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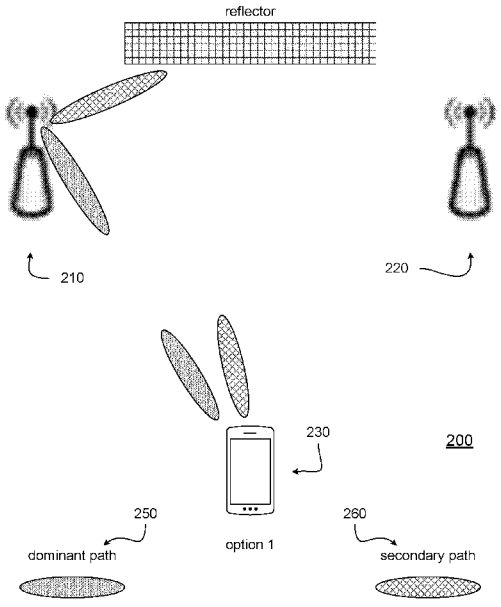


Fig. 2

(57) Abstract: Described is an apparatus of a User Equipment (UE). The apparatus may comprise a first circuitry, a second circuitry, and a third circuitry. The first circuitry may be operable to identify a number M of UE Receive (Rx) beams as being associated with optimum performance relative to a received beamforming reference signal parameter. The second circuitry may be operable to process a transmission from the eNB carrying an indicator of one or more UE Rx beams to be used for Physical Downlink Control Channel (PDCCH) transmission. The third circuitry may be operable to select one or more of the number M of UE Rx beams for PDCCH reception, in accordance with the indicator of one or more UE Rx beams.

WO 2018/031953 A1

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BEAMFORMING AND SIGNALING SUPPORT FOR DOWNLINK CONTROL CHANNEL TRANSMISSION

CLAIM OF PRIORITY

[0001] The present application claims priority under 35 U.S.C. § 119(e) to United States Provisional Patent Application Serial Number 62/373,460 filed August 11, 2016, and to United States Provisional Patent Application Serial Number 62/373,828 filed August 11, 2016, which are herein incorporated by reference in their entirety.

BACKGROUND

[0002] A variety of wireless cellular communication systems have been implemented, including a 3rd Generation Partnership Project (3GPP) Universal Mobile Telecommunications System, a 3GPP Long-Term Evolution (LTE) system, and a 3GPP LTE-Advanced (LTE-A) system. Next-generation wireless cellular communication systems based upon LTE and LTE-A systems are being developed, such as a fifth generation (5G) wireless system / 5G mobile networks system. Next-generation wireless cellular communication systems may provide support for higher bandwidths in part by supporting higher carrier frequencies, such as centimeter-wave and millimeter-wave frequencies. In turn, next-generation wireless cellular communication systems may provide support for higher bandwidths in part by supporting beamforming.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] The embodiments of the disclosure will be understood more fully from the detailed description given below and from the accompanying drawings of various embodiments of the disclosure. However, while the drawings are to aid in explanation and understanding, they are only an aid, and should not be taken to limit the disclosure to the specific embodiments depicted therein.

[0004] **Fig. 1** illustrates a scenario of a first beamforming option, in accordance with some embodiments of the disclosure.

[0005] **Fig. 2** illustrates a scenario of a second beamforming option, in accordance with some embodiments of the disclosure.

[0006] **Fig. 3** illustrates a scenario of a third beamforming option, in accordance with some embodiments of the disclosure.

[0007] **Fig. 4** illustrates an Evolved Node B (eNB) and a User Equipment (UE), in accordance with some embodiments of the disclosure.

[0008] **Fig. 5** illustrates hardware processing circuitries for a UE for Downlink (DL) control channel beamforming, in accordance with some embodiments of the disclosure.

[0009] **Fig. 6** illustrates hardware processing circuitries for a UE for facilitating physical control channel CoMP transmission that may be disposed to incorporating different UE Rx beam directions, in accordance with some embodiments of the disclosure.

[0010] **Fig. 7** illustrates methods for a UE for DL control channel beamforming, in accordance with some embodiments of the disclosure.

[0011] **Fig. 8** illustrates methods for a UE for facilitating physical control channel CoMP transmission that may be disposed to incorporating different UE Rx beam directions, in accordance with some embodiments of the disclosure.

[0012] **Fig. 9** illustrates example components of a device, in accordance with some embodiments of the disclosure.

[0013] **Fig. 10** illustrates example interfaces of baseband circuitry, in accordance with some embodiments of the disclosure.

DETAILED DESCRIPTION

[0014] Various wireless cellular communication systems have been implemented or are being proposed, including a 3rd Generation Partnership Project (3GPP) Universal Mobile Telecommunications System (UMTS), a 3GPP Long-Term Evolution (LTE) system, a 3GPP LTE-Advanced system, and a 5th Generation wireless system / 5th Generation mobile networks (5G) system / 5th Generation new radio (NR) system.

[0015] As antenna architecture evolves, increasing numbers of antennas may be equipped with an Evolved Node-B (eNB), a User Equipment (UE), or both to provide improved beamforming gain. A beamwidth of a large number of antennas may proportionally decrease as a number of antennas corresponding with the beamwidth increases.

[0016] In addition, some beamforming strategies may form a beam toward a strongest path to maximize a link quality. However, as the beam narrows, it may be more vulnerable to blockage. For example, if a path of the beam is blocked by an object, the link may be degraded or completely lost. The link might be recovered by periodic beam-management mechanism, but relying solely on such a mechanism may be not satisfactory for delay-sensitive applications.

[0017] Various mechanisms may support fast transitions to alternative links, which may serve as "hot standby" links, to minimize service disruption due to blockage. However, such mechanisms may be disposed to assuming Receive (Rx) beamforming for a best link, which may limit various aspects of performance.

[0018] Discussed herein are various mechanisms and methods for Downlink (DL) control channel beamforming. In various embodiments, use of various options may meet different performance goals, such as maximizing efficiency, supporting fast link switching, and supporting fast beam training.

[0019] Moreover, in order to improve or provide high area traffic capacities and consistent user experiences, 5G new radio (NR) access technologies may be designed to operate in both conventional cellular bands (e.g., below 6 gigahertz (GHz)) and high-frequency bands (e.g., above 6 GHz); may incorporate advanced Multiple-Input Multiple-Output (MIMO), such as massive MIMO; may incorporate Cooperative Multi-Point (CoMP) transmission and reception schemes; and may incorporate multi-connectivity. Narrow-beam based system operation with a large number of antennas may increase spectral efficiency by potentially reducing interference and enabling more users to be spatially multiplexed. Accordingly, beamforming may be a significant technology to facilitate or enable operation in mid-to-high frequency bands. Furthermore, flexible transmission/reception point (TRP) switching and multi-point beam aggregation, which may be realized via ideal-backhaul based CoMP schemes, or non-ideal-backhaul based multi-connectivity, may advantageously help overcome channel blockage in mid-to-high frequency bands, and may naturally support seamless mobility.

[0020] In the presence of highly spatial selective channels, it is observed that UE beamforming can considerably improve the receive performance. It is natural that the optimal UE receive beam directions with respect to geographically separated APs/TRPs can be different. Ideally, to exploit the full potential of receive beamforming, UE shall adapt its receive beam direction to the transmitter. Specifically, to improve the control channel reception reliability, it can be beneficial to enable DPS [Dynamic Point Selection] /CoMP transmission for physical control channel scheduling DL/UL data. In this case, the physical control channel can be dynamically transmitted from different TRPs on a subframe basis. If the optimal UE receive beam directions to different TRPs are different, and UE with only one analog beamformer, can steer only one receive beam direction with the maximum beamforming gain at a time, it is challenging for UE to simultaneously monitor all the possible control channel candidates from different TRPs. It is therefore necessary to take

these constraints into account for the physical control channel design with the support of CoMP operation.

