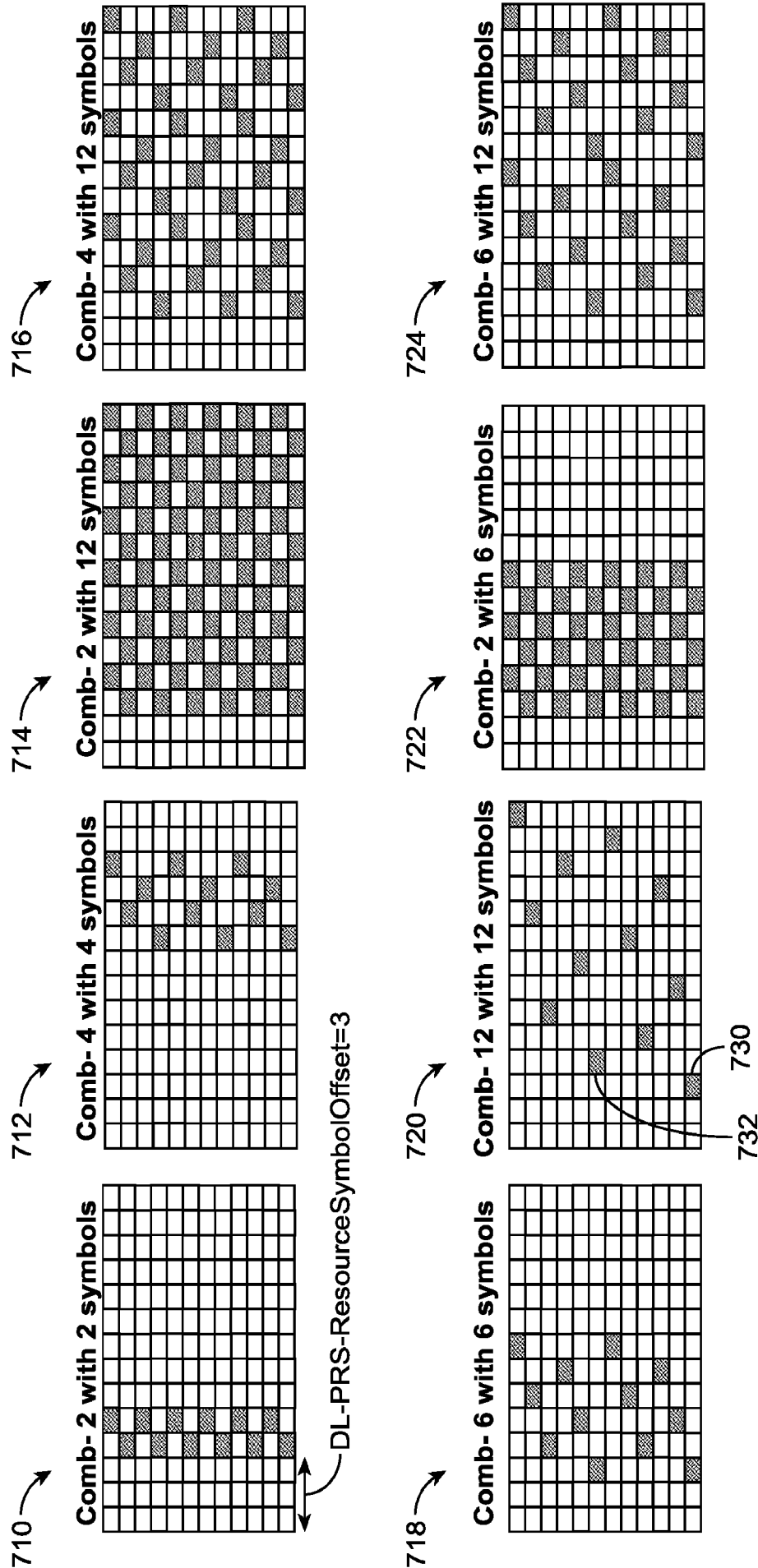


FIG. 7



800

⋮

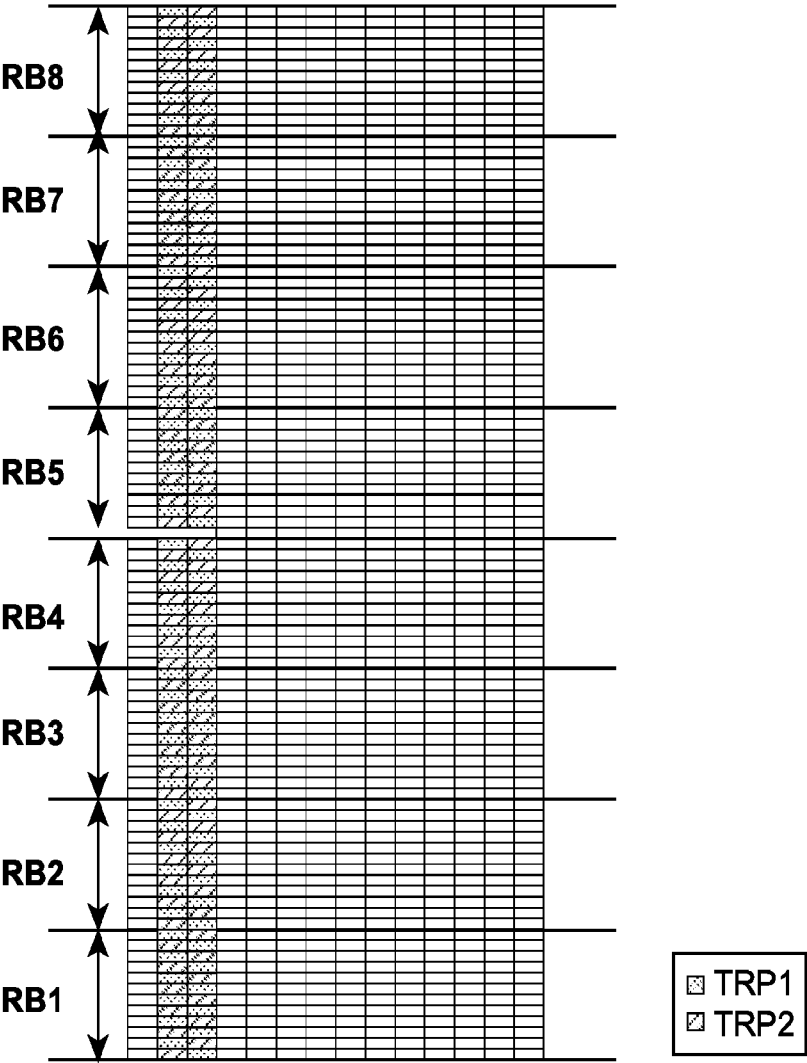


