

(51) International Patent Classification:  
*H04W 24/10* (2009.01) *H04B 7/06* (2006.01)(21) International Application Number:  
PCT/CN2015/097558(22) International Filing Date:  
16 December 2015 (16.12.2015)

(25) Filing Language: English

(26) Publication Language: English

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

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(54) Title: USER EQUIPMENT (UE) AND METHODS FOR COMMUNICATION USING BEAM AGGREGATION

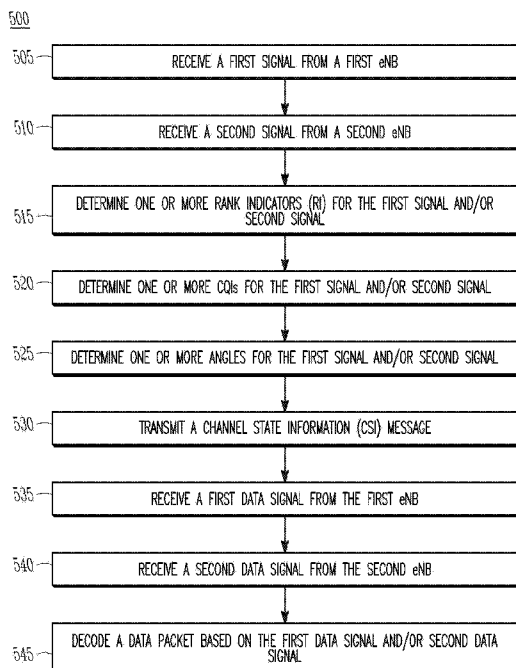


FIG. 5

(57) Abstract: Embodiments of a User Equipment (UE) and methods for communication using beam aggregation are generally described herein. The UE may receive first and second directional signals from a first eNB and a second eNB as part of a beam aggregation. The UE may transmit one or more channel state information (CSI) messages to the eNBs. The CSI messages may include rank indicators (RI) for the first and second signals. The RIs may indicate numbers of directional beams between the eNBs and the UE that are determined as part of the reception of the first signal. In some cases, when multiple transmit beams are included in a directional signal, the CSI messages may include multiple RIs for each of the transmitted beams.

**Declarations under Rule 4.17:**

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *of inventorship (Rule 4.17(iv))*

**Published:**

- *with international search report (Art. 21(3))*

USER EQUIPMENT (UE) AND METHODS FOR COMMUNICATION  
USING BEAM AGGREGATION

5 TECHNICAL FIELD

[0001] Embodiments pertain to wireless communications. Some  
embodiments relate to wireless networks including 3GPP (Third Generation  
Partnership Project) networks, 3GPP LTE (Long Term Evolution) networks, and  
10 3GPP LTE-A (LTE Advanced) networks, although the scope of the  
embodiments is not limited in this respect. Some embodiments relate to beam  
aggregation. Some embodiments relate to communication of channel state  
information (CSI). Some embodiments relate to antenna diversity.

15 BACKGROUND

[0002] A mobile network may support communication with mobile  
devices. In some cases, a mobile device may experience degradation in  
20 performance for any number of reasons. As an example, the mobile device may  
be out of coverage of base stations in the network. As another example, the  
mobile device may experience a reduction in signal quality in a challenging  
environment. In such scenarios, a performance of the device and/or a user  
experience may suffer. Accordingly, there is a general need for methods and  
25 systems for improving coverage and/or signal quality in these and other  
scenarios.

BRIEF DESCRIPTION OF THE DRAWINGS  
30

[0003] FIG. 1 is a functional diagram of a 3GPP network in accordance  
with some embodiments;

- [0004] FIG. 2 illustrates a block diagram of an example machine in accordance with some embodiments;
- [0005] FIG. 3 is a block diagram of an Evolved Node-B (eNB) in accordance with some embodiments;
- 5 [0006] FIG. 4 is a block diagram of a User Equipment (UE) in accordance with some embodiments;
- [0007] FIG. 5 illustrates the operation of a method of communication in accordance with some embodiments;
- [0008] FIG. 6 illustrates an example of a beam aggregation scenario in accordance with some embodiments;
- 10 [0009] FIG. 7 illustrates examples of multiple beam transmission in accordance with some embodiments;
- [0010] FIG. 8 illustrates the operation of another method of communication in accordance with some embodiments;
- 15 [0011] FIG. 9 illustrates example scenarios of communication using ideal and non-ideal backhaul connections in accordance with some embodiments; and
- [0012] FIG. 10 illustrates an example of a random access procedure in accordance with some embodiments.
- 20

## DETAILED DESCRIPTION

- [0013] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.
- 25
- 30 [0014] FIG. 1 is a functional diagram of a 3GPP network in accordance with some embodiments. It should be noted that embodiments are not limited to the example 3GPP network shown in FIG. 1, as other networks may be used in

some embodiments. As an example, a Fifth Generation (5G) network may be used in some cases. Such a 5G network or other network may or may not include some or all of the components shown in FIG. 1, and may include additional components and/or alternative components in some cases.

5   **[0015]**       The network comprises a radio access network (RAN) (e.g., as depicted, the E-UTRAN or evolved universal terrestrial radio access network) 100 and the core network 120 (e.g., shown as an evolved packet core (EPC)) coupled together through an S1 interface 115. For convenience and brevity sake, only a portion of the core network 120, as well as the RAN 100, is shown.

10   **[0016]**       The core network 120 includes a mobility management entity (MME) 122, a serving gateway (serving GW) 124, and packet data network gateway (PDN GW) 126. The RAN 100 includes Evolved Node-B's (eNBs) 104 (which may operate as base stations) for communicating with User Equipment (UE) 102. The eNBs 104 may include macro eNBs and low power (LP) eNBs.

15   **[0017]**       In some embodiments, the UE 102 may receive a first signal from a first eNB 104 according to a first receive direction between the UE 102 and the first eNB 104. The UE 102 may receive a second signal from a second eNB 104 according to a second receive direction between the UE 102 and the second eNB 104. The UE 102 may transmit one or more channel state information (CSI)  
20   messages to the eNBs 104. These embodiments will be described in more detail below.

**[0018]**       The MME 122 is similar in function to the control plane of legacy Serving GPRS Support Nodes (SGSN). The MME 122 manages mobility aspects in access such as gateway selection and tracking area list management.

25   The serving GW 124 terminates the interface toward the RAN 100, and routes data packets between the RAN 100 and the core network 120. In addition, it may be a local mobility anchor point for inter-eNB handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement. The serving GW 124 and the  
30   MME 122 may be implemented in one physical node or separate physical nodes. The PDN GW 126 terminates an SGi interface toward the packet data network (PDN). The PDN GW 126 routes data packets between the EPC 120 and the

external PDN, and may be a key node for policy enforcement and charging data collection. It may also provide an anchor point for mobility with non-LTE accesses. The external PDN can be any kind of IP network, as well as an IP Multimedia Subsystem (IMS) domain. The PDN GW 126 and the serving GW 124 may be implemented in one physical node or separated physical nodes.

5 [0019] The eNBs 104 (macro and micro) terminate the air interface protocol and may be the first point of contact for a UE 102. In some embodiments, an eNB 104 may fulfill various logical functions for the RAN 100 including but not limited to RNC (radio network controller functions) such as  
10 radio bearer management, uplink and downlink dynamic radio resource management and data packet scheduling, and mobility management. In accordance with embodiments, UEs 102 may be configured to communicate Orthogonal Frequency Division Multiplexing (OFDM) communication signals with an eNB 104 over a multicarrier communication channel in accordance with  
15 an Orthogonal Frequency Division Multiple Access (OFDMA) communication technique. The OFDM signals may comprise a plurality of orthogonal subcarriers.

[0020] The S1 interface 115 is the interface that separates the RAN 100 and the EPC 120. It is split into two parts: the S1-U, which carries traffic data  
20 between the eNBs 104 and the serving GW 124, and the S1-MME, which is a signaling interface between the eNBs 104 and the MME 122. The X2 interface is the interface between eNBs 104. The X2 interface comprises two parts, the X2-C and X2-U. The X2-C is the control plane interface between the eNBs 104, while the X2-U is the user plane interface between the eNBs 104.

25 [0021] With cellular networks, LP cells are typically used to extend coverage to indoor areas where outdoor signals do not reach well, or to add network capacity in areas with very dense phone usage, such as train stations. As used herein, the term low power (LP) eNB refers to any suitable relatively low power eNB for implementing a narrower cell (narrower than a macro cell) such  
30 as a femtocell, a picocell, or a micro cell. Femtocell eNBs are typically provided by a mobile network operator to its residential or enterprise customers. A femtocell is typically the size of a residential gateway or smaller and generally

connects to the user's broadband line. Once plugged in, the femtocell connects to the mobile operator's mobile network and provides extra coverage in a range of typically 30 to 50 meters for residential femtocells. Thus, a LP eNB might be a femtocell eNB since it is coupled through the PDN GW 126. Similarly, a  
5 picocell is a wireless communication system typically covering a small area, such as in-building (offices, shopping malls, train stations, etc.), or more recently in-aircraft. A picocell eNB can generally connect through the X2 link to another eNB such as a macro eNB through its base station controller (BSC) functionality. Thus, LP eNB may be implemented with a picocell eNB since it is  
10 coupled to a macro eNB via an X2 interface. Picocell eNBs or other LP eNBs may incorporate some or all functionality of a macro eNB. In some cases, this may be referred to as an access point base station or enterprise femtocell.

**[0022]** In some embodiments, a downlink resource grid may be used for downlink transmissions from an eNB 104 to a UE 102, while uplink  
15 transmission from the UE 102 to the eNB 104 may utilize similar techniques. The grid may be a time-frequency grid, called a resource grid or time-frequency resource grid, which is the physical resource in the downlink in each slot. Such a time-frequency plane representation is a common practice for OFDM systems, which makes it intuitive for radio resource allocation. Each column and each row  
20 of the resource grid correspond to one OFDM symbol and one OFDM subcarrier, respectively. The duration of the resource grid in the time domain corresponds to one slot in a radio frame. The smallest time-frequency unit in a resource grid is denoted as a resource element (RE). Each resource grid comprises a number of resource blocks (RBs), which describe the mapping of  
25 certain physical channels to resource elements. Each resource block comprises a collection of resource elements in the frequency domain and may represent the smallest quanta of resources that currently can be allocated. There are several different physical downlink channels that are conveyed using such resource blocks. With particular relevance to this disclosure, two of these physical  
30 downlink channels are the physical downlink shared channel and the physical down link control channel.

**[0023]** The physical downlink shared channel (PDSCH) carries user data and higher-layer signaling to a UE 102 (FIG. 1). The physical downlink control channel (PDCCH) carries information about the transport format and resource allocations related to the PDSCH channel, among other things. It also informs  
5 the UE 102 about the transport format, resource allocation, and hybrid automatic repeat request (HARQ) information related to the uplink shared channel. Typically, downlink scheduling (e.g., assigning control and shared channel resource blocks to UEs 102 within a cell) may be performed at the eNB 104 based on channel quality information fed back from the UEs 102 to the eNB 104,  
10 and then the downlink resource assignment information may be sent to a UE 102 on the control channel (PDCCH) used for (assigned to) the UE 102.

**[0024]** The PDCCH uses CCEs (control channel elements) to convey the control information. Before being mapped to resource elements, the PDCCH complex-valued symbols are first organized into quadruplets, which are then  
15 permuted using a sub-block inter-leaver for rate matching. Each PDCCH is transmitted using one or more of these control channel elements (CCEs), where each CCE corresponds to nine sets of four physical resource elements known as resource element groups (REGs). Four QPSK symbols are mapped to each REG. The PDCCH can be transmitted using one or more CCEs, depending on the size  
20 of DCI and the channel condition. There may be four or more different PDCCH formats defined in LTE with different numbers of CCEs (e.g., aggregation level, L=1, 2, 4, or 8).

**[0025]** As used herein, the term "circuitry" may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit,  
25 a processor (shared, dedicated, or group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable hardware components that provide the described functionality. In some embodiments, the circuitry may be implemented in, or functions associated with the circuitry may be implemented  
30 by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware. Embodiments

described herein may be implemented into a system using any suitably configured hardware and/or software.

**[0026]** FIG. 2 illustrates a block diagram of an example machine in accordance with some embodiments. The machine 200 is an example machine upon which any one or more of the techniques and/or methodologies discussed herein may be performed. In alternative embodiments, the machine 200 may operate as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine 200 may operate in the capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine 200 may act as a peer machine in peer-to-peer (P2P) (or other distributed) network environment. The machine 200 may be a UE 102, eNB 104, access point (AP), station (STA), mobile device, base station, personal computer (PC), a tablet PC, a set-top box (STB), a personal digital assistant (PDA), a mobile telephone, a smart phone, a web appliance, a network router, switch or bridge, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine. Further, while only a single machine is illustrated, the term “machine” shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein, such as cloud computing, software as a service (SaaS), other computer cluster configurations.

**[0027]** Examples as described herein, may include, or may operate on, logic or a number of components, modules, or mechanisms. Modules are tangible entities (e.g., hardware) capable of performing specified operations and may be configured or arranged in a certain manner. In an example, circuits may be arranged (e.g., internally or with respect to external entities such as other circuits) in a specified manner as a module. In an example, the whole or part of one or more computer systems (e.g., a standalone, client or server computer system) or one or more hardware processors may be configured by firmware or software (e.g., instructions, an application portion, or an application) as a module that operates to perform specified operations. In an example, the software may reside on a machine readable medium. In an example, the software, when

executed by the underlying hardware of the module, causes the hardware to perform the specified operations.