[0021] Discussed herein are various mechanisms and methods to facilitate or enable physical control channel CoMP transmission that may be disposed to incorporating different UE Rx beam directions.

[0022] In the following description, numerous details are discussed to provide a more thorough explanation of embodiments of the present disclosure. It will be apparent to one skilled in the art, however, that embodiments of the present disclosure may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form, rather than in detail, in order to avoid obscuring embodiments of the present disclosure.

[0023] Note that in the corresponding drawings of the embodiments, signals are represented with lines. Some lines may be thicker, to indicate a greater number of constituent signal paths, and/or have arrows at one or more ends, to indicate a direction of information flow. Such indications are not intended to be limiting. Rather, the lines are used in connection with one or more exemplary embodiments to facilitate easier understanding of a circuit or a logical unit. Any represented signal, as dictated by design needs or preferences, may actually comprise one or more signals that may travel in either direction and may be implemented with any suitable type of signal scheme.

[0024] Throughout the specification, and in the claims, the term "connected" means a direct electrical, mechanical, or magnetic connection between the things that are connected, without any intermediary devices. The term "coupled" means either a direct electrical, mechanical, or magnetic connection between the things that are connected or an indirect connection through one or more passive or active intermediary devices. The term "circuit" or "module" may refer to one or more passive and/or active components that are arranged to cooperate with one another to provide a desired function. The term "signal" may refer to at least one current signal, voltage signal, magnetic signal, or data/clock signal. The meaning of "a," "an," and "the" include plural references. The meaning of "in" includes "in" and "on."

[0025] The terms "substantially," "close," "approximately," "near," and "about" generally refer to being within +/- 10% of a target value. Unless otherwise specified the use of the ordinal adjectives "first," "second," and "third," etc., to describe a common object, merely indicate that different instances of like objects are being referred to, and are not intended to imply that the objects so described must be in a given sequence, either temporally, spatially, in ranking, or in any other manner.

[0026] It is to be understood that the terms so used are interchangeable under appropriate circumstances such that the embodiments of the invention described herein are, for example, capable of operation in other orientations than those illustrated or otherwise described herein.

[0027] The terms "left," "right," "front," "back," "top," "bottom," "over," "under," and the like in the description and in the claims, if any, are used for descriptive purposes and not necessarily for describing permanent relative positions.

[0028] For purposes of the embodiments, the transistors in various circuits, modules, and logic blocks are Tunneling FETs (TFETs). Some transistors of various embodiments may comprise metal oxide semiconductor (MOS) transistors, which include drain, source, gate, and bulk terminals. The transistors may also include Tri-Gate and FinFET transistors, Gate All Around Cylindrical Transistors, Square Wire, or Rectangular Ribbon Transistors or other devices implementing transistor functionality like carbon nanotubes or spintronic devices. MOSFET symmetrical source and drain terminals i.e., are identical terminals and are interchangeably used here. A TFET device, on the other hand, has asymmetric Source and Drain terminals. Those skilled in the art will appreciate that other transistors, for example, Bi-polar junction transistors-BJT PNP/NPN, BiCMOS, CMOS, etc., may be used for some transistors without departing from the scope of the disclosure.

[0029] For the purposes of the present disclosure, the phrases "A and/or B" and "A or B" mean (A), (B), or (A and B). For the purposes of the present disclosure, the phrase "A, B, and/or C" means (A), (B), (C), (A and B), (A and C), (B and C), or (A, B and C).

[0030] In addition, the various elements of combinatorial logic and sequential logic discussed in the present disclosure may pertain both to physical structures (such as AND gates, OR gates, or XOR gates), or to synthesized or otherwise optimized collections of devices implementing the logical structures that are Boolean equivalents of the logic under discussion.

[0031] In addition, for purposes of the present disclosure, the term “eNB” may refer to a legacy LTE capable Evolved Node-B (eNB), a next-generation or 5G capable eNB, a millimeter-wave (mmWave) capable eNB or an mmWave small cell, an Access Point (AP), and/or another base station for a wireless communication system. For purposes of the present disclosure, the term “UE” may refer to a legacy LTE capable User Equipment (UE), a next-generation or 5G capable UE, an mmWave capable UE, a Station (STA), and/or another mobile equipment for a wireless communication system.

[0032] Various embodiments of eNBs and/or UEs discussed below may process one or more transmissions of various types. Some processing of a transmission may comprise demodulating, decoding, detecting, parsing, and/or otherwise handling a transmission that has been received. In some embodiments, an eNB or UE processing a transmission may determine or recognize the transmission's type and/or a condition associated with the transmission. For some embodiments, an eNB or UE processing a transmission may act in accordance with the transmission's type, and/or may act conditionally based upon the transmission's type. An eNB or UE processing a transmission may also recognize one or more values or fields of data carried by the transmission. Processing a transmission may comprise moving the transmission through one or more layers of a protocol stack (which may be implemented in, e.g., hardware and/or software-configured elements), such as by moving a transmission that has been received by an eNB or a UE through one or more layers of a protocol stack.

[0033] Various embodiments of eNBs and/or UEs discussed below may also generate one or more transmissions of various types. Some generating of a transmission may comprise modulating, encoding, formatting, assembling, and/or otherwise handling a transmission that is to be transmitted. In some embodiments, an eNB or UE generating a transmission may establish the transmission's type and/or a condition associated with the transmission. For some embodiments, an eNB or UE generating a transmission may act in accordance with the transmission's type, and/or may act conditionally based upon the transmission's type. An eNB or UE generating a transmission may also determine one or more values or fields of data carried by the transmission. Generating a transmission may comprise moving the transmission through one or more layers of a protocol stack (which may be implemented in, e.g., hardware and/or software-configured elements), such as by moving a transmission to be sent by an eNB or a UE through one or more layers of a protocol stack.

[0034] In various embodiments, resources may span various Resource Blocks (RBs), Physical Resource Blocks (PRBs), and/or time periods (e.g., frames, subframes, and/or slots) of a wireless communication system. In some contexts, allocated resources (e.g., channels, Orthogonal Frequency-Division Multiplexing (OFMD) symbols, subcarrier frequencies, resource elements (REs), and/or portions thereof) may be formatted for (and prior to) transmission over a wireless communication link. In other contexts, allocated resources (e.g., channels, OFDM symbols, subcarrier frequencies, REs, and/or portions thereof) may be detected from (and subsequent to) reception over a wireless communication link.

[0035] Various embodiments may incorporate a beam training or beam management mechanism. During the beam training or beam management mechanism, a UE may identify a number M of best beams among one or more potential beams transmitted by TRPs (e.g., base stations, eNBs, and/or a network (NW)). A way of finding the number M of best beams may be measuring a received signal strength of a beamformed reference signal, and different beam reference signals can be transmitted from different TRPs.

[0036] **Fig. 1** illustrates a scenario of a first beamforming option, in accordance with some embodiments of the disclosure. A scenario 100 may pertain to a single TRP Transmit (Tx) and UE Rx beam pair link, which may be aligned with a dominant channel cluster direction. Scenario 100 may comprise an eNB 110 and a UE 130, which may be in wireless communication with each other via a dominant path 150 (e.g., via a beam pair link associated with dominant path 150).

[0037] In some embodiments, a beamforming method (e.g., in accordance with scenario 100) may maximize an efficiency. In some embodiments, a TRP/NW (e.g., an eNB) may configure a UE to use a single best beam to receive a control channel. The TRP/NW may inform the UE that it will use a best beam, and the TRP may use a best beam for both data and control (e.g., data channel and control channel). The UE may form a receive beam corresponding to the best TRP beam.

[0038] For some embodiments, the TRP/NW may configure a UE to use a single best beam by higher-layer signaling. For example, the TRP/NW may configure the UE via Medium Access Control (MAC) Control Element (CE) signaling, and/or Radio Resource Control (RRC) signaling. A best beam (e.g., a best beam pair, of a best beam pair link) may be determined during a beam management protocol.