FIG. 8A





805 ↘

⋮

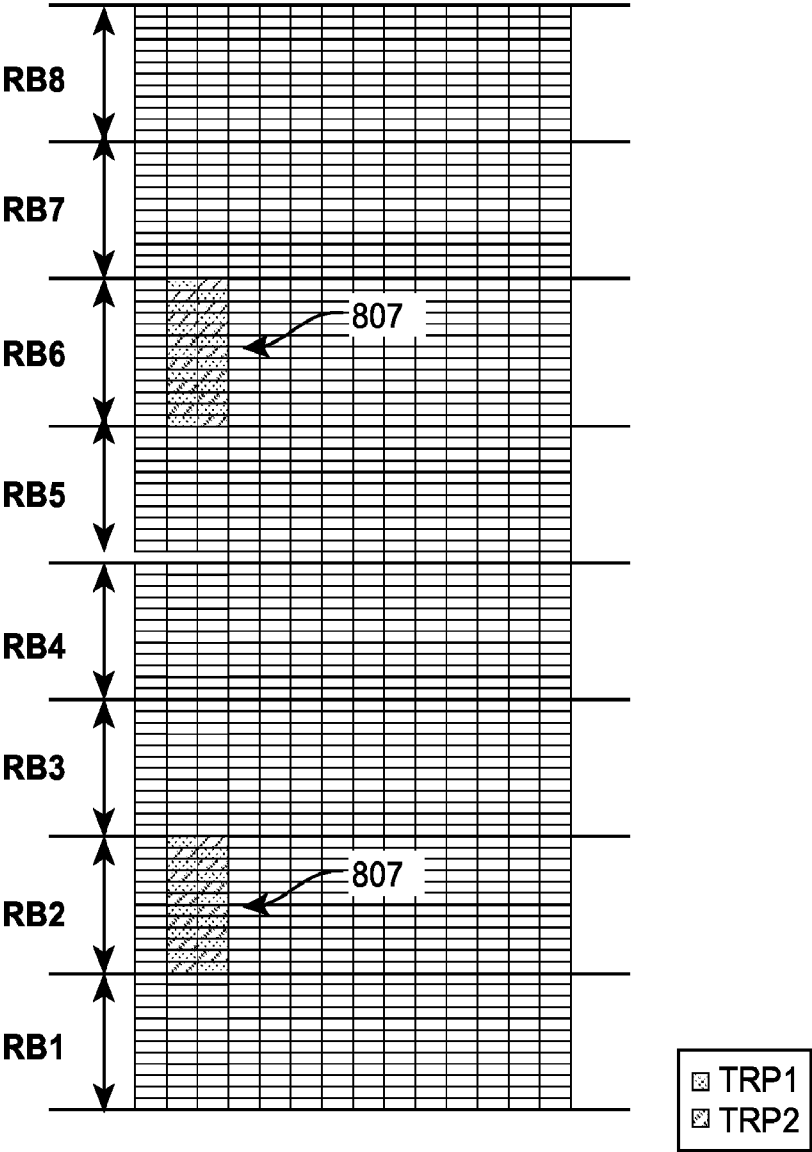


FIG. 8B





810 ↘

⋮