**[0028]** Accordingly, the term “module” is understood to encompass a tangible entity, be that an entity that is physically constructed, specifically  
5 configured (e.g., hardwired), or temporarily (e.g., transitorily) configured (e.g., programmed) to operate in a specified manner or to perform part or all of any operation described herein. Considering examples in which modules are temporarily configured, each of the modules need not be instantiated at any one moment in time. For example, where the modules comprise a general-purpose  
10 hardware processor configured using software, the general-purpose hardware processor may be configured as respective different modules at different times. Software may accordingly configure a hardware processor, for example, to constitute a particular module at one instance of time and to constitute a different module at a different instance of time.

**[0029]** The machine (e.g., computer system) 200 may include a hardware processor 202 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 204 and a static memory 206, some or all of which may communicate with each other via an interlink (e.g., bus) 208. The machine 200 may further include a  
20 display unit 210, an alphanumeric input device 212 (e.g., a keyboard), and a user interface (UI) navigation device 214 (e.g., a mouse). In an example, the display unit 210, input device 212 and UI navigation device 214 may be a touch screen display. The machine 200 may additionally include a storage device (e.g., drive unit) 216, a signal generation device 218 (e.g., a speaker), a network interface  
25 device 220, and one or more sensors 221, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The machine 200 may include an output controller 228, such as a serial (e.g., universal serial bus (USB), parallel, or other wired or wireless (e.g., infrared (IR), near field communication (NFC), etc.) connection to communicate or control one or more  
30 peripheral devices (e.g., a printer, card reader, etc.).

**[0030]** The storage device 216 may include a machine readable medium 222 on which is stored one or more sets of data structures or instructions 224

(e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 224 may also reside, completely or at least partially, within the main memory 204, within static memory 206, or within the hardware processor 202 during execution thereof by the machine

5 200. In an example, one or any combination of the hardware processor 202, the main memory 204, the static memory 206, or the storage device 216 may constitute machine readable media.

**[0031]** While the machine readable medium 222 is illustrated as a single medium, the term "machine readable medium" may include a single medium or  
10 multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) configured to store the one or more instructions 224. The term "machine readable medium" may include any medium that is capable of storing, encoding, or carrying instructions for execution by the machine 200 and that cause the machine 200 to perform any one or more of the techniques of the  
15 present disclosure, or that is capable of storing, encoding or carrying data structures used by or associated with such instructions. Non-limiting machine readable medium examples may include solid-state memories, and optical and magnetic media. Specific examples of machine readable media may include: non-volatile memory, such as semiconductor memory devices (e.g., Electrically  
20 Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; Random Access Memory (RAM); and CD-ROM and DVD-ROM disks. In some examples, machine readable media may include non-transitory  
25 machine readable media. In some examples, machine readable media may include machine readable media that is not a transitory propagating signal.

**[0032]** The instructions 224 may further be transmitted or received over a communications network 226 using a transmission medium via the network interface device 220 utilizing any one of a number of transfer protocols (e.g.,  
30 frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communication networks may include a local area network (LAN), a wide area

network (WAN), a packet data network (e.g., the Internet), mobile telephone networks (e.g., cellular networks), Plain Old Telephone (POTS) networks, and wireless data networks (e.g., Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards known as Wi-Fi®, IEEE 802.16 family of standards known as WiMax®), IEEE 802.15.4 family of standards, a Long Term Evolution (LTE) family of standards, a Universal Mobile Telecommunications System (UMTS) family of standards, peer-to-peer (P2P) networks, among others. In an example, the network interface device 220 may include one or more physical jacks (e.g., Ethernet, coaxial, or phone jacks) or one or more antennas to connect to the communications network 226. In an example, the network interface device 220 may include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), multiple-input multiple-output (MIMO), or multiple-input single-output (MISO) techniques. In some examples, the network interface device 220 may wirelessly communicate using Multiple User MIMO techniques. The term “transmission medium” shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution by the machine 200, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

**[0033]** FIG. 3 is a block diagram of an Evolved Node-B (eNB) in accordance with some embodiments. It should be noted that in some embodiments, the eNB 300 may be a stationary non-mobile device. The eNB 300 may be suitable for use as an eNB 104 as depicted in FIG. 1. The eNB 300 may include physical layer circuitry 302 and a transceiver 305, one or both of which may enable transmission and reception of signals to and from the UE 200, other eNBs, other UEs or other devices using one or more antennas 301. As an example, the physical layer circuitry 302 may perform various encoding and decoding functions that may include formation of baseband signals for transmission and decoding of received signals. As another example, the transceiver 305 may perform various transmission and reception functions such as conversion of signals between a baseband range and a Radio Frequency (RF) range. Accordingly, the physical layer circuitry 302 and the transceiver 305 may

be separate components or may be part of a combined component. In addition, some of the described functionality related to transmission and reception of signals may be performed by a combination that may include one, any or all of the physical layer circuitry 302, the transceiver 305, and other components or layers. The eNB 300 may also include medium access control layer (MAC) circuitry 304 for controlling access to the wireless medium. The eNB 300 may also include processing circuitry 306 and memory 308 arranged to perform the operations described herein. The eNB 300 may also include one or more interfaces 310, which may enable communication with other components, including other eNBs 104 (FIG. 1), components in the EPC 120 (FIG. 1) or other network components. In addition, the interfaces 310 may enable communication with other components that may not be shown in FIG. 1, including components external to the network. The interfaces 310 may be wired or wireless or a combination thereof. It should be noted that in some embodiments, an eNB or other base station may include some or all of the components shown in either FIG. 2 or FIG. 3 or both.

**[0034]** FIG. 4 is a block diagram of a User Equipment (UE) in accordance with some embodiments. The UE 400 may be suitable for use as a UE 102 as depicted in FIG. 1. In some embodiments, the UE 400 may include application circuitry 402, baseband circuitry 404, Radio Frequency (RF) circuitry 406, front-end module (FEM) circuitry 408 and one or more antennas 410, coupled together at least as shown. In some embodiments, other circuitry or arrangements may include one or more elements and/or components of the application circuitry 402, the baseband circuitry 404, the RF circuitry 406 and/or the FEM circuitry 408, and may also include other elements and/or components in some cases. As an example, “processing circuitry” may include one or more elements and/or components, some or all of which may be included in the application circuitry 402 and/or the baseband circuitry 404. As another example, “transceiver circuitry” may include one or more elements and/or components, some or all of which may be included in the RF circuitry 406 and/or the FEM circuitry 408. These examples are not limiting, however, as the processing circuitry and/or the transceiver circuitry may also include other elements and/or

components in some cases. It should be noted that in some embodiments, a UE or other mobile device may include some or all of the components shown in either FIG. 2 or FIG. 4 or both.

**[0035]** The application circuitry 402 may include one or more application processors. For example, the application circuitry 402 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with and/or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications and/or operating systems to run on the system.

**[0036]** The baseband circuitry 404 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 404 may include one or more baseband processors and/or control logic to process baseband signals received from a receive signal path of the RF circuitry 406 and to generate baseband signals for a transmit signal path of the RF circuitry 406. Baseband processing circuitry 404 may interface with the application circuitry 402 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 406. For example, in some embodiments, the baseband circuitry 404 may include a second generation (2G) baseband processor 404a, third generation (3G) baseband processor 404b, fourth generation (4G) baseband processor 404c, and/or other baseband processor(s) 404d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 404 (e.g., one or more of baseband processors 404a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 406. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 404 may include Fast-Fourier Transform (FFT), precoding, and/or constellation

mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 404 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

**[0037]** In some embodiments, the baseband circuitry 404 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (EUTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), and/or radio resource control (RRC) elements. A central processing unit (CPU) 404e of the baseband circuitry 404 may be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP and/or RRC layers. In some embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (DSP) 404f. The audio DSP(s) 404f may be include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments. Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the baseband circuitry 404 and the application circuitry 402 may be implemented together such as, for example, on a system on a chip (SOC).

**[0038]** In some embodiments, the baseband circuitry 404 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 404 may support communication with an evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 404 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

**[0039]** RF circuitry 406 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 406 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network.

5 RF circuitry 406 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 408 and provide baseband signals to the baseband circuitry 404. RF circuitry 406 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 404 and provide RF output  
10 signals to the FEM circuitry 408 for transmission.

**[0040]** In some embodiments, the RF circuitry 406 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 406 may include mixer circuitry 406a, amplifier circuitry 406b and filter circuitry 406c. The transmit signal path of the RF circuitry 406 may include  
15 filter circuitry 406c and mixer circuitry 406a. RF circuitry 406 may also include synthesizer circuitry 406d for synthesizing a frequency for use by the mixer circuitry 406a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 406a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 408  
20 based on the synthesized frequency provided by synthesizer circuitry 406d. The amplifier circuitry 406b may be configured to amplify the down-converted signals and the filter circuitry 406c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be  
25 provided to the baseband circuitry 404 for further processing. In some embodiments, the output baseband signals may be zero-frequency baseband signals, although this is not a requirement. In some embodiments, mixer circuitry 406a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect. In some embodiments, the  
30 mixer circuitry 406a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 406d to generate RF output signals for the FEM circuitry

408. The baseband signals may be provided by the baseband circuitry 404 and may be filtered by filter circuitry 406c. The filter circuitry 406c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

5     **[0041]**         In some embodiments, the mixer circuitry 406a of the receive signal path and the mixer circuitry 406a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and/or upconversion respectively. In some embodiments, the mixer circuitry 406a of the receive signal path and the mixer circuitry 406a of the transmit signal path may  
10   include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 406a of the receive signal path and the mixer circuitry 406a may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 406a of the receive signal path and the mixer circuitry 406a  
15   of the transmit signal path may be configured for super-heterodyne operation.

**[0042]**         In some embodiments, the output baseband signals and the input baseband signals may be analog baseband signals, although the scope of the embodiments is not limited in this respect. In some alternate embodiments, the output baseband signals and the input baseband signals may be digital baseband  
20   signals. In these alternate embodiments, the RF circuitry 406 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 404 may include a digital baseband interface to communicate with the RF circuitry 406. In some dual-mode embodiments, a separate radio IC circuitry may be provided for processing signals for each  
25   spectrum, although the scope of the embodiments is not limited in this respect.

**[0043]**         In some embodiments, the synthesizer circuitry 406d may be a fractional-N synthesizer or a fractional N/N+1 synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 406d may be a  
30   delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider. The synthesizer circuitry 406d may be configured to synthesize an output frequency for use by the mixer circuitry

406a of the RF circuitry 406 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 406d may be a fractional  $N/N+1$  synthesizer. In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry 404 or the applications processor 402 depending on the desired output frequency. In some embodiments, a divider control input (e.g.,  $N$ ) may be determined from a look-up table based on a channel indicated by the applications processor 402.

5 [0044] Synthesizer circuitry 406d of the RF circuitry 406 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either  $N$  or  $N+1$  (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into  $N_d$  equal packets of phase, where  $N_d$  is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that

10 20 the total delay through the delay line is one VCO cycle.

[0045] In some embodiments, synthesizer circuitry 406d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency may be a LO frequency ( $f_{LO}$ ). In some embodiments, the RF circuitry 406 may include an IQ/polar converter.

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30 [0046] FEM circuitry 408 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 410, amplify the received signals and provide the amplified versions of

the received signals to the RF circuitry 406 for further processing. FEM circuitry 408 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 406 for transmission by one or more of the one or more antennas 410.

- 5   **[0047]**        In some embodiments, the FEM circuitry 408 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF
- 10    signals as an output (e.g., to the RF circuitry 406). The transmit signal path of the FEM circuitry 408 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 406), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 410. In some embodiments, the UE 400 may include additional
- 15    elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface.

- [0048]**        The antennas 230, 301, 410 may comprise one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, patch antennas, loop antennas, microstrip antennas or other
- 20    types of antennas suitable for transmission of RF signals. In some multiple-input multiple-output (MIMO) embodiments, the antennas 230, 301, 410 may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result.

- [0049]**        In some embodiments, the UE 400 and/or the eNB 300 may be a
- 25    mobile device and may be a portable wireless communication device, such as a personal digital assistant (PDA), a laptop or portable computer with wireless communication capability, a web tablet, a wireless telephone, a smartphone, a wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, a wearable device such as a medical device (e.g., a
- 30    heart rate monitor, a blood pressure monitor, etc.), or other device that may receive and/or transmit information wirelessly. In some embodiments, the UE 400 or eNB 300 may be configured to operate in accordance with 3GPP

standards, although the scope of the embodiments is not limited in this respect.

Mobile devices or other devices in some embodiments may be configured to operate according to other protocols or standards, including IEEE 802.11 or other IEEE standards. In some embodiments, the UE 400, eNB 300 or other

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

**[0050]** Although the UE 400 and the eNB 300 are each illustrated as  
10 having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For example, some elements may comprise one or more microprocessors, DSPs, field-  
15 programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), radio-frequency integrated circuits (RFICs) and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements may refer to one or more processes operating on one or more processing elements.

20 **[0051]** Embodiments may be implemented in one or a combination of hardware, firmware and software. Embodiments may also be implemented as instructions stored on a computer-readable storage device, which may be read and executed by at least one processor to perform the operations described herein. A computer-readable storage device may include any non-transitory  
25 mechanism for storing information in a form readable by a machine (e.g., a computer). For example, a computer-readable storage device may include read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and other storage devices and media. Some embodiments may include one or more processors and may be  
30 configured with instructions stored on a computer-readable storage device.

**[0052]** It should be noted that in some embodiments, an apparatus used by the UE 400 and/or eNB 300 and/or machine 200 may include various

components of the UE 200 and/or the eNB 300 and/or the machine 200 as shown in FIGs. 2-4. Accordingly, techniques and operations described herein that refer to the UE 400 (or 102) may be applicable to an apparatus for a UE. In addition, techniques and operations described herein that refer to the eNB 300 (or 104)

5 may be applicable to an apparatus for an eNB.