[0039] **Fig. 2** illustrates a scenario of a second beamforming option, in accordance with some embodiments of the disclosure. A scenario 200 may pertain to multiple TRP Tx beams and multiple UE Rx beams, which may be aligned with a best set of B channel cluster directions. Scenario 200 may comprise a first eNB 210, a second eNB 220, and a UE 230. First eNB 210 and UE 230 may be in wireless communication with each other via a set of B paths (e.g., a set of B channel clusters and/or a set of B channel cluster directions), which may include a dominant path 250 and one or more secondary paths 260 (e.g., via a set of B beam pair links associated with dominant path 250 and secondary paths 260).

[0040] In some embodiments, a beamforming method (e.g., in accordance with scenario 200) may support fast link switching (e.g., fast beam switching, fast sectors switching, and/or fast TRP switching). In some embodiments, a TRP/NW may configure a

UE to use a best set of B beams to receive control channels. The NW may inform a UE that it may use a number B beams out of a number M of the best beams for control channel transmission. The UE may form one or more Rx beam corresponding to the best B beams during control channel reception.

[0041] For some embodiments, following the UE's formation of the one or more Rx beams, a TRP may use a best beam for both data channel transmissions and control channel transmissions. Absent an Acknowledgment (ACK) or a Not-Acknowledgement (NACK) from the UE, the TRP may then switch a beam to a secondary beam, and/or a secondary TERP may transmit a NR Physical Downlink Control Channel (PDCCH). Moreover, an NR PDCCH may carry a beam switching command, which may facilitate the UE in forming an Rx beam properly during an NR Physical Downlink Shared Channel (PDSCH).

[0042] In some such embodiments, an NW may configure a UE to use B beams out of the best M beams during NR PDCCH while configuring the UE to use a best beam during NR PDSCH by higher-layer signaling (e.g., via MAC CE and/or RRC signaling). A best M beam (e.g., beam pair and/or beam pair link) may be determined during a beam management protocol. Moreover, for some embodiments, a Downlink Control Information (DCI) carried by NR PDCCH may include a beam switching command for an NR PDSCH reception.

[0043] For some embodiments, following the UE's formation of the one or more Rx beams, a TRP may use the best B beams for control channel transmissions and may use a best beam for data channel transmission. The UE may measure a received signal strength at each different beam and, if a best beam direction is weaker than another beam direction, the UE may request that the NW/TRP switch beams, or may request a beam training procedure from the NW/TRP. The feedback information may be carried in an ACK/NACK channel.

[0044] In some such embodiments, an NW may configure a UE to use B beams out of the best M beams during NR PDCCH while configuring the UE to use a best beam during NR PDSCH by higher-layer signaling (e.g., via MAC CE and/or RRC signaling). A best M beam (e.g., beam pair and/or beam pair link) may be determined during a beam management protocol. Moreover, for some embodiments, an Uplink Control Information (UCI) carried by NR Physical Uplink Control Channel (PUCCH) may include a beam-switching request to inform an NW/TRP of a preference for a different beam.

[0045] **Fig. 3** illustrates a scenario of a third beamforming option, in accordance with some embodiments of the disclosure. A scenario 300 may pertain to multiple TRP Tx beams and an omnidirectional UE beam. Scenario 300 may comprise a first eNB 310, a second eNB 320, and a UE 330. First eNB 310 and UE 330 may be in wireless communication with each

other via a beam pair link associated with a dominant path 350 and/or one or more secondary paths 360, and second eNB 320 and UE 330 may be in wireless communication with each other via a dominant path 350 and/or a secondary path 360 (e.g., via one or more beam pair links).

[0046] In some embodiments, a beamforming method (e.g., in accordance with scenario 300) may support fast beam training. In some embodiments, a TRP/NW (e.g., an eNB) may configure a UE to use an omni-directional or pseudo-omni-directional beam to receive a control channel transmission. The TRP/NW may inform the UE that it may form arbitrary beams for control channel transmissions. The UE may form a Rx beam as an omni-directional beam (or pseudo-omni-directional beam) during a control channel reception. The TRP may use a best beam for both data channel transmissions and control channel transmissions. Absent an ACK or a NACK from the UE, the TRP may then initiate a beam training procedure and may instruct the UE.

[0047] For some embodiments, the TRP/NW may configure the UE to use an omni-directional beam (or pseudo-omni-directional beam) during an NR PDCCH while configuring the UE to use a best beam during NR PDSCH by higher-layer signaling (e.g., via MAC CE and/or RRC signaling). A best M beams (or beam pairs, or beam pair links) may be determined during a beam management protocol. Moreover, for some embodiments, a DCI carried by an NR PDCCH may include a beam sweeping command for a new beam training.

[0048] Various mechanisms and methods described herein may also be multiplexed in a Time-Division Multiplexing (TDM) manner. Accordingly, mechanisms and methods associated with the first beamforming option, the second beamforming option, and/or the third beamforming option may change from subframe to subframe. For example, mechanisms and methods associated with the first beamforming option may be utilized while utilizing mechanisms and methods associated with the second beamforming option or the third beamforming option in a certain subframe.

[0049] In various embodiments (e.g., in embodiments implementing the first beamforming option, the second beamforming option, and/or the third beamforming option), various additional mechanisms and methods may facilitate or enable physical control channel CoMP transmission that may be disposed to incorporating different UE Rx beam directions.

[0050] In embodiments of a first type, a UE may perform a measurement of mobility signals and/or Channel State Information Reference Signals (CSI-RSes) (e.g., beamformed CSI-RSes) of an NR TRP or eNB, which may include a small cell TRP or eNBs.

[0051] In embodiments of a second type, a UE may report a measurement result together with signaling information about a non-simultaneous reception from (or of) different APs/TRPs, which may be disposed toward different receive beam directions.

[0052] In embodiments of a third type, an NR eNB may design and configure a control channel search space by taking into account the above signaled restriction information. Various transmission schemes may be supported. In some transmission schemes, a beam and/or polarization diversity transmission may be supported while a UE is implicitly signaled about a proper Rx beam. For some transmission schemes, which may implement dynamic point transmission, a TRP specific control channel subframe pattern may be configured. At a particular subframe, a UE may merely monitor one or more Blind Decoding (BD) candidates associated with TRPs which may be received simultaneously by using the same receive beam direction. In some transmission schemes, which may implement control channels with repetitions from multiple TRPs, a control channel search space may comprise BD candidates repeated from different TRPs and subframes, in which different Rx beams may be employed in different subframes.

[0053] Various embodiments of the first type, the second type, and/or the third type may advantageously facilitate and/or enable the application of UE Rx beamforming for control channel reception. Accordingly, an achieved Rx beamforming gain may increase a control channel coverage and enhance a control channel spectrum efficiency, which may advantageously be further translated into control channel capacity improvement.

[0054] In various embodiments, mobility reference signals and/or CSI-RSes (e.g., beamformed CSI-Rses) may be transmitted in one or more NR small cells. After establishing an RRC connection, a UE may report a Reference Signal (RS) Received Power (RSRP) and/or Reference Signal Received Quality (RSRQ) of the detected reference signals to the anchor cell.

[0055] Based on the measurement report, an anchor cell may configure the UE with a control channel search space, which may include control channel candidates being transmitted from other NR small cells and/or different TRPs within the same cell. This may potentially improve a control channel coverage and/or control channel capacity due to the increased scheduling flexibility. When reported RSRP and/or RSRQ of different NR small cells or TRPs are obtained by using different receive beams in a time-sharing manner, it may be beneficial for the UE to indicate such restriction (e.g., non-simultaneous reception from different TRPs which may be disposed to different receive beams) to a camped anchor cell.

This may help the anchor cell to properly design a control channel search space to take into account the signaled UE receive restriction.

[0056] Various methods may facilitate or enable a UE to signal a reception restriction so that an anchor-cell eNB may properly design a control channel search space to support CoMP transmission with respect to those restrictions. Some signaling methods may indicate non-simultaneous reception of different TRPs. Some methods may pertain to control channel search space design.