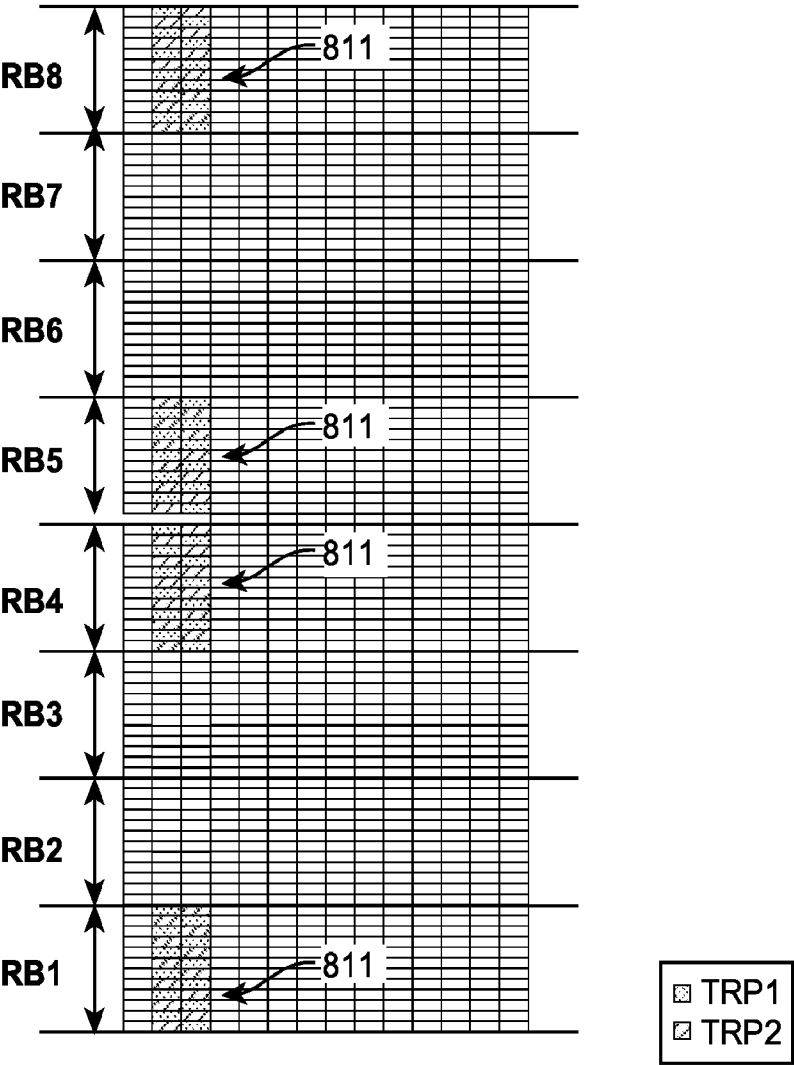


FIG. 8C





902 

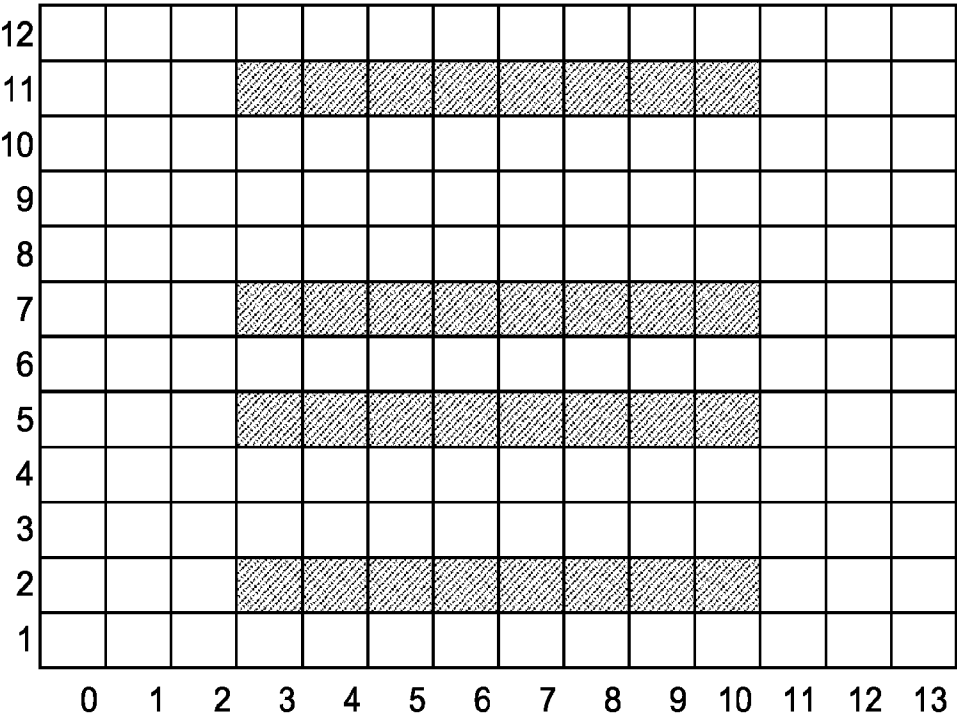


FIG. 9A