**[0053]** In accordance with embodiments, the UE 102 may receive a first signal from a first eNB 104 according to a first receive direction between the UE 102 and the first eNB 104. The UE 102 may receive a second signal from a second eNB 104 according to a second receive direction between the UE 102 and the second eNB 104. The UE 102 may transmit one or more channel state information (CSI) messages to the eNBs 104. The CSI message may include a first rank indicator (RI) that may indicate a number of directional beams, between the first eNB 104 and the UE 102, that are determined as part of the reception of the first signal. The CSI message may further include a second RI that may indicate a number of directional beams, between the second eNB 104 and the UE 102, that are determined as part of the reception of the second signal. These embodiments are described in more detail below.

**[0054]** FIG. 5 illustrates the operation of a method of communication in accordance with some embodiments. It is important to note that embodiments of the method 500 may include additional or even fewer operations or processes in comparison to what is illustrated in FIG. 5. In addition, embodiments of the method 500 are not necessarily limited to the chronological order that is shown in FIG. 5. In describing the method 500, reference may be made to FIGs. 1-4 and 6-10, although it is understood that the method 500 may be practiced with any other suitable systems, interfaces and components.

**[0055]** In addition, while the method 500 and other methods described herein may refer to eNBs 104 or UEs 102 operating in accordance with 3GPP or other standards, embodiments of those methods are not limited to just those eNBs 104 or UEs 102 and may also be practiced on other devices, such as a Wi-Fi access point (AP) or user station (STA). In addition, the method 500 and other methods described herein may be practiced by wireless devices configured to operate in other suitable types of wireless communication systems, including

systems configured to operate according to various IEEE standards such as IEEE 802.11. The method 500 may also refer to an apparatus for a UE 102 and/or eNB 104 and/or other device described above.

**[0056]** It should also be noted that although some techniques and/or operations described as part of the method 500 may refer to scenarios in which two eNBs 104 communicate with the UE 102, embodiments are not limited to usage of two eNBs. In some embodiments, some or all of the techniques and/or operations may be applicable to scenarios in which more than two eNBs 104 are used. For instance, the UE 102 may receive signals from more than two eNBs 104 and/or may provide feedback for more than two eNBs 104, in some embodiments.

**[0057]** At operation 505 of the method 500, the UE 102 may receive a first signal from a first eNB 104. At operation 510, the UE 102 may receive a second signal from a second eNB 104. In some embodiments, the first and/or second signals may be control signals, although embodiments are not limited as such. In some embodiments, the first and/or second signals may include and/or may be based on control bits, control information and/or data bits.

**[0058]** In some embodiments, directional transmission and/or directional reception may be used. As an example, the first signal may be received according to a first receive direction between the UE 102 and the first eNB 104. As another example, the second signal may be received according to a second receive direction between the UE 102 and the second eNB 104. As another example, the first signal may be transmitted according to a first transmit direction between the UE 102 and the first eNB 104. As another example, the second signal may be transmitted according to a second transmit direction between the UE 102 and the second eNB 104.

**[0059]** In some embodiments, the UE 102 may be configured to operate in a beam aggregation mode for diversity reception of downlink data packets from the first and second eNBs 104. For instance, the first eNB 104 may be arranged to operate as a serving Transmission Point (TP) and the second eNB 104 may be arranged to operate as an assistant TP, in some cases. Embodiments are not limited to beam aggregation scenarios, however, as some or all

techniques described herein may be applicable in some other scenarios.

Accordingly, although reference may be made to a “beam aggregation mode,” it is understood that some or all of the techniques and/or operations described may be applicable, in some cases, to scenarios in which beam aggregation may not necessarily be used.

**[0060]** FIG. 6 illustrates an example of a beam aggregation scenario in accordance with some embodiments. Although the example scenario 600 shown in FIG. 6 may illustrate some or all aspects of techniques disclosed herein, it is understood that embodiments are not limited by this example scenario 600. It should also be noted that embodiments are not limited to the components shown in the example scenario 600. Embodiments are not limited to usage of the UE 102 and/or the eNB 104, as other mobile devices and/or base station devices may be used in some cases. As an example, a station (STA) arranged to communicate using a wireless local area network (WLAN) protocol (or other protocol) may be used. As another example, an access point (AP) arranged to communicate using a WLAN protocol (or other protocol) may be used. As another example, some embodiments may include more than the two eNBs 104 shown in the example scenario 600 as shown in FIG. 6. The UE 102 and the eNBs 104 may be arranged to communicate using a Third Generation Partnership Protocol (3GPP) Long Term Evolution (LTE) protocol in some cases. Embodiments are not limited to usage of the 3GPP LTE protocol, however, as any suitable communication protocol, which may or may not be included as part of one or more standards, may be used.

**[0061]** In the example scenario 600, the UE 102 may exchange packets, signals and/or messages with the first eNB 104 over the first wireless link 610 and may exchange packets, signals and/or messages with the second eNB 104 over the second wireless link 620. In some embodiments, the UE 102 may receive packets from the eNBs 104 as part of beam aggregation, in which diversity may be realized in some cases. For instance, the eNBs 104 may transmit signals that are based on a same data packet to enable the UE 102 to receive multiple copies and/or versions of the data packet. Accordingly, diversity combining, diversity selection and/or other techniques may be used at

the UE 102 to realize a diversity gain. In some embodiments, the eNBs 104 may transmit the signals in a directional manner using beam-forming techniques and/or other techniques, although the scope of embodiments is not limited in this respect.

5    **[0062]**       Returning to the method 500, at operation 515, one or more rank indicators (RIs) for the first signal and/or second signal may be determined. In some embodiments, the RI for a signal received at the UE 102 from an eNB 104 may indicate a number of directional beams, between the eNB 104 and the UE 102, that are determined as part of the reception of the signal. That is, the RI  
10   may indicate or may be related to a number of beams that are discernible to the UE 102. For instance, a single transmitted beam may experience various effects when transmitted over a wireless medium and may appear, at the UE 102, as if multiple beams have been transmitted. In some cases, the UE 102 may determine information for the multiple beams, such as signal quality, channel  
15   state information (CSI), angle and/or other information.

**[0063]**       In some embodiments, the first signal and/or second signal may be transmitted according to multiple transmit directions from the eNBs 104. That is, multiple transmit beams may be used by either or both eNBs 104, in some cases. In some embodiments, the transmitted signals and/or beams may be  
20   based on one or more codewords. The codewords may be predetermined in some cases, and may be used by the UE 102 to determine CSI information, signal quality measurements and/or other information that may enable decoding of data packets, beam tracking and other operations.

**[0064]**       As an example, the first signal may be based at least partly on a  
25   first codeword. The first codeword may include a number of bits that may be produced in any suitable manner or may be predetermined. For instance, one or more transmitter tasks such as forward error correction (FEC), cyclic redundancy check (CRC) and/or others may be used to produce the first codeword. In some cases, one or more operations, such as bit-to-symbol mapping and/or others, may  
30   be applied to the first codeword to produce the first signal to be transmitted. The UE 102 may have knowledge of the first codeword, in some cases, and may operate on the received first signal accordingly. As a non-limiting example, the

UE 102 may determine a template of modulated symbols based on the first codeword, and may perform a correlation between the template and the received first signal. The correlation may be used to produce an RI for the first codeword and/or for the first signal.

- 5   **[0065]**       As another non-limiting example, the first signal may be transmitted according to multiple transmit beams, each of which may be based on a different codeword. Accordingly, the UE 102 may perform operations, like those described above, for each codeword to produce an RI (and/or other CSI related information) for each codeword. For instance, one of the transmitted  
10   beams may appear at the UE 102 as two or more beams, in which case the RI for that beam (or the related codeword for that beam) may be greater than one.

**[0066]**       Accordingly, the UE 102 may determine an RI for the first signal that may indicate a number of directional beams, between the first eNB 104 and the UE 102, that are determined as part of the reception of the first signal.

- 15   Similarly, the UE 102 may determine an RI for the second signal that may indicate a number of directional beams, between the second eNB 104 and the UE 102, that are determined as part of the reception of the second signal. As described previously, in some cases, the first signal and/or the second signal may be transmitted using multiple beams based on multiple codewords. For a signal  
20   transmitted using multiple beams, multiple RIs may be determined.

**[0067]**       At operation 520, one or more channel quality indicators (CQIs) may be determined. As an example, a CQI may be determined for each of the first and second signals. Embodiments are not limited to usage of the CQI, as other signal quality measurements, such as reference signal received power  
25   (RSRP), reference signal received quality (RSRQ), received signal strength indicator (RSSI), signal-to-noise ratio (SNR) and/or others, may be used in some cases.

- [0068]**       At operation 525, one or more angles for the first signal and/or second signal may be determined. In some embodiments, the angles may be  
30   determined using beam-forming techniques and/or other techniques, although the scope of embodiments is not limited in this respect.

**[0069]** FIG. 7 illustrates examples of multiple beam transmission in accordance with some embodiments. Although the example scenarios 700 and 750 shown in FIG. 7 may illustrate some or all aspects of techniques disclosed herein, it is understood that embodiments are not limited by this example scenarios 700 and 750. As described previously regarding FIG. 6, although eNBs 104 and UEs 102 are illustrated in FIG. 7, any suitable types of mobile devices, base stations, and communication protocols may be used. Embodiments are not limited to the number or type of components shown in FIG. 7 and are also not limited to the number or arrangement of transmitted beams shown in FIG. 7.

**[0070]** In the example scenario 700, the eNB 104 may transmit a signal on multiple beams 705-720, any or all of which may be received at the UE 102. It should be noted that the number of beams or transmission angles as shown are not limiting. As the beams 705-720 may be directional, transmitted energy from the beams 705-720 may be concentrated in the direction shown. Therefore, the UE 102 may not necessarily receive a significant amount of energy from beams 705 and 710 in some cases, due to the illustrated location of the UE 102. However, the UE 102 may receive a significant amount of energy from the beams 715 and 720 as shown. As an example, the beams 705-720 may be transmitted using different codewords, and the UE 102 may determine CSI feedback and/or other information for beams 715 and 720.

**[0071]** In the example scenario 750, the UE 102 may determine angles and/or other information (such as CSI feedback, CQI and/or other) for the beams 765 and 770. The UE 102 may also determine such information when received at other angles, such as the illustrated beams 775 and 780. The beams 775 and 780 are demarcated using a dotted line configuration to indicate that they may not necessarily be transmitted beams, but that the UE 102 may determine information, such as that previously described, using the directions of 775 and 780 as receive directions.

**[0072]** At operation 530, the UE 102 may transmit one or more channel state information (CSI) messages. Embodiments are not limited to dedicated CSI messages, however, as the UE 102 may include CSI information in control

messages and/or other messages that may or may not be dedicated for communication of the CSI information. The CSI messages may be transmitted to the first and/or second eNBs 104, in some embodiments. Separate messages may be sent to each of the first and second eNBs 104, in some cases, although  
5       embodiments are not limited as such. In some cases, one or more CSI messages may include CSI feedback for both eNBs 104 and may be sent as joint messages.

**[0073]**       As an example, the first signal received from the first eNB 104 may include a first directional beam based at least partly on a first codeword and a second directional beam based at least partly on a second codeword. The UE  
10       102 may determine an RI for the first codeword and an RI for the second codeword, and may transmit both RIs in the CSI messages. In addition, the UE 102 may determine one or more RIs for the second signal, and may also include them in the CSI messages in some cases. The UE 102 may also determine a CQI, a precoding matrix indicator (PMI), angles and/or other information for one  
15       or both of the first and second signals in some cases. Such information may be included, along with one or more RIs, in the one or more CSI messages.

**[0074]**       As an example, CSI feedback for the first eNB 104 and CSI feedback for the second eNB 104 may be transmitted in separate CSI messages. As another example, CSI feedback for the first eNB 104 and CSI feedback for  
20       the second eNB 104 may be transmitted jointly in one or more CSI messages.

**[0075]**       As an example, the first signal received from the first eNB 104 may include a first directional beam based at least partly on a first codeword and a second directional beam based at least partly on a second codeword. The UE  
25       102 may determine a first angle for the first directional beam and a second angle for the second directional beam. In addition, the UE 102 may determine first and second CQIs related to reception of the first signal at the first and second angles. The UE 102 may also determine a selected angle between the first angle and the second angle, wherein a CQI for reception of the first signal at the selected angle is greater than the first and second CQIs. The selected angle may  
30       be an improved angle for reception in comparison to the first and second angles, in some cases.

[0076] In some embodiments, the selected angle and/or the CQI for reception of the first signal at the selected angle may be indicated in the one or more CSI messages, in addition to or instead of other CSI feedback described herein. As an example, a bit field of two bits may be used for a beam selection indicator (BSI). For instance, the first angle may be denoted by  $\theta_1$ , the second angle by  $\theta_2$ , and a weighting scalar may be denoted as  $\alpha$ . As a non-limiting example, the selected angle, denoted by  $\theta$ , may be (or may be rounded off to)  $\alpha \cdot \theta_1 + (1 - \alpha) \cdot \theta_2$ . Values of  $\alpha$  may be selected from 0, 1/3, 2/3, and 1.0, which may be mapped to the two bit BSI in any suitable manner. This example is not limiting, however, as other suitable techniques may be used to communicate the selected angle in terms of two (or more) determined transmitted angles.

[0077] At operation 535, a first data signal may be received from the first eNB 104. At operation 540, a second data signal may be received from the second eNB 104. At operation 545, the UE 102 may decode a data packet based at least partly on the first and/or second data signals. In some embodiments, the first and second data signals may be based at least partly on a same downlink data packet. For instance, the data signals may be used to transmit the data packet to the UE 102 in a diversity format. It should be noted that either or both of the first and second data signals may be transmitted using one or more transmit beams. In some cases, the number of beams transmitted by either eNB 104 may be based at least partly on CSI feedback received from the UE 102, such as an RI, CQI, angle and/or other. The UE 102 may decode the packet using diversity combining, diversity selection and/or other suitable techniques.

[0078] As an example, the UE 102 may determine first and second CQIs for the first and second received signals. A diversity combining operation may be performed on the first and second data signals using combining weights that are based on the determined CQIs. Accordingly, a signal with a higher CQI may be combined with a higher weighting to produce combined metrics for usage in the decoding.