[0057] Regarding signaling methods to indicate non-simultaneous reception of different TRPs, a first type of embodiment may pertain to single measurement reports, and a second type of embodiment may pertain to multiple measurement reports. With respect to the first type of embodiment pertaining to signaling methods to indicate non-simultaneous reception of different TRPs, an RSRP and/or RSRQ measurement report, a UE may divide RSRP and/or RSRQ results of detected TRPs and/or NR small cells into several groups. One or more of the groups may comprise TRPs measured by using the same receive beam directions. Accordingly, TRPs in different groups may be detected and measured by using different receive beam directions.

[0058] For example, a set of four TRPs—which may be labeled C1, C2, C3, and C4—may be detected by a UE. The UE may employ a beam b1 for TRP C1 and TRP C2, a beam b2 for TRP C3, and a beam b3 for TRP C4. A measurement report may then be structured as follows:

Measurement report :=

{

{ Group 0: RSRP and/or RSPQ of TRP C1 and TRP C2 };

{ Group1: RSRP and/or RSPQ of TRP C3 };

{ Group2: RSRP and/or RSPQ of TRP C4 }

}

[0059] With respect to the second type of embodiment pertaining to signaling methods to indicate non-simultaneous reception of different TRPs, measurement results for different TRPs using different receive beams may be transmitted in separate measurement reports. In comparison with the first type of embodiment, the UE may transmit three measurement reports, which may be structured as follows:

Measurement report 1 :=

{ RSRP and/or RSPQ of TRP C1 and TRP C2 };

Measurement report 2 :=

{ RSRP and/or RSPQs of TRP C3 };

Measurement report 3 :=

{ RSRP and/or RSPQs of TRP C4 }

[0060] Various additional mechanisms and methods may pertain to the first type of embodiment and/or the second type of embodiment. In both types of embodiments, a UE may report more than one RSRP and/or RSRQ for one TRP measured with different non-coexisting UE beams. In such cases, RSRP and/or RSRQ measurements of one TRP and/or NR small cell may appear in either several groups of a measurement report of the first type of embodiment, or several measurement reports of the second type of embodiment. The multiple RSRP and/or RSRQ measurement results reported per TRP may potentially enable dynamic intra-TRP beam selection for control channel transmission. In both types of embodiments, a UE may yield different measurement results created from dual polarizations using one UE beam. A UE may also be able to provide multiple measurement reports from different beam directions using different polarizations.

[0061] Regarding methods pertaining to control channel search space design, a first type of embodiment may pertain to beam and/or polarization diversity transmission, a second type of embodiment may pertain to TRP-specific control channel subframe configuration, and a third type of embodiment may pertain to repetition across several TRPs. With respect to the first type of embodiment pertaining to methods pertaining to control channel search space design, if several beamformed CSI-RSs (some of which may be virtualized by using different polarizations of the antenna array) may be simultaneously transmitted from a TRP or NR small cell eNB, and if a UE is close to one TRP or NR small cell eNB, the UE may only report the RSRP and/or RSRQs of several beamformed CSI-RSs associated with the same TRP or NR small cell eNB.

[0062] In some embodiments, if reasonably good RSRP and/or RSRQs corresponding to several beamformed CSI-RSs (e.g., RSRP and/or RSRQ satisfying a predetermined threshold) may be measured by using the same Rx beam, and may then be reported in the same group of the measurement report (e.g. in the first type of embodiment of methods to indicate non-simultaneous reception of different TRPs discussed herein), or in the same measurement report (e.g., in the second type of embodiment of methods to indicate non-simultaneous reception of different TRPs), an anchor NR eNB may configure only one control channel search space (SS) associated with a strongly received TRP to the UE. In such embodiments, a beam and/or a polarization diversity transmission may advantageously be utilized to enhance the coverage of control channel.

[0063] In some embodiments, beam and/or polarization diversity may be enhanced or achieved by having each control channel candidate in a configured search space be transmitted by two beams, one or both of which may be merely transmitted from a single polarization. At a receiver side, a UE may also monitor the SS from two beam directions using two polarizations. This may advantageously increase diversity and/or robustness against blockage of single-beam transmission and reception of control channels in one SS.

[0064] For some embodiments, an SS configuration may be disposed to include a relationship between a Demodulation Reference Signal (DMRS) port and beamformed CSI-RSes. For example, a measurement report (e.g., in the second type of embodiment of methods to indicate non-simultaneous reception of different TRPs) may have the following information:

Measurement report 1:=

{ RSRP and/or RSRQ of beamformed CSI-RS 1 & beamformed CSI-RS 2 }

Where beamformed CSI-RS 1 and beamformed CSI-RS 2 may be simultaneously transmitted from one TRP. In some embodiments, an example configuration may be set up as:

DMRS port 7: Beamformed CSI-RS 1 of measurement report 1

DMRS port 8: Beamformed CSI-RS 2 of measurement report 1

For a SS in accordance with the above two DMRS-port configuration, beam diversity transmission may advantageously be naturally supported.

[0065] With respect to the second type of embodiment pertaining to methods pertaining to control channel search space design, in various embodiments, an anchor cell may configure several control channel sets. One or more of the control channel sets may be associated with a particular TRP, to the UE. Moreover, one or more of the control channel sets may be configured with a specific subframe pattern, on which the UE may monitor one or more blind decoding candidates of the respective control channel set. Subframe patterns of control channel sets associated with TRPs which can't be simultaneously received by the UE may be disposed to not overlap each other.

[0066] For example, with the measurement report in the first type of embodiment of methods to indicate non-simultaneous reception of different TRPs discussed herein, an anchor cell may configure three TRP-specific control channel sets to a UE, which may be labeled SS1 (associated with TRP C1), SS2 (associated with TRP C2), and SS3 (associated with TRP C3). One or more of the SSes may be configured with a specific subframe pattern. Since TRP C1 and TRP C2 may be received simultaneously by the same receive beam

direction, a subframe pattern of SS1 and a subframe pattern of SS2 may advantageously be the same.

[0067] However, a subframe pattern of SS3 may be disposed to not overlapping with a subframe pattern of SS1 and/or to not overlapping with a subframe pattern of SS2. For example, SS1 and SS2 may be configured with a subframe pattern including a first set of subframes {0, 1, 3, 4, 6, 7, 9, 10}, while SS3 may be configured with a subframe pattern including a second set of subframes {2, 5, 8} that do not overlap the first set of subframes.

[0068] In this method, each SS configuration shall include the information about the identity of associated TRP or NR small cell, so that UE is able to determine which Rx beam direction should be applied to monitor the SS during a particular subframe.

[0069] With respect to the third type of embodiment pertaining to methods pertaining to control channel search space design, to enhance a control channel reliability, in addition to use different aggregation levels, some embodiments may also adopt control channel candidates with different repetition levels, such as single-BD candidates comprising several repetitions transmitted in different TRPs. For example, in addition to search spaces SS1, SS2, and SS3 (e.g., as defined in the first type of embodiment pertaining to methods pertaining to control channel search space design), a UE may be configured with one or more additional SSes, for example with an SS labeled as SS4, in which each BD candidate can comprise one or more Aggregation Level 1 (AL1) candidates from SS1, SS2, and/or SS3. As a result, each BD candidate in SS4 may benefit from a beam diversity from TRP C1, TRP C2, and/or TRP C3. To allow the UE to apply an appropriate Rx beam to decode a BD candidate of SS4, a configuration message for SS4 may include information about the identities of multiple TRPs and/or NR small cells, as well as corresponding subframe patterns.

[0070] **Fig. 4** illustrates an eNB and a UE, in accordance with some embodiments of the disclosure. **Fig. 4** includes block diagrams of an eNB 410 and a UE 430 which are operable to co-exist with each other and other elements of an LTE network. High-level, simplified architectures of eNB 410 and UE 430 are described so as not to obscure the embodiments. It should be noted that in some embodiments, eNB 410 may be a stationary non-mobile device.