904 

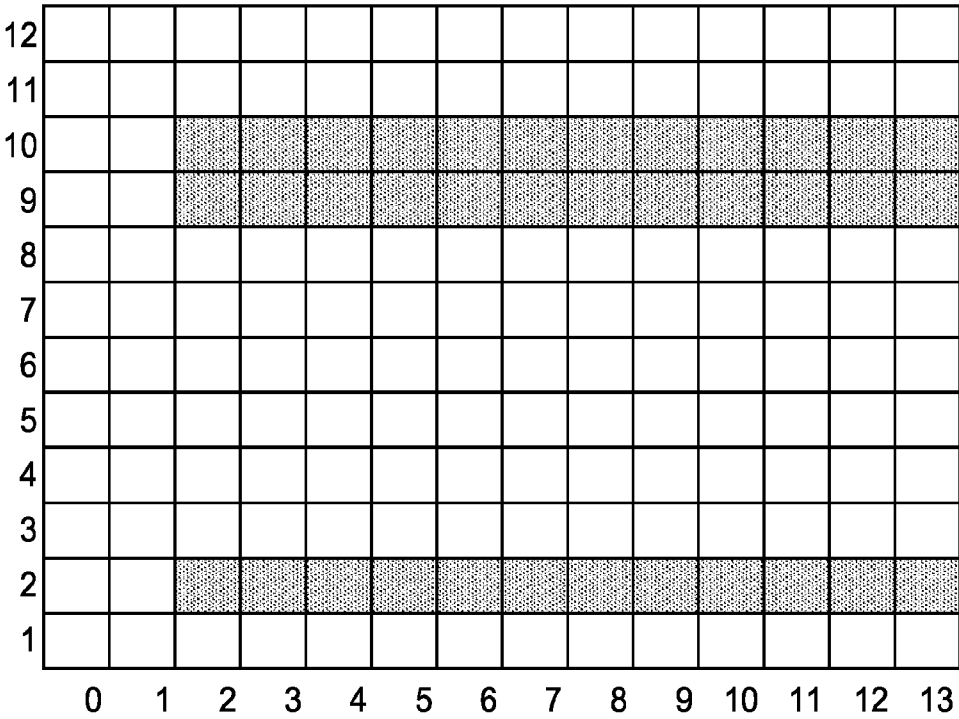


FIG. 9B





1002 →

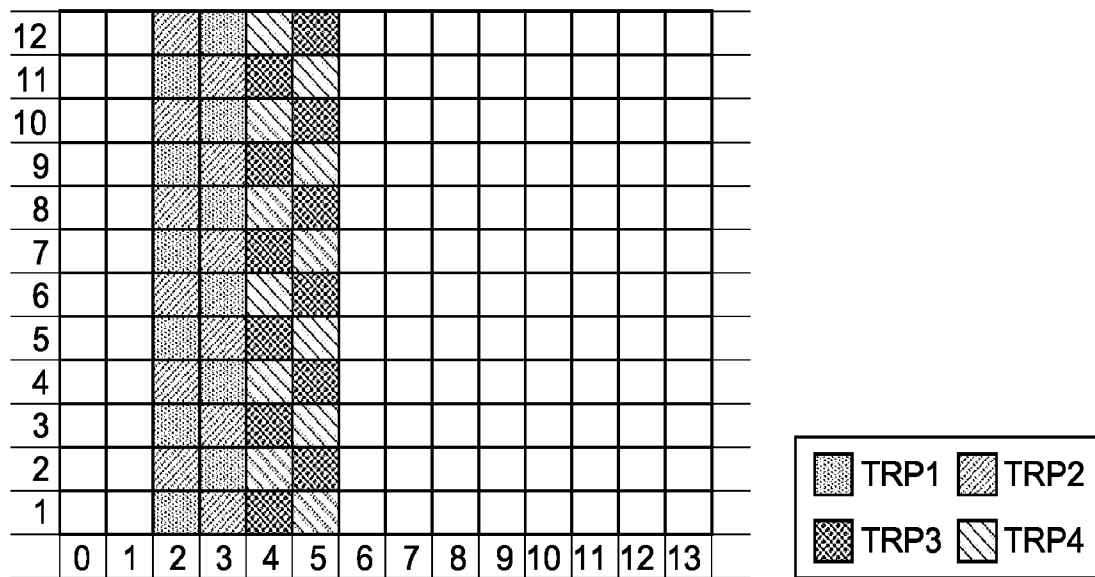