[0079] As another example, the data signals may be transmitted by the eNBs 104 and/or received by the UE 102 in accordance with a number of

directional beams that may be based on the reported RIs in the CSI messages. That is, one or both of the eNBs 104 may update a transmission format based on the reported RIs. For instance, the first data signal may be transmitted by the first eNB 104 according to a transmission format (such as spatial multiplexing, diversity, single antenna or other) based on the first RI reported in the CSI messages. The second data signal may be transmitted by the second eNB 104 according to a transmission format based on the second RI reported in the CSI messages.

**[0080]** In some embodiments, the UE 102 may be configured with one or more CSI processes per serving cell by higher layers. Each CSI process may be associated with a CSI Reference Signal (CSI-RS) resource and a CSI-interference measurement (CSI-IM).

**[0081]** In some embodiments, two coherent CSI processes may be used to feedback both CSI of both TPs individually. One may measure the CSI-RS from a serving TP and feedback the primary CSI. The other may measure the CSI-RS from an assistant TP and feedback the secondary CSI. Each CSI may include a Rank Indicator (RI), a Precoder Matrix Indicator (PMI) and/or a Channel Quality Indicator (CQI). In some cases, the RI may be wideband, the PMI and the CQI may be sub-band or wideband, and one CSI may include one codeword only. In some cases, the RI of the two processes shall meet the following example requirement to confirm the validation of both CSIs:

$$\gamma_1 + \gamma_2 + 2 \leq \min(N_{rx}, N_{tx}).$$

The RI in CSI process  $j$  may be denoted as  $\gamma_j$ , and the number of receiving and transmitting antenna ports (AP) may be denoted as  $N_{rx}$  and  $N_{tx}$ . To confirm that the CSI feedback for the two coherent CSI processes could meet that requirement, it may be necessary to indicate the two CSI processes are coherent. In some embodiments, a “coherent CSI process” may be a CSI included in a group of CSIs for which a sum of rank indicators does not exceed a maximum rank. As an example, a criterion such as  $\gamma_1 + \gamma_2 + 2 \leq \min(N_{rx}, N_{tx})$  may be used to determine whether a first and second CSI process are coherent.

**[0082]** In some embodiments, a UE 102 in beam aggregation mode may be configured with two CSI processes only, which are considered as coherent

CSI processes. In some embodiments, a UE 102 may be configured with more than two CSI processes, and two of them may be implicitly considered as coherent CSI processes. An example is to select the first two CSI processes as coherent CSI processes. In some embodiments, a UE 102 may be configured with more than two CSI processes, and a bit map may be used to indicate which CSI processes are coherent. The bit map may be configured via RRC signaling. As an example, three CSI processes may be configured for the UE 102, two of which are coherent and one of which is not coherent. A bitmap may indicate which of the three CSI processes are coherent. For instance, if the first and second CSI process are coherent and the third is not coherent, an RRC message may indicate a bitmap value of [ 1 1 0 ].

**[0083]** As another example, the UE 102 may be configured with a group of candidate CSI processes. Accordingly, the UE 102 may be configured to receive one or more control signals, such as CSI-RS, and to take CSI measurements accordingly for usage in reception of data signals, determination of RIs and/or other operations. An indicator (such as a bitmap or other) received from one or more of the eNBs 104 may indicate which of the candidate CSI processes are to be used by the UE 102. The bitmap may indicate a combination (sub-set or other) of the candidate CSI processes in the group that may be used, by the UE 102. The particular combination indicated in the bitmap may be a function of RIs of one or more RIs for candidate CSI processes in the group, in some cases. The particular combination may also be based on a threshold, such as a maximum rank or other, which may be based on a number of transmit antennas and/or receive antennas used by the eNB 104 and/or UE 102. A criteria, such as  $\gamma_1 + \gamma_2 + 2 \leq \min(N_{rx}, N_{tx})$  or other, may be used by the eNB 104 or other component to determine the bitmap.

**[0084]** In some embodiments, one CSI process may be used to jointly feedback the CSI. The feedback CSI may include a codeword specific RI, a wideband or sub-band CQI per codeword, a wideband or sub-band PMI, and/or a codeword-specific wideband or sub-band PMI. As a result of a codeword to layer mapping method, it may be necessary to indicate the number of layers per codeword in CSI feedback operation. Therefore the RI may be codeword

specific. In some cases, the pre-coder for two TPs may be different. Hence a codeword specific PMI may be used. On the other hand, if the receiving signal is obtained with a joint pre-coder, the PMI may not be codeword specific. The codeword of index 0 may implicitly indicate the CSI for the serving TP and the  
5 codeword of index 1 may be for the assistant TP.

**[0085]** In some embodiments, the eNB 104 may transmit several CSI-RS groups with different beams. However, those beams may not cover all possible beams for each UE 102, in some cases. A UE 102 may be configured with two beams within a CSI process. The two beams may be  
10 mapped into two CSI-RS groups. For example, two Antenna Ports (AP) may use a first beam and two other Antenna Ports may use a second beam. The selected beam may not be covered by the candidate measurement beams set. The eNB 104 could only know whether the first or second beam may be better for the UE 102. However actually the best beam for the UE 102 may  
15 be between the first and second beams. Then the UE 102 may report its best beam with a Beam Selection Indicator (BSI), which may be included in CSI feedback. The BSI may also be included in one or more CSI messages sent from the UE 102 to the eNB 104. In some cases, the BSI may be codeword specific.

**[0086]** In some embodiments, several CSI-RSs may be grouped to use one beam for CSI measurement when multiple beams are used in an eNB 104. The Antenna Ports (APs) for each CSI-RS group may be explicitly configured via RRC signaling as well as the number of CSI-RS groups for one CSI process. In some embodiments, the UE 102 may measure the CSI for CSI-RS groups  
25 within a sub-frame in one CSI process and may select the CSI in the best beam to include in a CSI message. The best beam may indicate the one by which the highest Spectrum Efficiency (SE) could be achieved. For coherent CSI processes, previously described criteria may also be applied for the best beam selection. To support such CSI feedback, the CSI message may include a  
30 selected CSI-RS group index, in some embodiments. In some embodiments, the beam selection may be done by the eNB 104. A UE 102 may report all CSIs in each CSI-RS group within a CSI process. The reported CSI message may

include RI per CSI-RS group, wideband or sub-band PMI per CSI-RS group and/or wideband or sub-band CQI for one codeword per CSI-RS group. In some embodiments, the UE 102 may report a CSI-RS group index pair to indicate the selected CSI-RS groups from both serving TP and assistant TP. Then the CSI

5 may contain an additional primary CSI-RS group index and secondary CSI-RS group index. The primary CSI-RS group index may indicate the group index from serving TP and the secondary CSI-RS group index may indicate the group index from assistant TP. In some embodiments, the UE 102 may judge whether the assistant beam could come from the serving TP. Therefore it may explicitly

10 indicate which TP the CSI-RS comes from. Then an indicator with one bit for primary CSI-RS group index and an indicator of one bit for secondary CSI-RS group index may be used. A value of 0 may indicate the serving TP and a value of 1 may indicate the assistant TP. The CSI message may include a primary CSI-RS group index, a secondary CSI-RS group index, a TP indicator for the primary

15 CSI-RS group index and a TP indicator for the secondary CSI-RS group index. In some embodiments, the CSI for all possible beam groups or  $N$  beam groups with the highest performance may be reported. The number  $N$  may be configured by RRC signaling in some cases. The primary and secondary group index may be included in the CSI message and/or in CSI feedback.

20 **[0087]** FIG. 8 illustrates the operation of another method of communication in accordance with some embodiments. As mentioned previously regarding the method 500, embodiments of the method 800 may include additional or even fewer operations or processes in comparison to what is illustrated in FIG. 8 and embodiments of the method 800 are not necessarily

25 limited to the chronological order that is shown in FIG. 8. In describing the method 800, reference may be made to FIGs. 1-7 and 9-10, although it is understood that the method 800 may be practiced with any other suitable systems, interfaces and components. In addition, embodiments of the method 800 may refer to UEs 102, eNBs 104, APs, STAs or other wireless or mobile

30 devices. The method 800 may also refer to an apparatus for an eNB 104 and/or UE 102 or other device described above.

[0088] In addition, previous discussion of various techniques and concepts may be applicable to the method 800 in some cases, including beam aggregation, multiple beam transmission, signal quality measurements, CQIs and others. In addition, some or all aspects of the example scenarios 600, 700, and/or 750 may be applicable in some cases. Although the method 800 may be described for beam aggregation scenarios in which two eNBs 104 are used, embodiments are not limited to beam aggregation scenarios or to two eNBs 104.

5 [0089] At operation 805, the UE 102 may receive a first signal from a first eNB 104. At operation 810, the UE 102 may receive a second signal from a second eNB 104. As described previously, these signals may be transmitted and/or received in a directional manner. In some embodiments, the UE 102 may be configured to operate in a beam aggregation mode for diversity reception of downlink data packets from the eNB 104. In addition, the eNBs 104 may be configured to operate in a beam aggregation mode for diversity transmission of downlink data packets to the UE 102.

10 [0090] FIG. 9 illustrates example scenarios of communication using ideal and non-ideal backhaul connections in accordance with some embodiments. It should be noted that embodiments are not limited by the example scenarios 900 and 950 shown in FIG. 9. The first and second eNBs 104 may be a serving TP and an assistant TP, respectively. In the ideal backhaul scenario 900, the first and second eNBs 104 may communicate with a server device 920 or other device over links 925 and 930, respectively. In the ideal backhaul scenario 900, the UE 102 may be jointly scheduled and baseband processing for the UE 102 (such as uplink packet reception) may be performed jointly.

20 [0091] In the non-ideal backhaul scenario 950, the first eNB 104 may communicate with a server device 960 or other device over link 975. The second eNB 104 may communicate with a server device 980 or other device over link 985. In the non-ideal backhaul scenario 950, the UE 102 may be scheduled independently and some load balancing operations among these two TPs (and perhaps others) may be performed.

30

[0092] At operation 815, one or more signal quality measurements may be determined for the first signal and/or second signal. Although embodiments are not limited as such, measurements described herein may be used in some cases, including but not limited to RI, CQI, PMI, RSSI, RSRQ, RSSI, SNR  
5 and/or other measurements.

[0093] At operation 820, the UE 102 may select a serving eNB 104 for a beam aggregation mode. In some embodiments, the serving eNB 104 may be selected from either the first eNB or the second eNB. The selection may be based at least partly on the signal quality measurements for the first eNB and the  
10 second eNB in some cases. For instance, the eNB 104 with a highest CQI, RSSI, SNR or other signal quality measurement may be selected as the serving eNB 104. In some cases, the other eNB 104 (the eNB 104 not selected as the serving eNB 104) may be selected as an assistant eNB 104 for the beam aggregation mode. As a non-limiting example, the serving eNB 104 may  
15 operate as a primary or main eNB 104 while the assistant eNB 104 may operate as a secondary eNB 104. For instance, certain control messages related to connectivity between the UE 102 and the eNBs 104 may be exchanged between the UE 102 and the serving eNB 104.

[0094] At operation 830, a physical random access channel (PRACH)  
20 preamble may be transmitted to the serving eNB 104. In some embodiments, a group of PRACH preambles may be available for PRACH transmission. The group may be divided into at least two groups. One of the groups (a serving group) may be reserved for and/or allocated for PRACH preamble transmissions to eNBs 104 that have been selected as serving eNBs 104. The serving group  
25 may be restricted from usage for communication between the UE 102 and assistant eNBs 104, in some cases. Another group (an assistant group) may be reserved for and/or allocated for PRACH preamble transmissions to eNBs 104 that have been selected as assistant eNBs 104. The assistant group may be restricted from usage for communication between the UE 102 and serving eNBs  
30 104, in some cases. Accordingly, the eNB 104 may determine whether it is to operate as a serving eNB 104 or an assistant eNB 104 in the beam aggregation

based on the group (serving group or assistant group) in which the detected PRACH preamble is included.

[0095] FIG. 10 illustrates an example of a random access procedure in accordance with some embodiments. It should be noted that embodiments are not limited by the example random access procedure 1000 shown in FIG. 10, in terms of the number, arrangement, ordering or type of messages that are exchanged. Some embodiments may or may not necessarily include exchanging of all messages shown in the example procedure 1000, and some embodiments may include exchanging of additional messages not shown in the example procedure 1000. Although the messages shown may be part of a 3GPP standard or other standard, embodiments are not limited to usage of such messages.

[0096] At operation 1010, a “Msg1” or PRACH preamble may be transmitted by the UE 102 to the eNB 104. At operation 1020, a “Msg2” or random access response (RAR) message may be transmitted by the eNB 104 to the UE 102. At operation 1030, a “Msg3” or physical uplink shared channel (PUSCH) message may be transmitted by the UE 102 to the eNB 104.

[0097] At operation 835, the UE 102 may receive, from the serving eNB 104, a PRACH preamble response message (such as the RAR 1020 or other). At operation 840, the UE 102 may receive information that indicates a loading of the serving eNB 104. The loading may indicate a resource utilization (RU), an estimated delay for the first scheduling of the UE 102 to be attached and/or other related information. In some cases, loading information may also be received for the assistant eNB 104 and/or other eNBs 104. In some embodiments, the UE 102 may determine such a loading for one or more of the eNBs 104. The usage of such loadings may enable a traffic aware access procedure, which may result in a reduced delay in some cases.

[0098] In some embodiments, the PRACH preamble response message may indicate such a loading of the serving eNB 104. In some embodiments, the UE 102 may receive, from the first and/or second eNBs, one or more radio resource control (RRC) messages that may indicate loading of the first and/or second eNBs 104. For instance, one or more system information blocks (SIB) and/or master information blocks (MIB) may be used. In some embodiments,

the UE 102 may determine such loadings based on received signals from the eNBs 104. For instance, loadings may be determined based on bandwidth utilizations, such as a number of resource blocks (RBs) occupied, of the received first signal and received second signal. In some cases, such information may be  
5 determined without decoding of downlink data from the eNBs 104.