[0071] eNB 410 is coupled to one or more antennas 405, and UE 430 is similarly coupled to one or more antennas 425. However, in some embodiments, eNB 410 may incorporate or comprise antennas 405, and UE 430 in various embodiments may incorporate or comprise antennas 425.

[0072] In some embodiments, antennas 405 and/or antennas 425 may comprise one or more directional or omni-directional antennas, including monopole antennas, dipole antennas, loop antennas, patch antennas, microstrip antennas, coplanar wave antennas, or other types of antennas suitable for transmission of RF signals. In some MIMO (multiple-input and multiple output) embodiments, antennas 405 are separated to take advantage of spatial diversity.

[0073] eNB 410 and UE 430 are operable to communicate with each other on a network, such as a wireless network. eNB 410 and UE 430 may be in communication with each other over a wireless communication channel 450, which has both a downlink path from eNB 410 to UE 430 and an uplink path from UE 430 to eNB 410.

[0074] As illustrated in **Fig. 4**, in some embodiments, eNB 410 may include a physical layer circuitry 412, a MAC (media access control) circuitry 414, a processor 416, a memory 418, and a hardware processing circuitry 420. A person skilled in the art will appreciate that other components not shown may be used in addition to the components shown to form a complete eNB.

[0075] In some embodiments, physical layer circuitry 412 includes a transceiver 413 for providing signals to and from UE 430. Transceiver 413 provides signals to and from UEs or other devices using one or more antennas 405. In some embodiments, MAC circuitry 414 controls access to the wireless medium. Memory 418 may be, or may include, a storage media/medium such as a magnetic storage media (e.g., magnetic tapes or magnetic disks), an optical storage media (e.g., optical discs), an electronic storage media (e.g., conventional hard disk drives, solid-state disk drives, or flash-memory-based storage media), or any tangible storage media or non-transitory storage media. Hardware processing circuitry 420 may comprise logic devices or circuitry to perform various operations. In some embodiments, processor 416 and memory 418 are arranged to perform the operations of hardware processing circuitry 420, such as operations described herein with reference to logic devices and circuitry within eNB 410 and/or hardware processing circuitry 420.

[0076] Accordingly, in some embodiments, eNB 410 may be a device comprising an application processor, a memory, one or more antenna ports, and an interface for allowing the application processor to communicate with another device.

[0077] As is also illustrated in **Fig. 4**, in some embodiments, UE 430 may include a physical layer circuitry 432, a MAC circuitry 434, a processor 436, a memory 438, a hardware processing circuitry 440, a wireless interface 442, and a display 444. A person

skilled in the art would appreciate that other components not shown may be used in addition to the components shown to form a complete UE.

[0078] In some embodiments, physical layer circuitry 432 includes a transceiver 433 for providing signals to and from eNB 410 (as well as other eNBs). Transceiver 433 provides signals to and from eNBs or other devices using one or more antennas 425. In some embodiments, MAC circuitry 434 controls access to the wireless medium. Memory 438 may be, or may include, a storage media/medium such as a magnetic storage media (e.g., magnetic tapes or magnetic disks), an optical storage media (e.g., optical discs), an electronic storage media (e.g., conventional hard disk drives, solid-state disk drives, or flash-memory-based storage media), or any tangible storage media or non-transitory storage media. Wireless interface 442 may be arranged to allow the processor to communicate with another device. Display 444 may provide a visual and/or tactile display for a user to interact with UE 430, such as a touch-screen display. Hardware processing circuitry 440 may comprise logic devices or circuitry to perform various operations. In some embodiments, processor 436 and memory 438 may be arranged to perform the operations of hardware processing circuitry 440, such as operations described herein with reference to logic devices and circuitry within UE 430 and/or hardware processing circuitry 440.

[0079] Accordingly, in some embodiments, UE 430 may be a device comprising an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate with another device, and a touch-screen display.

[0080] Elements of **Fig. 4**, and elements of other figures having the same names or reference numbers, can operate or function in the manner described herein with respect to any such figures (although the operation and function of such elements is not limited to such descriptions). For example, **Figs. 5-6 and 9-10** also depict embodiments of eNBs, hardware processing circuitry of eNBs, UEs, and/or hardware processing circuitry of UEs, and the embodiments described with respect to **Fig. 4** and **Figs. 5-6 and 9-10** can operate or function in the manner described herein with respect to any of the figures.

[0081] In addition, although eNB 410 and UE 430 are each described as 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 and/or other hardware elements. In some embodiments of this disclosure, the functional elements can refer to one or more processes operating on one or more processing elements. Examples of software and/or hardware configured elements include Digital Signal Processors (DSPs), one or more microprocessors, DSPs, Field-Programmable Gate Arrays (FPGAs), Application

Specific Integrated Circuits (ASICs), Radio-Frequency Integrated Circuits (RFICs), and so on.

[0082] **Fig. 5** illustrates hardware processing circuitries for a UE for DL control channel beamforming, in accordance with some embodiments of the disclosure. **Fig. 6** illustrates hardware processing circuitries for a UE for facilitating physical control channel CoMP transmission that may be disposed to incorporating different UE Rx beam directions, in accordance with some embodiments of the disclosure. With reference to **Fig. 4**, a UE may include various hardware processing circuitries discussed herein (such as hardware processing circuitry 500 of **Fig. 5** or hardware processing circuitry 600 of **Fig. 6**), which may in turn comprise logic devices and/or circuitry operable to perform various operations. For example, in **Fig. 4**, UE 430 (or various elements or components therein, such as hardware processing circuitry 440, or combinations of elements or components therein) may include part of, or all of, these hardware processing circuitries.

[0083] In some embodiments, one or more devices or circuitries within these hardware processing circuitries may be implemented by combinations of software-configured elements and/or other hardware elements. For example, processor 436 (and/or one or more other processors which UE 430 may comprise), memory 438, and/or other elements or components of UE 430 (which may include hardware processing circuitry 440) may be arranged to perform the operations of these hardware processing circuitries, such as operations described herein with reference to devices and circuitry within these hardware processing circuitries. In some embodiments, processor 436 (and/or one or more other processors which UE 430 may comprise) may be a baseband processor.

[0084] Returning to **Fig. 5**, an apparatus of UE 430 (or another UE or mobile handset), which may be operable to communicate with one or more eNBs on a wireless network, may comprise hardware processing circuitry 500. In some embodiments, hardware processing circuitry 500 may comprise one or more antenna ports 505 operable to provide various transmissions over a wireless communication channel (such as wireless communication channel 450). Antenna ports 505 may be coupled to one or more antennas 507 (which may be antennas 425). In some embodiments, hardware processing circuitry 500 may incorporate antennas 507, while in other embodiments, hardware processing circuitry 500 may merely be coupled to antennas 507.

[0085] Antenna ports 505 and antennas 507 may be operable to provide signals from a UE to a wireless communications channel and/or an eNB, and may be operable to provide signals from an eNB and/or a wireless communications channel to a UE. For example,

antenna ports 505 and antennas 507 may be operable to provide transmissions from UE 430 to wireless communication channel 450 (and from there to eNB 410, or to another eNB). Similarly, antennas 507 and antenna ports 505 may be operable to provide transmissions from a wireless communication channel 450 (and beyond that, from eNB 410, or another eNB) to UE 430.

[0086] Hardware processing circuitry 500 may comprise various circuitries operable in accordance with the various embodiments discussed herein. With reference to **Fig. 5**, hardware processing circuitry 500 may comprise a first circuitry 510, a second circuitry 520, a third circuitry 530, and/or a fourth circuitry 540. First circuitry 510 may be operable to identify a number M of UE Rx beams as being associated with optimum performance relative to a received beamforming reference signal parameter. Second circuitry 520 may be operable to process a transmission from the eNB carrying an indicator of one or more UE Rx beams to be used for PDCCH transmission. Third circuitry 530 may be operable to select one or more of the number M of UE Rx beams for PDCCH reception, in accordance with the indicator of one or more UE Rx beams. First circuitry 510 may be operable to provide the number M of UE Rx beams to third circuitry 530 via an interface 512. Second circuitry 520 may be operable to provide the one or more UE Rx beams to be used for PDCCH transmission to third circuitry 530 via an interface 522. Hardware processing circuitry 500 may also comprise an interface for receiving the transmission from a receiving circuitry.