FIG. 10A





1004

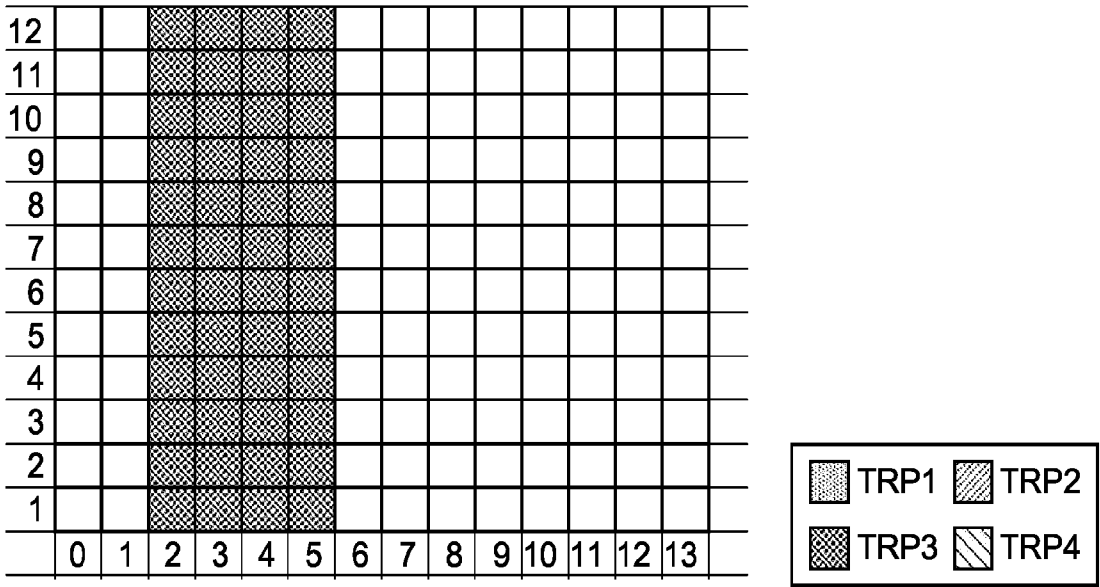


FIG. 10B



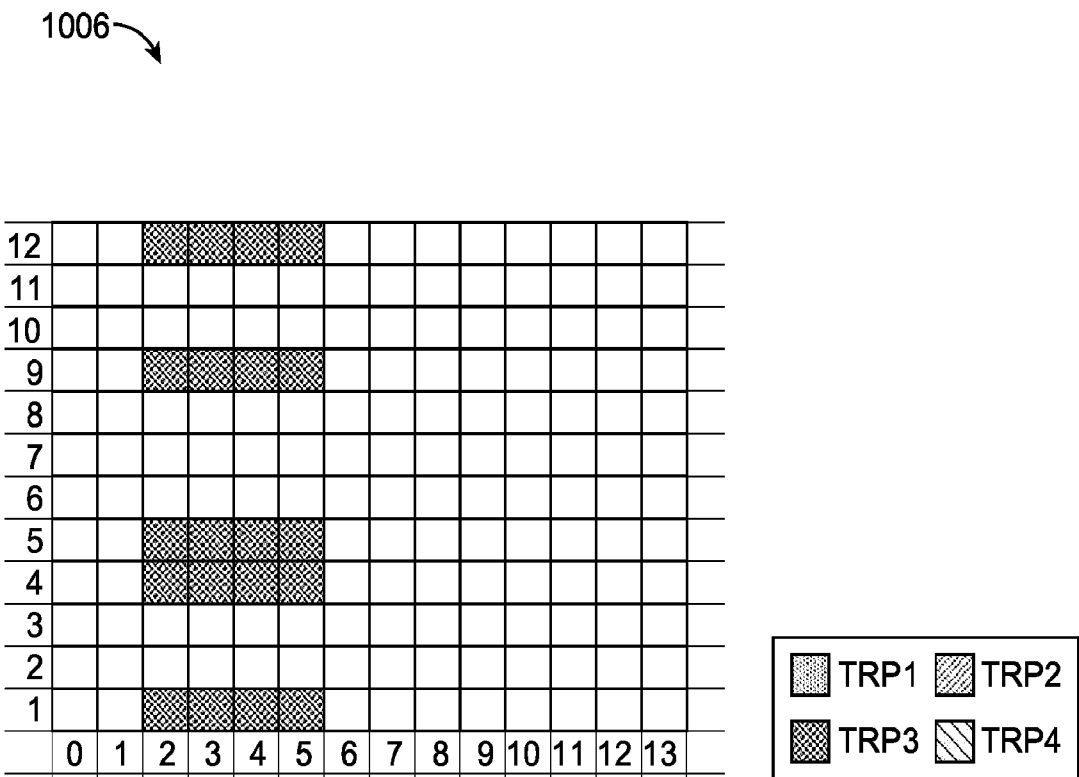