**[0099]** At operation 845, the UE 102 may determine, based at least partly on the loading, whether the serving eNB 104 is to continue operating as the serving eNB 104. For instance, if the serving eNB 104 is too heavily loaded (in comparison to a predetermined threshold), the UE 102 may re-select another  
10 eNB 104 to operate as the serving eNB 104. As an example, the assistant eNB 104 or other eNB 104 may be selected as a replacement serving eNB 104.

**[00100]** At operation 850, the UE 102 may transmit a PRACH preamble (selected from the serving group) to the replacement serving eNB 104. Accordingly, the random access procedure may be performed for the  
15 replacement serving eNB 104 starting with Msg1. As previously described, some embodiments of the method 800 may not necessarily include all operations shown in FIG. 8. In some embodiments, the method 800 may include operation 850 when the UE 102 determines that the original serving eNB 104 is to be replaced by the replacement serving eNB 104. In some cases, the random access  
20 procedure with the original serving eNB 104 may be discontinued when the UE 102 determines that the original serving eNB 104 is no longer to continue in that role. In addition, the Msg3 or PUSCH message may be transmitted accordingly when the UE 102 has received the Msg2 from an eNB 104 (original serving eNB 104 or replacement serving eNB 104) that is to continue as the serving eNB 104.

**[00101]** At operation 855, the UE 102 may transmit a PRACH preamble (selected from the assistant group) to the assistant eNB 104. In addition, the UE 102 may continue the random access procedure shown in FIG. 10 (or other appropriate procedure) with the assistant eNB 104.

**[00102]** In some embodiments, a UE 102 may have more than one  
30 antenna panel. Each antenna panel may be working as a directional antenna in some cases. This may provide a coverage enhancement for a UE 102 in some cases, such as in millimeter (mm) wave communication. In some cases,

the UE 102 may have different measurement results in each antenna panel, such as a different Reference Signal Receiving Power (RSRP) and Reference Signal Receiving Quality (RSRQ). The UE 102 may report antenna panel specific RSRP and RSRQ and may select TPs and antenna panels in beam aggregation mode. In some embodiments, different Ues 102 may have different traffic types, so they may have different Quality of Service (QoS) requirements. By using beam aggregation and multiple antenna panels, a UE 102 may have enough flexibility to select which TP to access and which antenna panel to use. Different TPs may have different loading, in some cases. Accordingly, the load of each TP and traffic QoS requirements of the UEs 102 may be considered as part of such selections.

**[00103]** In some embodiments, a UE 102 with multiple antenna panels may work in the beam aggregation mode, where each antenna panel may receive one beam. The aggregated beams may come from different TPs in some cases. Hence a UE 102 may measure antenna panel specific results and may select the target accessing TP from which the highest RSRP or RSRQ is measured. The RSRP and RSRQ may be measured with or without beam-forming. For assistant TP selection, when a single antenna panel is used, the criteria may be as follows. A first RSRP (or RSRQ for alternative) may be a maximum RSRP from neighbor TPs and a second RSRP (or RSRQ for alternative) may be from the serving TP. A difference between the two values may be compared to a threshold (which may be defined by each eNB 104 in some cases) as part of the selection.

**[00104]** In Example 1, an apparatus for a User Equipment (UE) may comprise transceiver circuitry and hardware processing circuitry. The hardware processing circuitry may configure the transceiver circuitry to receive a first signal from a first Evolved Node-B (eNB) according to a first receive direction between the UE and the first eNB. The hardware processing circuitry may further configure the transceiver circuitry to receive a second signal from a second eNB according to a second receive direction between the UE and the second eNB. The hardware processing circuitry may further configure the transceiver circuitry to transmit a channel state information (CSI) message to the

first and second eNBs. The CSI message may include a first rank indicator (RI) that indicates a number of directional beams, between the first eNB and the UE, that are determined as part of the reception of the first signal. The CSI message may further include a second RI that indicates a number of directional beams,  
5 between the second eNB and the UE, that are determined as part of the reception of the second signal.

**[00105]** In Example 2, the subject matter of Example 1, wherein the CSI message may further include a channel quality indicator (CQI) for the reception of the first signal and a CQI for the reception of the second signal.

10 **[00106]** In Example 3, the subject matter of one or any combination of Examples 1-2, wherein the hardware processing circuitry may be configured to determine the first RI based at least partly on a determined correlation between the first signal and a predetermined first codeword. The first signal may be based at least partly on the first codeword. The hardware processing circuitry  
15 may be further configured to determine the second RI based at least partly on a determined correlation between the second signal and a predetermined second codeword. The second signal may be based at least partly on the second codeword.

**[00107]** In Example 4, the subject matter of one or any combination of  
20 Examples 1-3, wherein the first signal may include a first directional beam based at least partly on a first codeword and a second directional beam based at least partly on a second codeword. The first RI may be based at least partly on a determined correlation between the first signal and the first codeword. The CSI message may further include a third RI that is based at least partly on a  
25 determined correlation between the first signal and the second codeword.

**[00108]** In Example 5, the subject matter of one or any combination of Examples 1-4, wherein the first signal may include a first directional beam based at least partly on a first codeword and a second directional beam based at least partly on a second codeword. The hardware processing circuitry may be  
30 configured to determine, based on the reception of the first signal, a first angle for the first directional beam and a second angle for the second directional beam, a first channel quality indicator (CQI) for reception of the first signal at the first

angle, a second CQI for reception of the first signal at the second angle, and a selected angle between the first angle and the second angle. A CQI for reception of the first signal at the selected angle may be greater than the first and second CQIs. The CSI message may further include a beam selection indicator (BSI) that indicates the selected angle.

**[00109]** In Example 6, the subject matter of one or any combination of Examples 1-5, wherein the CSI message may further include the CQI for the reception of the first signal at the selected angle.

**[00110]** In Example 7, the subject matter of one or any combination of Examples 1-6, wherein the hardware processing circuitry may be configured to determine a first channel quality indicator (CQI) for the reception of the first signal and a second CQI for the reception of the second signal. The hardware processing circuitry may further configure the transceiver circuitry to receive a first data signal from the first eNB and a second data signal from the second eNB. The first and second data signals may be based at least partly on a downlink data block. The hardware processing circuitry may be further configured to determine combined metrics that include a combination of the first and second data signals according to one or more combining weights. The combining weights may be based at least partly on the first CQI and the second CQI. The hardware processing circuitry may be further configured to decode the downlink data block based on the combined metrics.

**[00111]** In Example 8, the subject matter of one or any combination of Examples 1-7, wherein the hardware processing circuitry may further configure the transceiver circuitry to receive, from the first eNB, a first data signal in accordance with a number of directional beams that is based on the first RI.

**[00112]** In Example 9, the subject matter of one or any combination of Examples 1-8, wherein the UE may be configured to operate in a beam aggregation mode for diversity reception of downlink data packets from the first eNB arranged to operate as a serving Transmission Point (TP) and from the second eNB arranged to operate as an assistant TP.

**[00113]** In Example 10, the subject matter of one or any combination of Examples 1-9, wherein the first eNB, the second eNB, and the UE may be

arranged to operate in a Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) network.

**[00114]** In Example 11, a non-transitory computer-readable storage medium may store instructions for execution by one or more processors to perform operations for communication by a User Equipment (UE). The operations may configure the one or more processors to configure the UE to transmit one or more channel state information (CSI) messages that include a rank indicator (RI) for a reception of a first control signal from a first Evolved Node-B (eNB) and an RI for a reception of a second control signal from a second eNB. The operations may further configure the one or more processors to configure the UE to receive a first data signal from the first eNB and a second data signal from the second eNB. The first and second data signals may be based at least partly on a downlink data packet. The operations may further configure the one or more processors to decode the downlink data packet based on the received first and second data signals.

**[00115]** In Example 12, the subject matter of Example 11, wherein the UE may be configured to operate in a beam aggregation mode for diversity reception of downlink data packets from the eNBs.

**[00116]** In Example 13, the subject matter of one or any combination of Examples 11-12, wherein the RIs may indicate, for each of the first and second control signals, a number of beams that are discernible at the UE as part of the reception of the control signals.

**[00117]** In Example 14, the subject matter of one or any combination of Examples 11-13, wherein the first control signal may be a first CSI reference signal (CSI-RS) and the reception of the first control signal may be performed in first CSI-RS resources. The second control signal may be a second CSI-RS and the reception of the second control signal may be performed in second CSI-RS resources. The operations may further configure the one or more processors to configure the UE to receive or to refrain from reception of additional CSI-RS based on an indicator received from the first eNB.

**[00118]** In Example 15, the subject matter of one or any combination of Examples 11-14, wherein the indicator received from the eNB may include a

coherence bitmap that indicates which control signals are to be received by the UE. The coherence bitmap may be based at least partly on a comparison of a sum of the RIs and a maximum rank. The maximum rank may be based on a minimum of a number of transmit antennas at the first eNB, a number of  
5 transmit antennas at the second eNB, and a number of receive antennas at the UE.

**[00119]** In Example 16, the subject matter of one or any combination of Examples 11-15, wherein the UE may be configured to transmit separate CSI messages to the first and second eNBs.

10 **[00120]** In Example 17, the subject matter of one or any combination of Examples 11-16, wherein the RI for the reception of the first control signal may be based at least partly on a determined correlation between the first control signal and a predetermined first codeword. The first control signal may be based at least partly on the first codeword. The RI for the reception of the second  
15 control signal may be based at least partly on a determined correlation between the second control signal and a predetermined second codeword. The second control signal may be based at least partly on the second codeword.

**[00121]** In Example 18, the subject matter of one or any combination of Examples 11-17, wherein the first control signal may include multiple  
20 directional beams based at least partly on different codewords. The CSI messages may include multiple RIs for the reception of the first control signal based at least partly on determined correlations between the first control signal and the codewords.

**[00122]** In Example 19, an apparatus for a User Equipment (UE) may  
25 comprise transceiver circuitry and hardware processing circuitry. The hardware processing circuitry may configure the transceiver circuitry to receive a first signal from a first Evolved Node-B (eNB) and a second signal from a second eNB. The UE may be configured to operate in a beam aggregation mode for diversity reception of downlink data packets from the eNBs. The hardware  
30 processing circuitry may be configured to select, from either the first eNB or the second eNB, a serving eNB for the beam aggregation mode based at least partly on signal quality measurements for the first eNB and the second eNB. The

hardware processing circuitry may further configure the transceiver circuitry to transmit a physical random access channel (PRACH) preamble to the serving eNB. The transmitted PRACH preamble may be selected, by the UE, from a serving group of candidate PRACH preambles allocated for random access communication between UEs and serving eNBs.

**[00123]** In Example 20, the subject matter of Example 19, wherein of the first or second eNB, the eNB for which the signal quality measurement is greater may be selected as the serving eNB and the eNB for which the signal quality measurement is lesser may be selected as an assistant eNB for the beam aggregation mode.

**[00124]** In Example 21, the subject matter of one or any combination of Examples 19-20, wherein the serving group of candidate PRACH preambles may be restricted from usage for random access communication between UEs and assistant eNBs.

**[00125]** In Example 22, the subject matter of one or any combination of Examples 19-21, wherein the transmitted PRACH preamble may be a first PRACH preamble. The eNB, of the first or second eNB, that is not selected as the serving eNB may be selected as an assistant eNB. The hardware processing circuitry may further configure the transceiver circuitry to transmit a second PRACH preamble to the assistant eNB. The second PRACH preamble may be selected, by the UE, from an assistant group of candidate PRACH preambles allocated for random access communication between UEs and assistant eNBs.

**[00126]** In Example 23, the subject matter of one or any combination of Examples 19-22, wherein the hardware processing circuitry may further configure the transceiver circuitry to receive, from the serving eNB, a PRACH preamble response message that indicates a loading of the serving eNB. The hardware processing circuitry may further configure the transceiver circuitry to, when the loading of the serving eNB is not greater than a predetermined threshold, transmit a physical uplink shared channel (PUSCH) message to the serving eNB. The hardware processing circuitry be further configured to, when the loading of the serving eNB is greater than the predetermined threshold, select another eNB to operate as the serving eNB for the beam aggregation mode.

**[00127]** In Example 24, the subject matter of one or any combination of Examples 19-23, wherein when the loading of the serving eNB is greater than the predetermined threshold, the assistant eNB may be selected to operate as a replacement serving eNB for the beam aggregation mode. The hardware processing circuitry may further configure the transceiver circuitry to transmit, to the replacement serving eNB, a PRACH preamble selected from the serving group of candidate PRACH preambles.

**[00128]** In Example 25, the subject matter of one or any combination of Examples 19-24, wherein the hardware processing circuitry may further configure the transceiver circuitry to receive, from the first and/or second eNBs, one or more radio resource control (RRC) messages that indicate loadings of the first and/or second eNBs. The selection of the serving eNB may be further based at least partly on the indicated loadings.

**[00129]** In Example 26, the subject matter of one or any combination of Examples 19-25, wherein the hardware processing circuitry may be further configured to determine, based on bandwidth utilizations of the received first signal and received second signal, loadings of the first and second eNBs. The selection of the serving eNB may be further based at least partly on the indicated loadings.

**[00130]** The Abstract is provided to comply with 37 C.F.R. Section 1.72(b) requiring an abstract that will allow the reader to ascertain the nature and gist of the technical disclosure. It is submitted with the understanding that it will not be used to limit or interpret the scope or meaning of the claims. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate embodiment.