[0087] In some embodiments, the received beamforming reference signal parameter may be a signal strength parameter. For some embodiments, the indicator may indicate use of an optimum beam of the number M of UE Rx beams. In some embodiments, the indicator may indicate use of a number B of the optimum beams of the number M of UE Rx beams. For some embodiments, B may be 2, 3, or 4, for example. In some embodiments, the indicator may indicate use of one of: an omni-directional beam, or a pseudo-omni-directional beam.

[0088] For some embodiments, second circuitry 520 may also be operable to process a second transmission from the eNB carrying a second indicator of one or more UE Rx beams to be used for PDCCH transmission, the second transmission being processed one or more subframes after the first transmission. In some embodiments, third circuitry 530 may be operable to select one or more of the number M of UE Rx beams for PDCCH reception, in accordance with the second indicator of one or more UE Rx beams.

[0089] In some embodiments, second circuitry 520 may be operable process a PDCCH transmission having a DCI, wherein the DCI may carry a beam switching command

indicator for selecting one or more of the number M of UE Rx beams for PDSCH reception. For some embodiments, fourth circuitry 540 may be operable to generate a PUCCH transmission having a UCI, wherein the UCI may carry at least one of: a beam switching request indicator, or a preferred beam indicator. First circuitry 510 may be operable to provide the preferred beam indicator to fourth circuitry 540 via an interface 514.

[0090] In some embodiments, first circuitry 510, second circuitry 520, third circuitry 530, and/or fourth circuitry 540 may be implemented as separate circuitries. In other embodiments, first circuitry 510, second circuitry 520, third circuitry 530, and/or fourth circuitry 540 may be combined and implemented together in a circuitry without altering the essence of the embodiments.

[0091] Returning to **Fig. 6**, an apparatus of UE 430 (or another UE or mobile handset), which may be operable to communicate with one or more eNBs on a wireless network, may comprise hardware processing circuitry 600. In some embodiments, hardware processing circuitry 600 may comprise one or more antenna ports 605 operable to provide various transmissions over a wireless communication channel (such as wireless communication channel 450). Antenna ports 605 may be coupled to one or more antennas 607 (which may be antennas 425). In some embodiments, hardware processing circuitry 600 may incorporate antennas 607, while in other embodiments, hardware processing circuitry 600 may merely be coupled to antennas 607.

[0092] Antenna ports 605 and antennas 607 may be operable to provide signals from a UE to a wireless communications channel and/or an eNB, and may be operable to provide signals from an eNB and/or a wireless communications channel to a UE. For example, antenna ports 605 and antennas 607 may be operable to provide transmissions from UE 430 to wireless communication channel 450 (and from there to eNB 410, or to another eNB). Similarly, antennas 607 and antenna ports 605 may be operable to provide transmissions from a wireless communication channel 450 (and beyond that, from eNB 410, or another eNB) to UE 430.

[0093] Hardware processing circuitry 600 may comprise various circuitries operable in accordance with the various embodiments discussed herein. With reference to **Fig. 6**, hardware processing circuitry 600 may comprise a first circuitry 610, a second circuitry 620, and/or a third circuitry 630. First circuitry 610 may be operable to process a request for measurement of a RS selected from one a mobility RS and/or a beamformed CSI-RS. Second circuitry 620 may be operable to calculate at least one of an RSRP or an RSRQ of the RS. Third circuitry 630 may be operable to generate a measurement report of at least one of the

RSRP or the RSRQ of the RS. First circuitry 610 may be operable to provide the RS to second circuitry 620 via an interface 612, and second circuitry 620 may be operable to provide an RSRP and/or an RSRQ to third circuitry 630 via an interface 622. Hardware processing circuitry 600 may also comprise an interface for receiving the request for measurement of the RS and the RS from a receiving circuitry, and for sending the measurement report to a transmission circuitry.

[0094] In some embodiments, the measurement report may comprise one or more sub-reports. For some embodiments, at least one of the sub-reports may comprise an RSRP and/or an RSRQ of a first RS, and an RSRP and/or an RSRQ of a second RS.

[0095] For some embodiments, first circuitry 610 may be operable to process an SS configuration transmission associating one or more configured RSes with one or more respectively corresponding DMRS ports. In some embodiments, third circuitry 630 may be operable to generate one or more measurement reports respectively corresponding to the one or more configured RSes.

[0096] In some embodiments, the SS configuration transmission may identify a pattern of subframes for which RSRP or RSRQ of the one or more configured RSes is to be measured.

[0097] In some embodiments, first circuitry 610, second circuitry 620, and/or third circuitry 630 may be implemented as separate circuitries. In other embodiments, first circuitry 610, second circuitry 620, and/or third circuitry 630 may be combined and implemented together in a circuitry without altering the essence of the embodiments.

[0098] **Fig. 7** illustrates methods for a UE for DL control channel beamforming, in accordance with some embodiments of the disclosure. **Fig. 8** illustrates methods for a UE for facilitating physical control channel CoMP transmission that may be disposed to incorporating different UE Rx beam directions, in accordance with some embodiments of the disclosure. With reference to **Fig. 4**, methods that may relate to UE 430 and hardware processing circuitry 440 are discussed herein. Although the actions in the method 700 of **Fig. 7** and the method 800 of **Fig. 8** are shown in a particular order, the order of the actions can be modified. Thus, the illustrated embodiments can be performed in a different order, and some actions may be performed in parallel. Some of the actions and/or operations listed in **Fig. 7 and Fig. 8** are optional in accordance with certain embodiments. The numbering of the actions presented is for the sake of clarity and is not intended to prescribe an order of operations in which the various actions must occur. Additionally, operations from the various flows may be utilized in a variety of combinations.

[0099] Moreover, in some embodiments, machine readable storage media may have executable instructions that, when executed, cause UE 430 and/or hardware processing circuitry 440 to perform an operation comprising the methods of **Fig. 7 and Fig. 8**. Such machine readable storage media may include any of a variety of storage media, like magnetic storage media (e.g., magnetic tapes or magnetic disks), optical storage media (e.g., optical discs), electronic storage media (e.g., conventional hard disk drives, solid-state disk drives, or flash-memory-based storage media), or any other tangible storage media or non-transitory storage media.

[00100] In some embodiments, an apparatus may comprise means for performing various actions and/or operations of the methods of **Fig. 7 and Fig. 8**.

[00101] Returning to **Fig. 7**, various methods may be in accordance with the various embodiments discussed herein. A method 700 may comprise an identifying 710, a processing 715, and a selecting 720. Method 700 may also comprise a processing 730, a selecting 735, a processing 740, and/or a generating 750.

[00102] In identifying 710, a number M of UE Rx beams as being associated with optimum performance relative to a received beamforming reference signal parameter. In processing 715, a transmission from an eNB carrying an indicator of one or more UE Rx beams to be used for PDCCH transmission may be processed. In selecting 720, one or more of the number M of UE Rx beams for PDCCH reception may be selected, in accordance with the indicator of one or more UE Rx beams.

[00103] In some embodiments, the received beamforming reference signal parameter may be a signal strength parameter. For some embodiments, the indicator may indicate use of an optimum beam of the number M of UE Rx beams. In some embodiments, the indicator may indicate use of a number B of the optimum beams of the number M of UE Rx beams. For some embodiments, B may be 2, 3, or 4, for example. In some embodiments, the indicator may indicate use of one of: an omni-directional beam, or a pseudo-omni-directional beam.