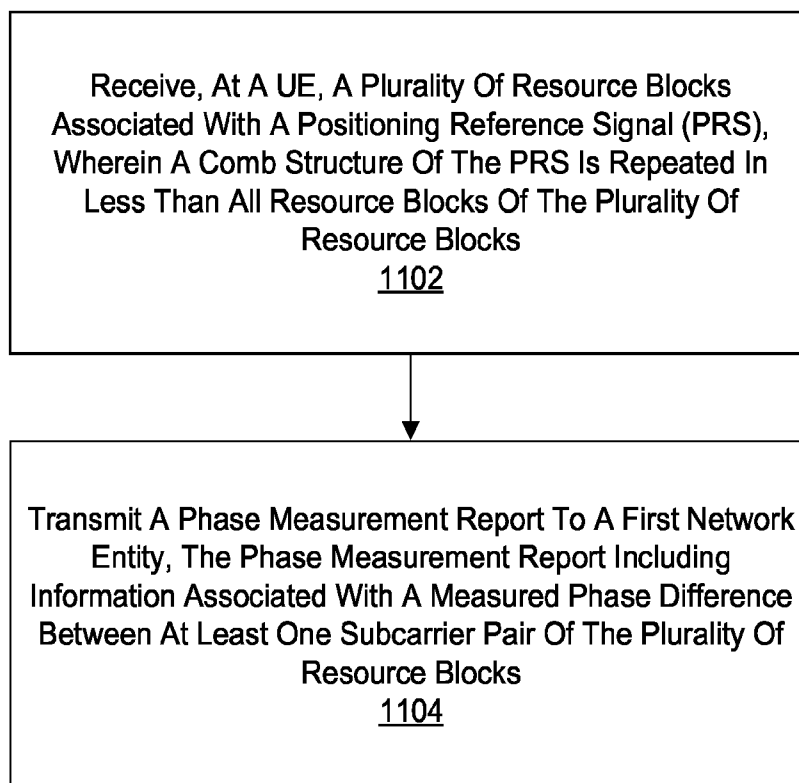
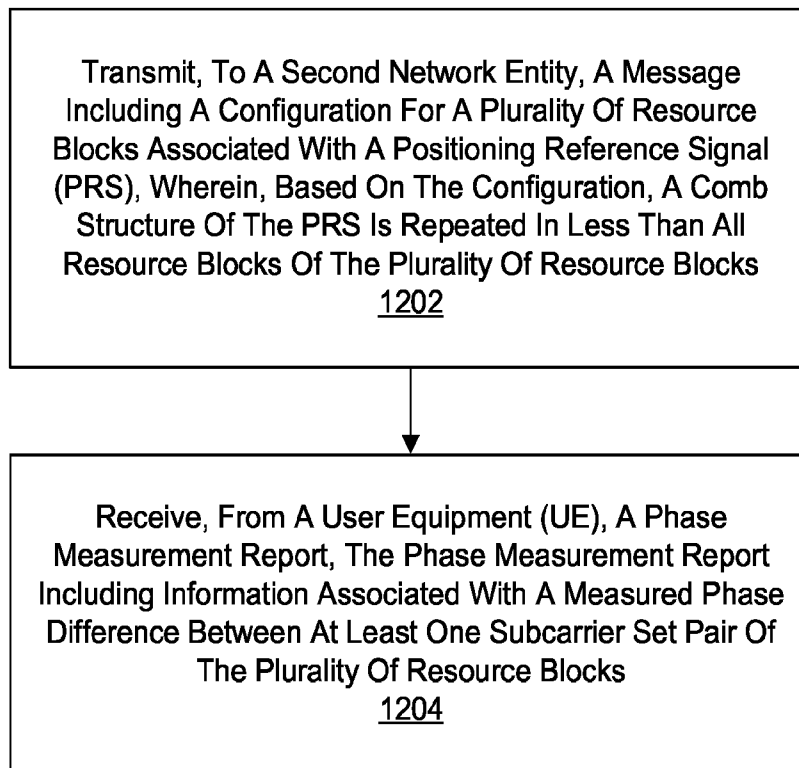