## CLAIMS

What is claimed is:

- 5           1. An apparatus for a User Equipment (UE), the apparatus comprising transceiver circuitry and hardware processing circuitry, the hardware processing circuitry to configure the transceiver circuitry to:
- receive a first signal from a first Evolved Node-B (eNB) according to a first receive direction between the UE and the first eNB;
- 10           receive a second signal from a second eNB according to a second receive direction between the UE and the second eNB;
- transmit a channel state information (CSI) message to the first and second eNBs,
- wherein the CSI message includes a first rank indicator (RI) that
- 15           indicates a number of directional beams, between the first eNB and the UE, that are determined as part of the reception of the first signal, and
- wherein the CSI message further includes a second RI that indicates a number of directional beams, between the second eNB and the UE, that are determined as part of the reception of the second signal.
- 20           2. The apparatus according to claim 1, wherein the CSI message further includes a channel quality indicator (CQI) for the reception of the first signal and a CQI for the reception of the second signal.
- 25           3. The apparatus according to claim 1, the hardware processing circuitry configured to:
- determine the first RI based at least partly on a determined correlation between the first signal and a predetermined first codeword, wherein the first signal is based at least partly on the first codeword; and
- 30           determine the second RI based at least partly on a determined correlation between the second signal and a predetermined second codeword, wherein the second signal is based at least partly on the second codeword.

4. The apparatus according to claim 1, wherein:

the first signal includes a first directional beam based at least partly on a first codeword and a second directional beam based at least partly on a second  
5 codeword,

the first RI is based at least partly on a determined correlation between the first signal and the first codeword, and

the CSI message further includes a third RI that is based at least partly on a determined correlation between the first signal and the second codeword.

10

5. The apparatus according to claim 1, wherein:

the first signal includes a first directional beam based at least partly on a first codeword and a second directional beam based at least partly on a second codeword,

15 the hardware processing circuitry is configured to determine, based on the reception of the first signal:

a first angle for the first directional beam and a second angle for the second directional beam,

20 a first channel quality indicator (CQI) for reception of the first signal at the first angle,

a second CQI for reception of the first signal at the second angle, and

a selected angle between the first angle and the second angle, wherein a CQI for reception of the first signal at the selected angle is greater  
25 than the first and second CQIs,

the CSI message further includes a beam selection indicator (BSI) that indicates the selected angle.

6. The apparatus according to claim 5, wherein the CSI message further  
30 includes the CQI for the reception of the first signal at the selected angle.

7. The apparatus according to claim 1, the hardware processing circuitry configured to:

determine a first channel quality indicator (CQI) for the reception of the first signal and a second CQI for the reception of the second signal,

5       configure the transceiver circuitry to receive a first data signal from the first eNB and a second data signal from the second eNB, the first and second data signals based at least partly on a downlink data block,

      determine combined metrics that include a combination of the first and second data signals according to one or more combining weights, the combining  
10       weights based at least partly on the first CQI and the second CQI, and

      wherein the hardware processing circuitry includes baseband processing circuitry to decode the downlink data block based on the combined metrics.

8. The apparatus according to claim 1, the hardware processing circuitry  
15       to further configure the transceiver circuitry to receive, from the first eNB, a first data signal in accordance with a number of directional beams that is based on the first RI.

9. The apparatus according to claim 1, wherein the UE is configured to  
20       operate in a beam aggregation mode for diversity reception of downlink data packets from the first eNB arranged to operate as a serving Transmission Point (TP) and from the second eNB arranged to operate as an assistant TP.

10. The apparatus according to claim 1, wherein the first eNB, the second  
25       eNB, and the UE are arranged to operate in a Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) network.

11. A computer-readable storage medium that stores instructions for  
      execution by one or more processors to perform operations for communication  
30       by a User Equipment (UE), the operations to configure the one or more processors to:

configure the UE to transmit one or more channel state information (CSI) messages that include a rank indicator (RI) for a reception of a first control signal from a first Evolved Node-B (eNB) and an RI for a reception of a second control signal from a second eNB;

5       configure the UE to receive a first data signal from the first eNB and a second data signal from the second eNB, the first and second data signals based at least partly on a downlink data packet; and

decode the downlink data packet based on the received first and second data signals.

10

12. The computer-readable storage medium according to claim 11, wherein the UE is configured to operate in a beam aggregation mode for diversity reception of downlink data packets from the eNBs.

15       13. The computer-readable storage medium according to claim 11, wherein the RIs indicate, for each of the first and second control signals, a number of beams that are discernible at the UE as part of the reception of the control signals.

20       14. The computer-readable storage medium according to claim 13, wherein:

the first control signal is a first CSI reference signal (CSI-RS) and the reception of the first control signal is performed in first CSI-RS resources,

the second control signal is a second CSI-RS and the reception of the

25       second control signal is performed in second CSI-RS resources, and

the operations further configure the one or more processors to configure the UE to receive or to refrain from reception of additional CSI-RS based on an indicator received from the first eNB.

30       15. The computer-readable storage medium according to claim 14, wherein:

the indicator received from the eNB includes a coherence bitmap that indicates which control signals are to be received by the UE,

the coherence bitmap is based at least partly on a comparison of a sum of the RIs and a maximum rank, and

5       the maximum rank is based on a minimum of a number of transmit antennas at the first eNB, a number of transmit antennas at the second eNB, and a number of receive antennas at the UE.

16. The computer-readable storage medium according to claim 11,  
10       wherein the UE is configured to transmit separate CSI messages to the first and second eNBs.

17. The computer-readable storage medium according to claim 11,  
wherein:

15       the RI for the reception of the first control signal is based at least partly on a determined correlation between the first control signal and a predetermined first codeword, wherein the first control signal is based at least partly on the first codeword, and

20       the RI for the reception of the second control signal is based at least partly on a determined correlation between the second control signal and a predetermined second codeword, wherein the second control signal is based at least partly on the second codeword.

18. The computer-readable storage medium according to claim 11,  
25       wherein:

the first control signal includes multiple directional beams based at least partly on different codewords, and

30       the CSI messages include multiple RIs for the reception of the first control signal based at least partly on determined correlations between the first control signal and the codewords.

19. An apparatus for a User Equipment (UE), the apparatus comprising transceiver circuitry and hardware processing circuitry, the hardware processing circuitry configured to:

5       configure the transceiver circuitry to receive a first signal from a first Evolved Node-B (eNB) and a second signal from a second eNB, wherein the UE is configured to operate in a beam aggregation mode for diversity reception of downlink data packets from the eNBs;

10       select, from either the first eNB or the second eNB, a serving eNB for the beam aggregation mode based at least partly on signal quality measurements for the first eNB and the second eNB;

      configure the transceiver circuitry to transmit a physical random access channel (PRACH) preamble to the serving eNB,

15       wherein the transmitted PRACH preamble is selected, by the UE, from a serving group of candidate PRACH preambles allocated for random access communication between UEs and serving eNBs.

20       20. The apparatus according to claim 19, wherein of the first or second eNB, the eNB for which the signal quality measurement is greater is selected as the serving eNB and the eNB for which the signal quality measurement is lesser is selected as an assistant eNB for the beam aggregation mode.

25       21. The apparatus according to claim 20, wherein the serving group of candidate PRACH preambles is restricted from usage for random access communication between UEs and assistant eNBs.

22. The apparatus according to claim 19, wherein:

      the transmitted PRACH preamble is a first PRACH preamble,

      the eNB, of the first or second eNB, that is not selected as the serving eNB is selected as an assistant eNB,

30       the hardware processing circuitry is to further configure the transceiver circuitry to transmit a second PRACH preamble to the assistant eNB,

the second PRACH preamble is selected, by the UE, from an assistant group of candidate PRACH preambles allocated for random access communication between UEs and assistant eNBs.

5           23. The apparatus according to claim 19, the hardware processing circuitry further configured to:  
              configure the transceiver circuitry to receive, from the serving eNB, a PRACH preamble response message that indicates a loading of the serving eNB;  
              configure the transceiver circuitry to, when the loading of the serving  
10 eNB is not greater than a predetermined threshold, transmit a physical uplink shared channel (PUSCH) message to the serving eNB; and  
              when the loading of the serving eNB is greater than the predetermined threshold, select another eNB to operate as the serving eNB for the beam aggregation mode.

15           24. The apparatus according to claim 23, wherein:  
              when the loading of the serving eNB is greater than the predetermined threshold, the assistant eNB is selected to operate as a replacement serving eNB for the beam aggregation mode, and  
20           the hardware processing circuitry is to further configure the transceiver circuitry to transmit, to the replacement serving eNB, a PRACH preamble selected from the serving group of candidate PRACH preambles.

              25. The apparatus according to claim 19, wherein:  
25           the hardware processing circuitry is to further configure the transceiver circuitry to receive, from the first and/or second eNBs, one or more radio resource control (RRC) messages that indicate loadings of the first and/or second eNBs, and  
              the selection of the serving eNB is further based at least partly on the  
30 indicated loadings.

26. The apparatus according to claim 19, wherein:

the hardware processing circuitry is further configured to determine,  
based on bandwidth utilizations of the received first signal and received second  
signal, loadings of the first and second eNBs, and

the selection of the serving eNB is further based at least partly on the  
5 indicated loadings.