[00104] For some embodiments, in processing 730, a second transmission from the eNB may be processed. The second transmission may carry a second indicator of one or more UE Rx beams to be used for PDCCH transmission, and the second transmission may process one or more subframes after the first transmission. In selecting 735, one or more of the number M of UE Rx beams may be selected for PDCCH reception, in accordance with the second indicator of one or more UE Rx beams.

[00105] In some embodiments, in processing 740, a PDCCH transmission having a DCI may be processed, wherein the DCI may carry a beam switching command indicator for selecting one or more of the number M of UE Rx beams for PDSCH reception. For some embodiments, in generating 750, a PUCCH transmission having an UCI may be generated, wherein the UCI may carry at least one of: a beam switching request indicator, or a preferred beam indicator.

[00106] Returning to **Fig. 8**, various methods may be in accordance with the various embodiments discussed herein. A method 800 may comprise a processing 810, a calculating 815, and a generating 820. In various embodiments, method 800 may also comprise a processing 830 and/or a generating 840.

[00107] In processing 810, a request may be processed for measurement of an RS selected from a mobility RS and/or a beamformed CSI-RS. In calculating 815, at least one of a RSRP or a RSRQ of the RS may be calculated. In generating 820, a measurement report of at least one of the RSRP or the RSRQ of the RS may be generated.

[00108] In some embodiments, the measurement report may comprise one or more sub-reports. For some embodiments, at least one of the sub-reports may comprise an RSRP and/or an RSRQ of a first RS, and an RSRP and/or an RSRQ of a second RS.

[00109] For some embodiments, in processing 830, an SS configuration transmission associating one or more configured RSes with one or more respectively corresponding DMRS ports may be processed. In some embodiments, in generating 840, one or more measurement reports respectively corresponding to the one or more configured RSes may be generated.

[00110] In some embodiments, the SS configuration transmission may identify a pattern of subframes for which RSRP or RSRQ of the one or more configured RSes is to be measured.

[00111] **Fig. 9** illustrates example components of a device, in accordance with some embodiments of the disclosure. In some embodiments, the device 900 may include application circuitry 902, baseband circuitry 904, Radio Frequency (RF) circuitry 906, front-end module (FEM) circuitry 908, one or more antennas 910, and power management circuitry (PMC) 912 coupled together at least as shown. The components of the illustrated device 900 may be included in a UE or a RAN node. In some embodiments, the device 900 may include less elements (e.g., a RAN node may not utilize application circuitry 902, and instead include a processor/controller to process IP data received from an EPC). In some embodiments, the device 900 may include additional elements such as, for example, memory/storage, display,

camera, sensor, or input/output (I/O) interface. In other embodiments, the components described below may be included in more than one device (e.g., said circuitries may be separately included in more than one device for Cloud-RAN (C-RAN) implementations).

[00112] The application circuitry 902 may include one or more application processors. For example, the application circuitry 902 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 or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications or operating systems to run on the device 900. In some embodiments, processors of application circuitry 902 may process IP data packets received from an EPC.

[00113] The baseband circuitry 904 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 904 may include one or more baseband processors or control logic to process baseband signals received from a receive signal path of the RF circuitry 906 and to generate baseband signals for a transmit signal path of the RF circuitry 906. Baseband processing circuity 904 may interface with the application circuitry 902 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 906. For example, in some embodiments, the baseband circuitry 904 may include a third generation (3G) baseband processor 904A, a fourth generation (4G) baseband processor 904B, a fifth generation (5G) baseband processor 904C, or other baseband processor(s) 904D for other existing generations, generations in development or to be developed in the future (e.g., second generation (2G), sixth generation (6G), etc.). The baseband circuitry 904 (e.g., one or more of baseband processors 904A-D) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 906. In other embodiments, some or all of the functionality of baseband processors 904A-D may be included in modules stored in the memory 904G and executed via a Central Processing Unit (CPU) 904E. 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 904 may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 904 may include convolution, tail-biting convolution, turbo, Viterbi, 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.

[00114] In some embodiments, the baseband circuitry 904 may include one or more audio digital signal processor(s) (DSP) 904F. The audio DSP(s) 904F 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 904 and the application circuitry 902 may be implemented together such as, for example, on a system on a chip (SOC).

[00115] In some embodiments, the baseband circuitry 904 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 904 may support communication with an evolved universal terrestrial radio access network (EUTRAN) 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 904 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[00116] RF circuitry 906 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 906 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 906 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 908 and provide baseband signals to the baseband circuitry 904. RF circuitry 906 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 904 and provide RF output signals to the FEM circuitry 908 for transmission.

[00117] In some embodiments, the receive signal path of the RF circuitry 906 may include mixer circuitry 906A, amplifier circuitry 906B and filter circuitry 906C. In some embodiments, the transmit signal path of the RF circuitry 906 may include filter circuitry 906C and mixer circuitry 906A. RF circuitry 906 may also include synthesizer circuitry 906D for synthesizing a frequency for use by the mixer circuitry 906A of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 906A of the

receive signal path may be configured to down-convert RF signals received from the FEM circuitry 908 based on the synthesized frequency provided by synthesizer circuitry 906D. The amplifier circuitry 906B may be configured to amplify the down-converted signals and the filter circuitry 906C 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 provided to the baseband circuitry 904 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 906A of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[00118] In some embodiments, the mixer circuitry 906A of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 906D to generate RF output signals for the FEM circuitry 908. The baseband signals may be provided by the baseband circuitry 904 and may be filtered by filter circuitry 906C.

[00119] In some embodiments, the mixer circuitry 906A of the receive signal path and the mixer circuitry 906A of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and upconversion, respectively. In some embodiments, the mixer circuitry 906A of the receive signal path and the mixer circuitry 906A of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 906A of the receive signal path and the mixer circuitry 906A may be arranged for direct downconversion and direct upconversion, respectively. In some embodiments, the mixer circuitry 906A of the receive signal path and the mixer circuitry 906A of the transmit signal path may be configured for super-heterodyne operation.

[00120] 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 signals. In these alternate embodiments, the RF circuitry 906 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 904 may include a digital baseband interface to communicate with the RF circuitry 906.

[00121] In some dual-mode embodiments, a separate radio IC circuitry may be provided for processing signals for each spectrum, although the scope of the embodiments is not limited in this respect.

[00122] In some embodiments, the synthesizer circuitry 906D 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 906D may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[00123] The synthesizer circuitry 906D may be configured to synthesize an output frequency for use by the mixer circuitry 906A of the RF circuitry 906 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 906D may be a fractional N/N+1 synthesizer.

[00124] 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 904 or the applications processor 902 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 902.

[00125] Synthesizer circuitry 906D of the RF circuitry 906 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 Nd equal packets of phase, where Nd is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

[00126] In some embodiments, synthesizer circuitry 906D 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 (fLO). In some embodiments, the RF circuitry 906 may include an IQ/polar converter.

[00127] FEM circuitry 908 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 910, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 906 for further processing. FEM circuitry 908 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 906 for transmission by one or more of the one or more antennas 910. In various embodiments, the amplification through the transmit or receive signal paths may be done solely in the RF circuitry 906, solely in the FEM 908, or in both the RF circuitry 906 and the FEM 908.

[00128] In some embodiments, the FEM circuitry 908 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 an LNA to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 906). The transmit signal path of the FEM circuitry 908 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 906), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 910).

[00129] In some embodiments, the PMC 912 may manage power provided to the baseband circuitry 904. In particular, the PMC 912 may control power-source selection, voltage scaling, battery charging, or DC-to-DC conversion. The PMC 912 may often be included when the device 900 is capable of being powered by a battery, for example, when the device is included in a UE. The PMC 912 may increase the power conversion efficiency while providing desirable implementation size and heat dissipation characteristics.

[00130] While **Fig. 9** shows the PMC 912 coupled only with the baseband circuitry 904. However, in other embodiments, the PMC 912 may be additionally or alternatively coupled with, and perform similar power management operations for, other components such as, but not limited to, application circuitry 902, RF circuitry 906, or FEM 908.