FIG. 10C



1100 **FIG. 11**

1200 **FIG. 12**

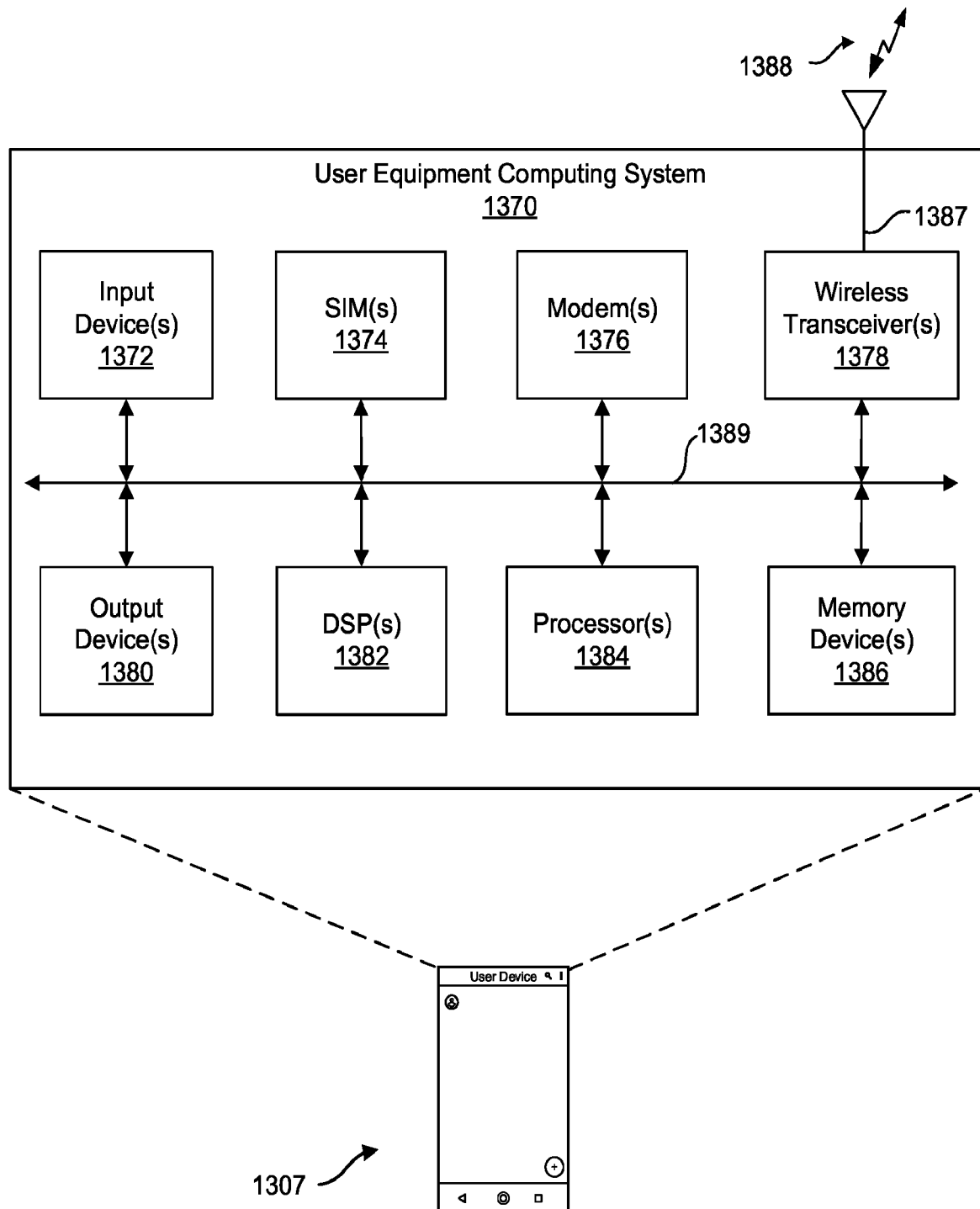


FIG. 13

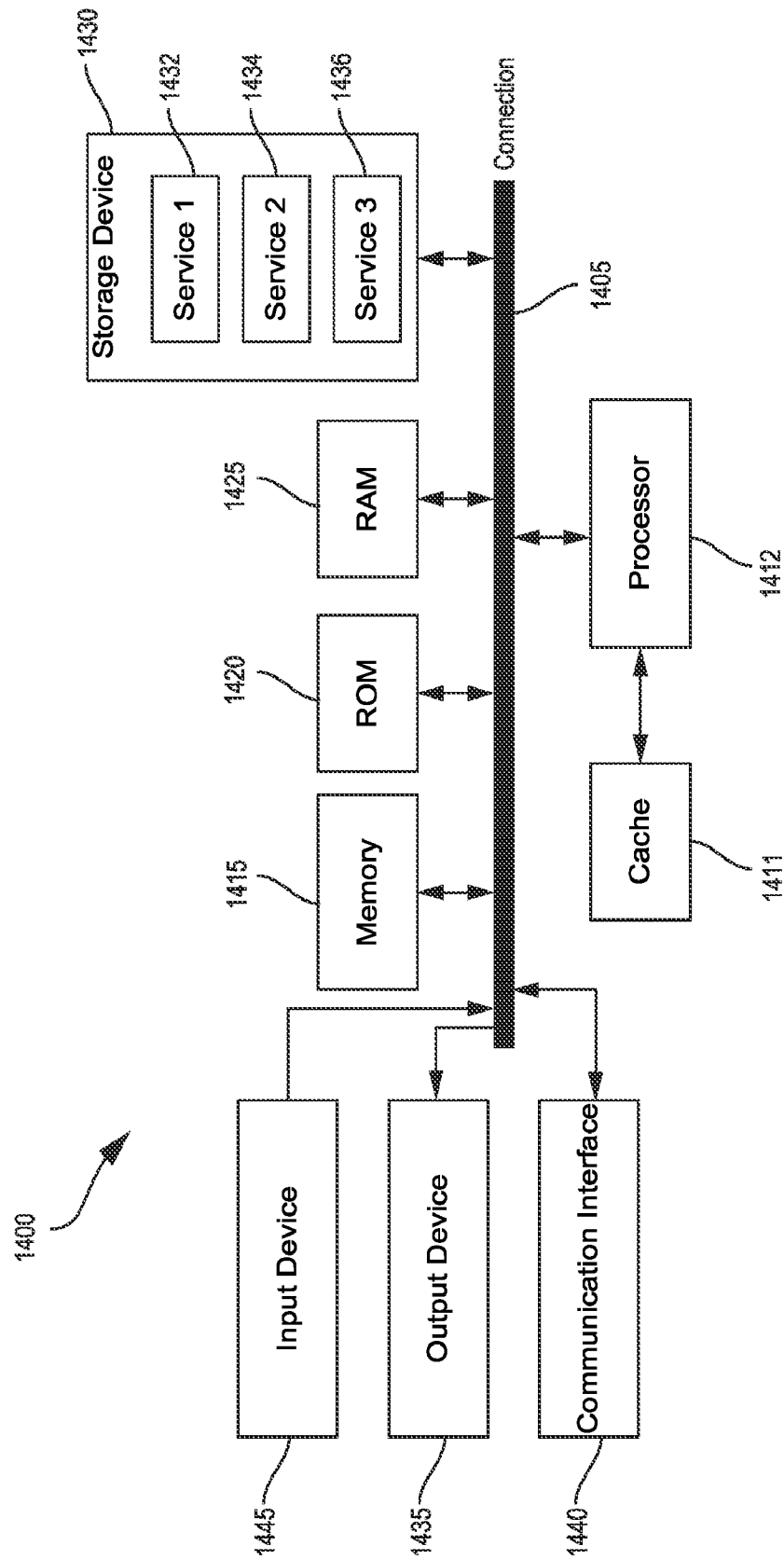


FIG. 14

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2022/082071

A. CLASSIFICATION OF SUBJECT MATTER INV. H04L5/00 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) H04L		
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) EPO-Internal, COMPENDEX, INSPEC, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2021/259318 A1 (DATANG MOBILE COMMUNICATIONS EQUIPMENT CO LTD [CN]) 30 December 2021 (2021-12-30) page 11, line 21; figure 4 page 12, line 6 page 1, line 11 page 12, line 20	1-70
A	WO 2020/167052 A1 (SAMSUNG ELECTRONICS CO LTD [KR]) 20 August 2020 (2020-08-20) paragraphs [0101] - [0103]; figure 2	1-70
	----- -/--	
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
13 April 2023		24/04/2023
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer May, David