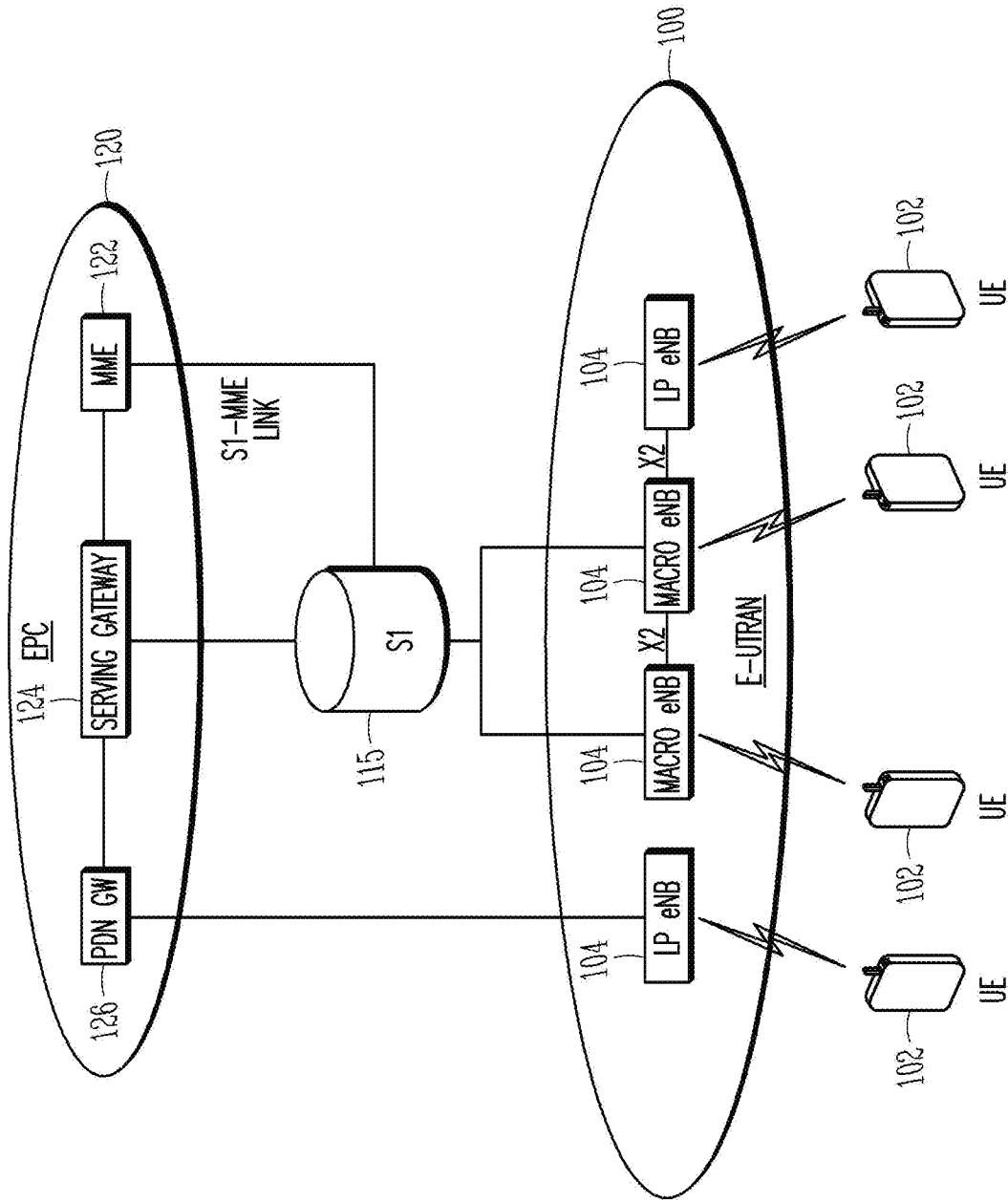


FIG. 1

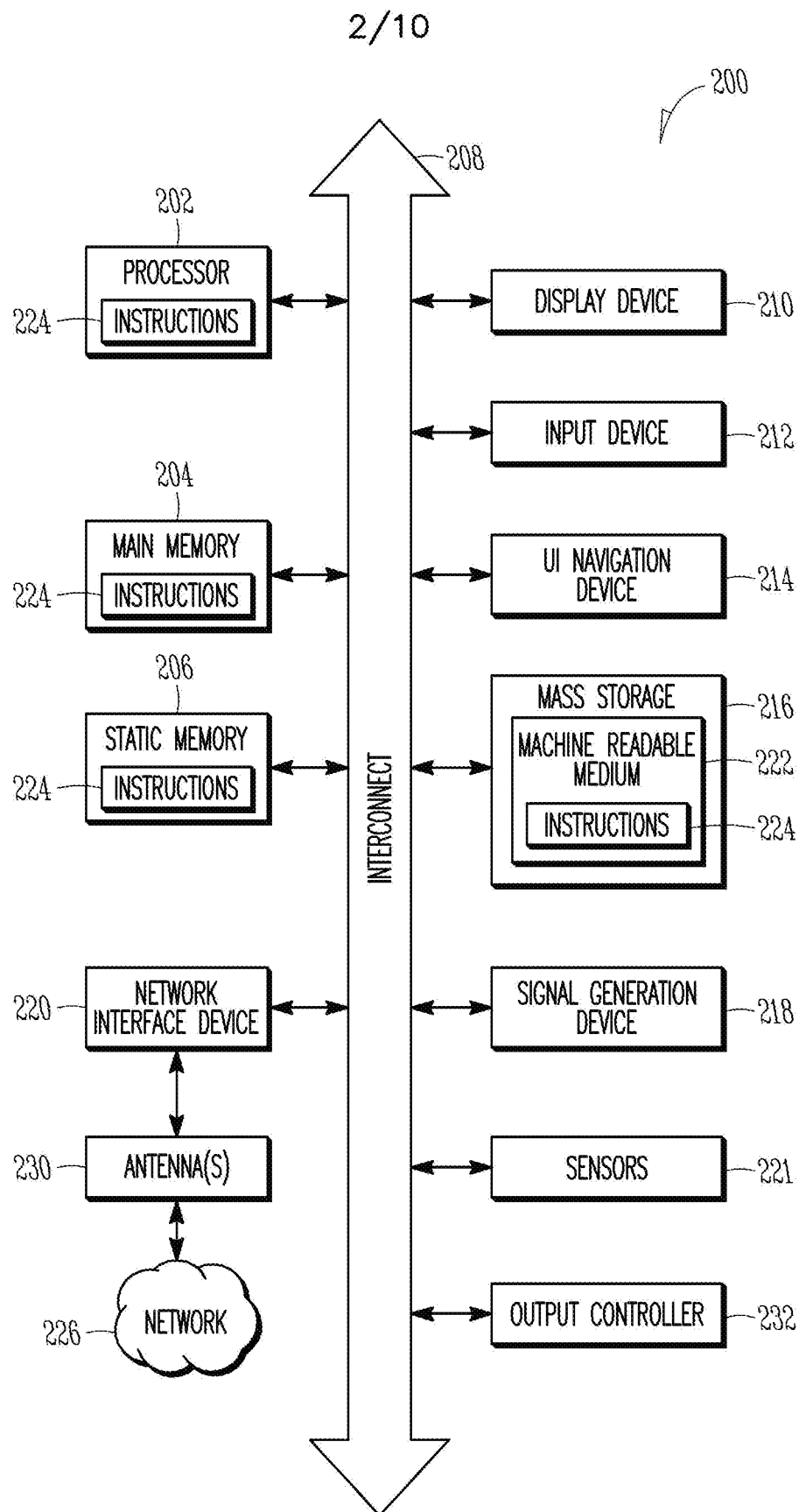
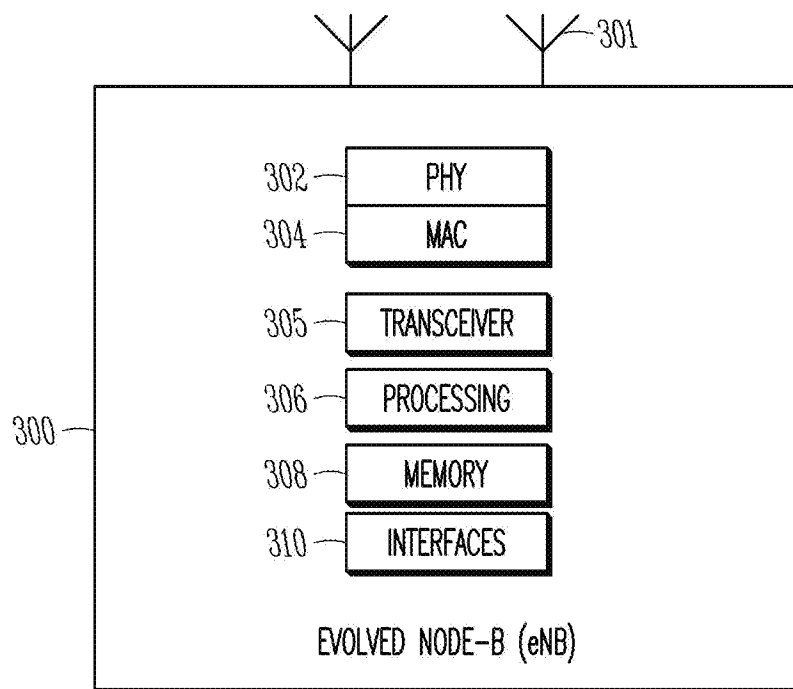


FIG. 2

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**FIG. 3**

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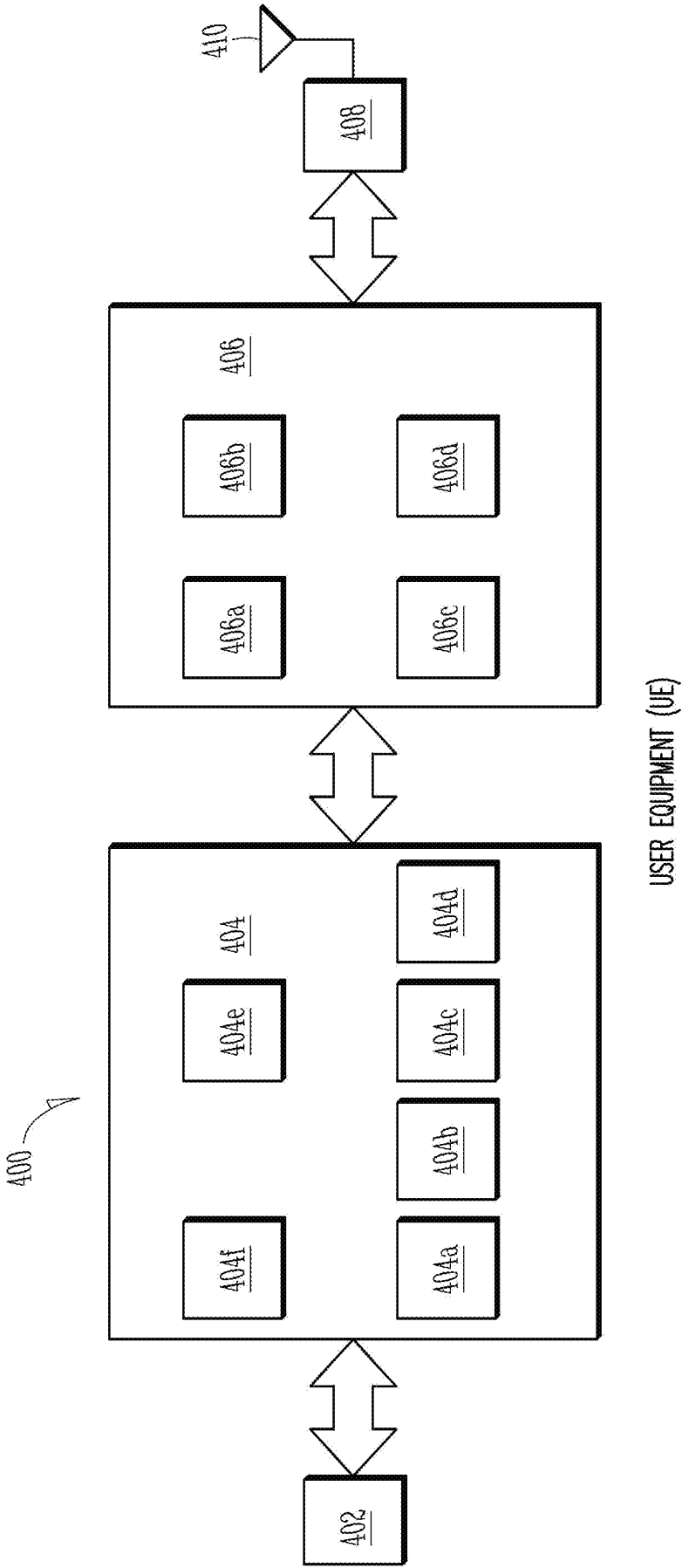


FIG. 4

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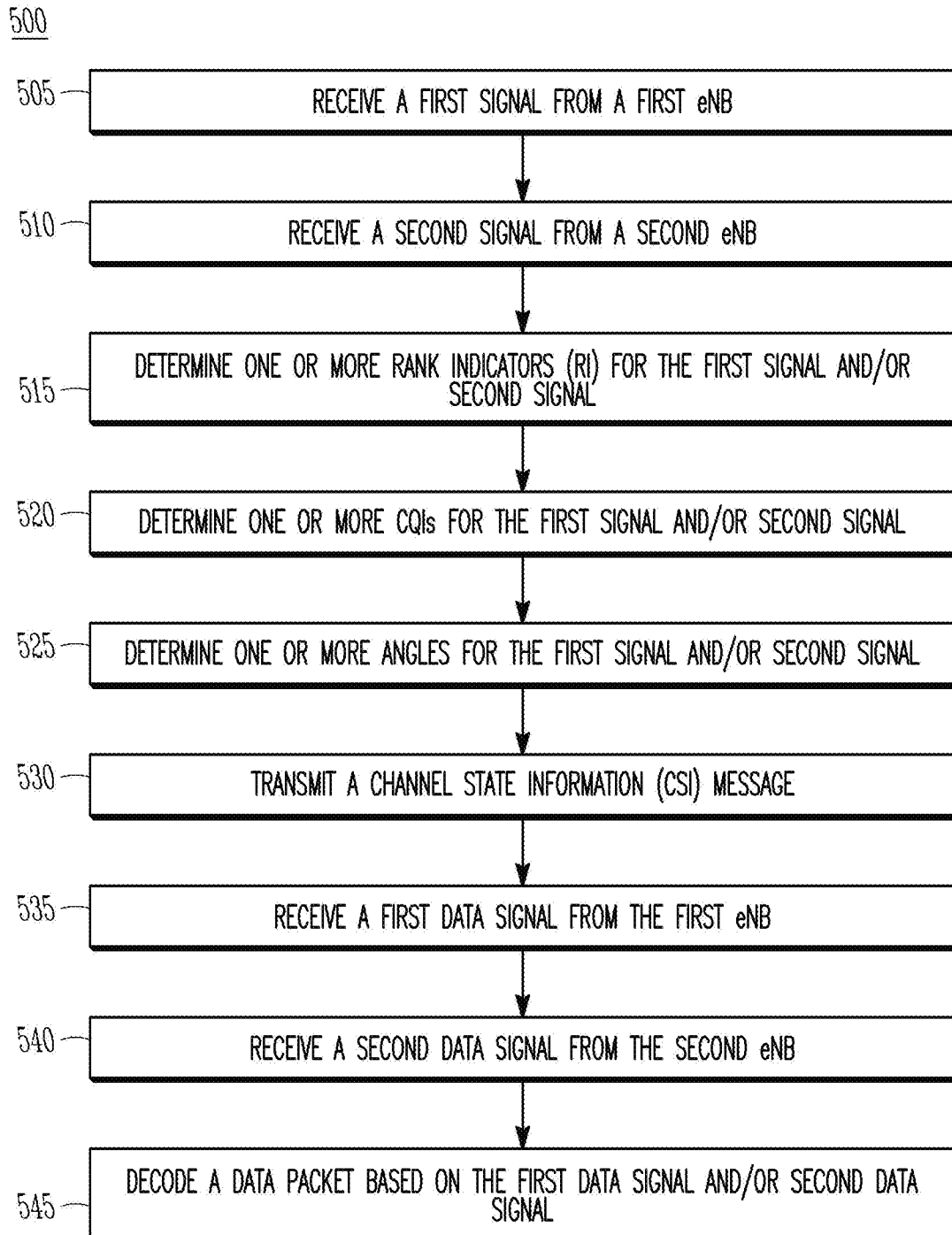
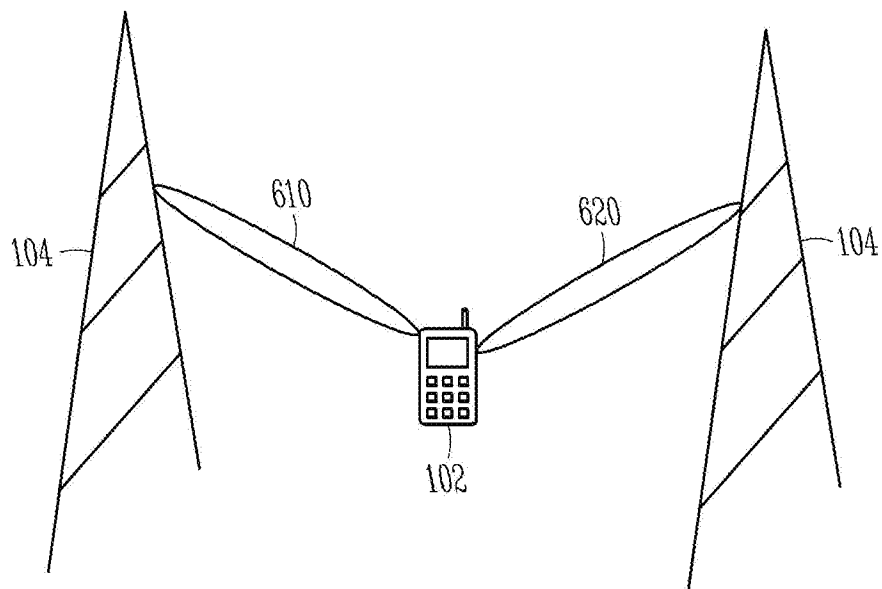


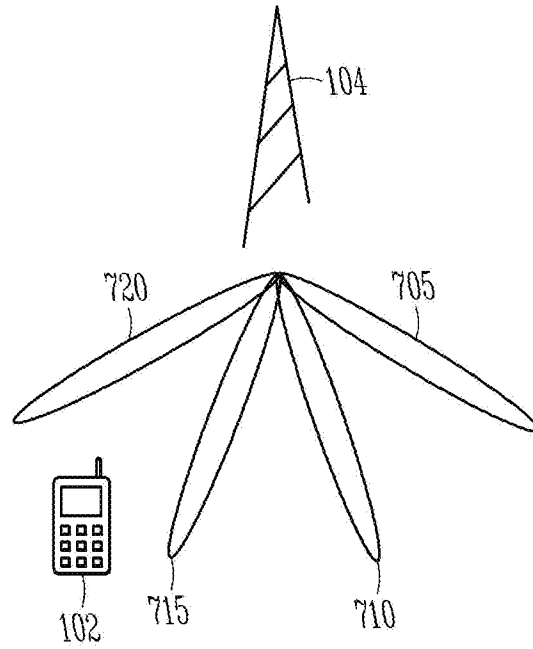
FIG. 5

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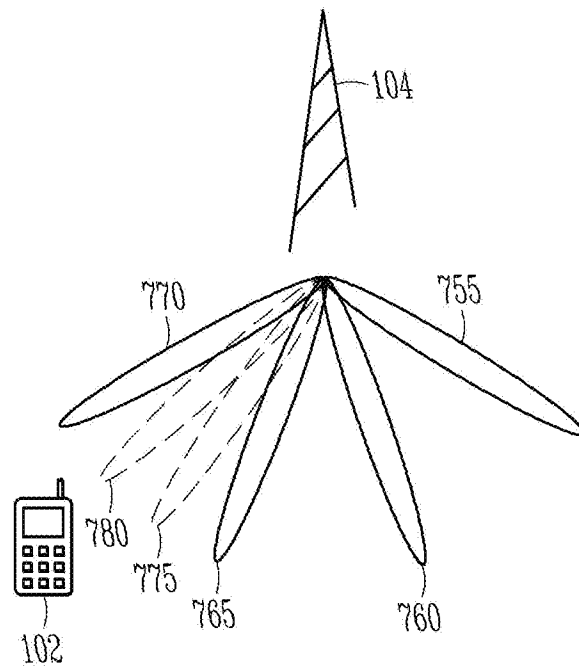
600**FIG. 6**

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700



750



**FIG. 7**

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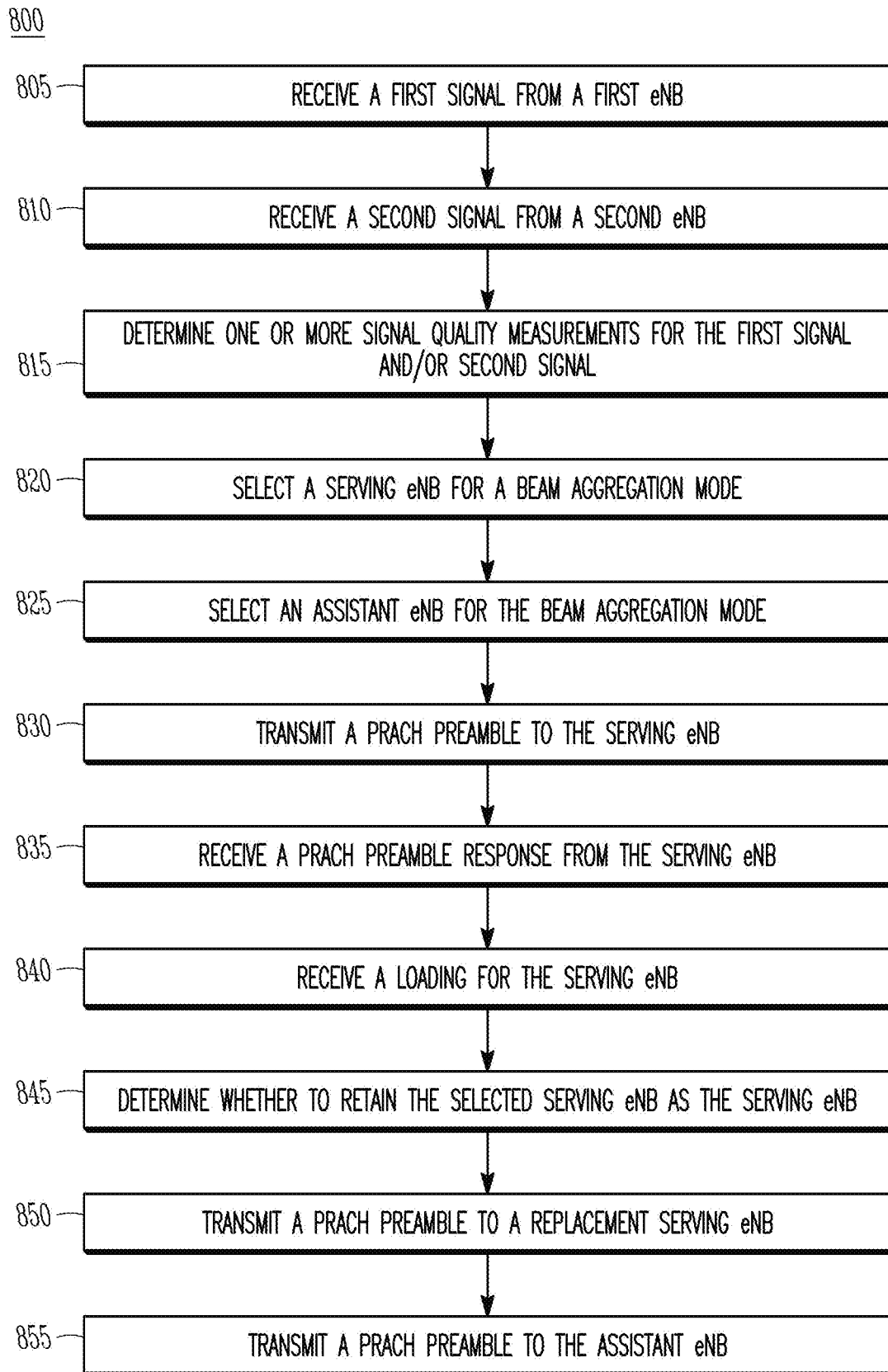
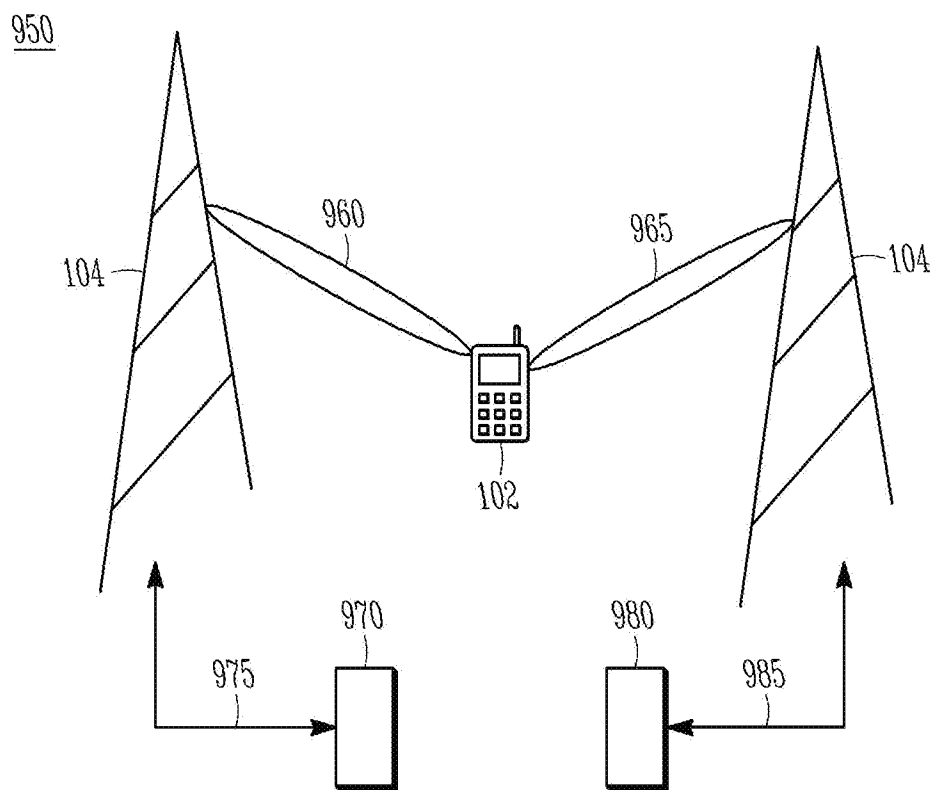
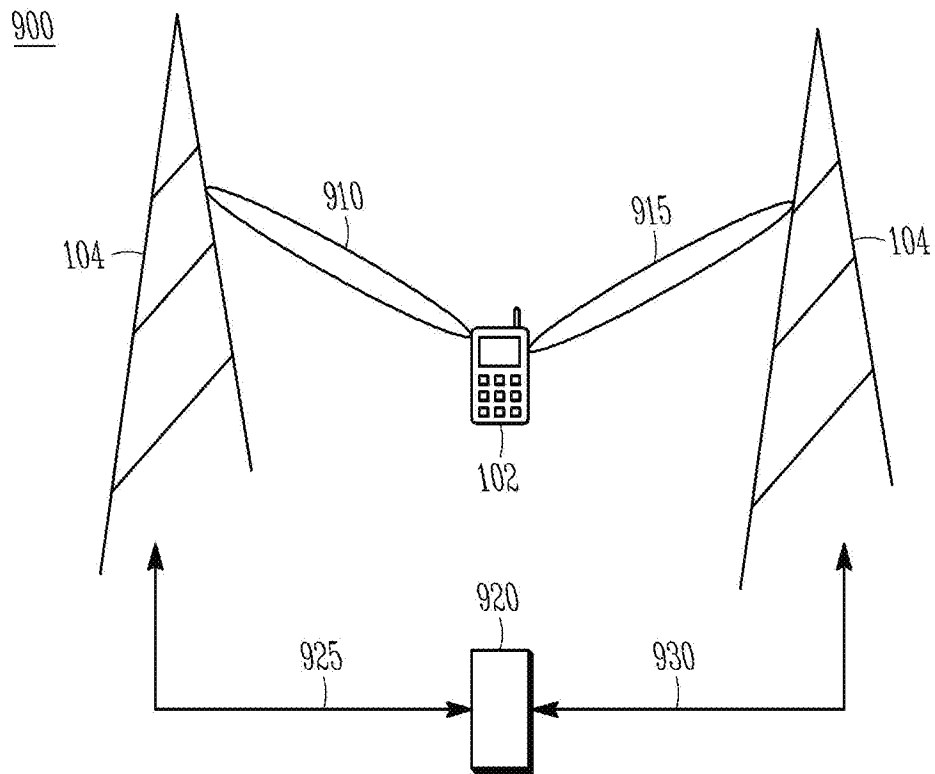


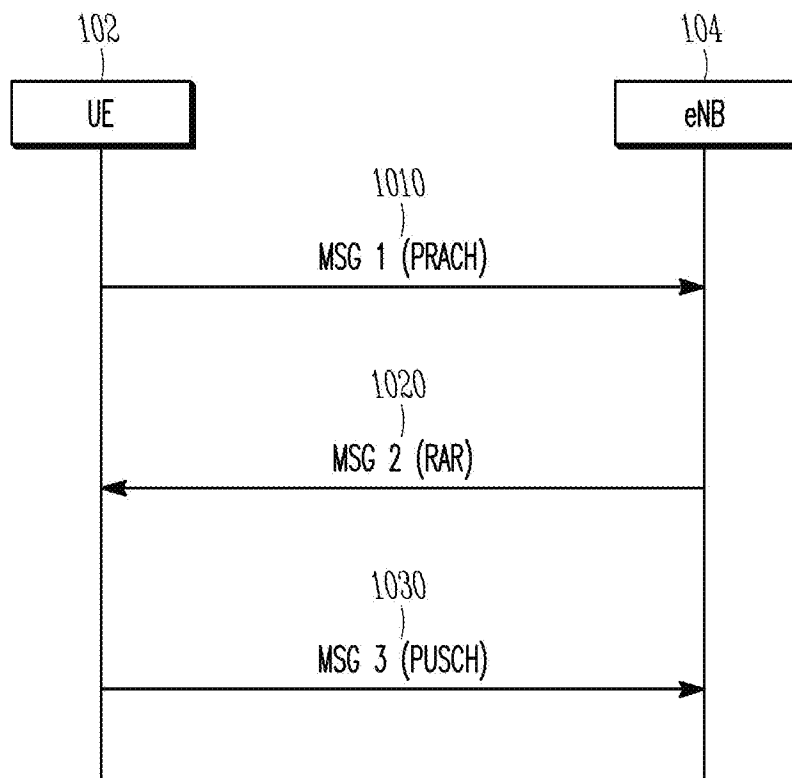
FIG. 8

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**FIG. 9**

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1000**FIG. 10**

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2015/097558

**A. CLASSIFICATION OF SUBJECT MATTER**

H04W 24/10(2009.01)i; H04B 7/06(2006.01)i

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

H04W;H04Q

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)

CNPAT,CNKI,WPI,EPODOC,3GPP:LTE,UE,eNB,CSI,RI,CQI,beam+,rank indicator,direct+, angle

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                               | Relevant to claim No. |
|-----------|----------------------------------------------------------------------------------------------------------------------------------|-----------------------|
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| Y         | US 2015341097 A1 (YANG, WEIDONG ET AL.) 26 November 2015 (2015-11-26)<br>description, paragraphs [0045]-[0056], FIG.2a, 4-6      | 1-18                  |
| A         | CN 104796996 A (ZTE CORP.) 22 July 2015 (2015-07-22)<br>the whole document                                                       | 1-26                  |
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☐ Further documents are listed in the continuation of Box C.
 ☒ See patent family annex.

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Date of the actual completion of the international search

29 July 2016

Date of mailing of the international search report

24 August 2016

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**INTERNATIONAL SEARCH REPORT**  
**Information on patent family members**

International application No.

**PCT/CN2015/097558**

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