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	MITSUBISHI ELECTRIC: "Views on DL reference signal designs for NR positioning", 3GPP DRAFT; R1-1912836, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. RAN WG1, no. Reno, USA; 20191118 - 20191122 8 November 2019 (2019-11-08), XP051820208, Retrieved from the Internet: URL:https://ftp.3gpp.org/tsg_ran/WG1_RL1/TSGR1_99/Docs/R1-1912836.zip [retrieved on 2019-11-08] sections 2.2. and 2.3; figure 3 -----	1-70
A	WO 2020/145873 A1 (ERICSSON TELEFON AB L M [SE]) 16 July 2020 (2020-07-16) page 19, line 572; figure 10 -----	8, 9, 28, 29, 43, 44, 63, 64

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2022/082071

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2021259318 A1	30-12-2021	CN 113840227 A	24-12-2021
		EP 4175327 A1	03-05-2023
		WO 2021259318 A1	30-12-2021

WO 2020167052 A1	20-08-2020	EP 3878131 A1	15-09-2021
		GB 2581772 A	02-09-2020
		KR 20210118851 A	01-10-2021
		US 2022104140 A1	31-03-2022
		WO 2020167052 A1	20-08-2020

WO 2020145873 A1	16-07-2020	EP 3909210 A1	17-11-2021
		US 2022116169 A1	14-04-2022
		WO 2020145873 A1	16-07-2020