[00131] In some embodiments, the PMC 912 may control, or otherwise be part of, various power saving mechanisms of the device 900. For example, if the device 900 is in an RRC_Connected state, where it is still connected to the RAN node as it expects to receive traffic shortly, then it may enter a state known as Discontinuous Reception Mode (DRX) after

a period of inactivity. During this state, the device 900 may power down for brief intervals of time and thus save power.

[00132] If there is no data traffic activity for an extended period of time, then the device 900 may transition off to an RRC_Idle state, where it disconnects from the network and does not perform operations such as channel quality feedback, handover, etc. The device 900 goes into a very low power state and it performs paging where again it periodically wakes up to listen to the network and then powers down again. The device 900 may not receive data in this state, in order to receive data, it must transition back to RRC_Connected state.

[00133] An additional power saving mode may allow a device to be unavailable to the network for periods longer than a paging interval (ranging from seconds to a few hours). During this time, the device is totally unreachable to the network and may power down completely. Any data sent during this time incurs a large delay and it is assumed the delay is acceptable.

[00134] Processors of the application circuitry 902 and processors of the baseband circuitry 904 may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry 904, alone or in combination, may be used execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry 904 may utilize data (e.g., packet data) received from these layers and further execute Layer 4 functionality (e.g., transmission communication protocol (TCP) and user datagram protocol (UDP) layers). As referred to herein, Layer 3 may comprise a radio resource control (RRC) layer, described in further detail below. As referred to herein, Layer 2 may comprise a medium access control (MAC) layer, a radio link control (RLC) layer, and a packet data convergence protocol (PDCP) layer, described in further detail below. As referred to herein, Layer 1 may comprise a physical (PHY) layer of a UE/RAN node, described in further detail below.

[00135] **Fig. 10** illustrates example interfaces of baseband circuitry, in accordance with some embodiments of the disclosure. As discussed above, the baseband circuitry 904 of **Fig. 9** may comprise processors 904A-904E and a memory 904G utilized by said processors. Each of the processors 904A-904E may include a memory interface, 1004A-1004E, respectively, to send/receive data to/from the memory 904G.

[00136] The baseband circuitry 904 may further include one or more interfaces to communicatively couple to other circuitries/devices, such as a memory interface 1012 (e.g., an interface to send/receive data to/from memory external to the baseband circuitry 904), an

application circuitry interface 1014 (e.g., an interface to send/receive data to/from the application circuitry 902 of **Fig. 9**), an RF circuitry interface 1016 (e.g., an interface to send/receive data to/from RF circuitry 906 of **Fig. 9**), a wireless hardware connectivity interface 1018 (e.g., an interface to send/receive data to/from Near Field Communication (NFC) components, Bluetooth® components (e.g., Bluetooth® Low Energy), Wi-Fi® components, and other communication components), and a power management interface 1020 (e.g., an interface to send/receive power or control signals to/from the PMC 912.

[00137] It is pointed out that elements of any of the Figures herein having the same reference numbers and/or names as elements of any other Figure herein may, in various embodiments, operate or function in a manner similar those elements of the other Figure (without being limited to operating or functioning in such a manner).

[00138] Reference in the specification to "an embodiment," "one embodiment," "some embodiments," or "other embodiments" means that a particular feature, structure, or characteristic described in connection with the embodiments is included in at least some embodiments, but not necessarily all embodiments. The various appearances of "an embodiment," "one embodiment," or "some embodiments" are not necessarily all referring to the same embodiments. If the specification states a component, feature, structure, or characteristic "may," "might," or "could" be included, that particular component, feature, structure, or characteristic is not required to be included. If the specification or claim refers to "a" or "an" element, that does not mean there is only one of the elements. If the specification or claims refer to "an additional" element, that does not preclude there being more than one of the additional element.

[00139] Furthermore, the particular features, structures, functions, or characteristics may be combined in any suitable manner in one or more embodiments. For example, a first embodiment may be combined with a second embodiment anywhere the particular features, structures, functions, or characteristics associated with the two embodiments are not mutually exclusive.

[00140] While the disclosure has been described in conjunction with specific embodiments thereof, many alternatives, modifications and variations of such embodiments will be apparent to those of ordinary skill in the art in light of the foregoing description. For example, other memory architectures e.g., Dynamic RAM (DRAM) may use the embodiments discussed. The embodiments of the disclosure are intended to embrace all such alternatives, modifications, and variations as to fall within the broad scope of the appended claims.

[00141] In addition, well known power/ground connections to integrated circuit (IC) chips and other components may or may not be shown within the presented figures, for simplicity of illustration and discussion, and so as not to obscure the disclosure. Further, arrangements may be shown in block diagram form in order to avoid obscuring the disclosure, and also in view of the fact that specifics with respect to implementation of such block diagram arrangements are highly dependent upon the platform within which the present disclosure is to be implemented (i.e., such specifics should be well within purview of one skilled in the art). Where specific details (e.g., circuits) are set forth in order to describe example embodiments of the disclosure, it should be apparent to one skilled in the art that the disclosure can be practiced without, or with variation of, these specific details. The description is thus to be regarded as illustrative instead of limiting.

[00142] The following examples pertain to further embodiments. Specifics in the examples may be used anywhere in one or more embodiments. All optional features of the apparatus described herein may also be implemented with respect to a method or process.

[00143] Example 1 provides an apparatus of a User Equipment (UE) operable to communicate with an Evolved Node B (eNB) on a wireless network, comprising: one or more processors to: identify a number M of UE Receive (Rx) beams as being associated with optimum performance relative to a received beamforming reference signal parameter; process a transmission from the eNB carrying an indicator of one or more UE Rx beams to be used for Physical Downlink Control Channel (PDCCH) transmission; and select one or more of the number M of UE Rx beams for PDCCH reception, in accordance with the indicator of one or more UE Rx beams, and an interface for receiving the transmission from a receiving circuitry.

[00144] In example 2, the apparatus of example1, wherein the received beamforming reference signal parameter is a signal strength parameter.

[00145] In example 3, the apparatus of either of claims 1 or 2, wherein the indicator indicates use of an optimum beam of the number M of UE Rx beams.

[00146] In example 4, the apparatus of any of claims 1 through 3, wherein the indicator indicates use of a number B of the optimum beams of the number M of UE Rx beams.

[00147] In example 5, the apparatus of example4, wherein B is one of: 2, 3, or 4.

[00148] In example 6, the apparatus of any of claims 1 through 5, wherein the indicator indicates use of one of: an omni-directional beam, or a pseudo-omni-directional beam.

[00149] In example 7, the apparatus of any of claims 1 through 6, wherein the transmission is a first transmission, and wherein the one or more processors are to: process a

second transmission from the eNB carrying a second indicator of one or more UE Rx beams to be used for PDCCH transmission, the second transmission being processed one or more subframes after the first transmission; and select one or more of the number M of UE Rx beams for PDCCH reception, in accordance with the second indicator of one or more UE Rx beams.

[00150] In example 8, the apparatus of any of claims 1 through 7, wherein the one or more processors are to: process a PDCCH transmission having a Downlink Control Information (DCI), wherein the DCI carries a beam switching command indicator for selecting one or more of the number M of UE Rx beams for Physical Downlink Shared Channel (PDSCH) reception.

[00151] In example 9, the apparatus of any of claims 1 through 8, wherein the one or more processors are to: generate a Physical Uplink Control Channel (PUCCH) transmission having an Uplink Control Information (UCI), wherein the UCI carries at least one of: a beam switching request indicator, or a preferred beam indicator.

[00152] Example 10 provides a User Equipment (UE) device comprising an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate with another device, and a touch-screen display, the UE device including the apparatus of any of claims 1 through 9.

[00153] Example 11 provides a method comprising: identifying, for a User Equipment (UE), a number M of UE Receive (Rx) beams as being associated with optimum performance relative to a received beamforming reference signal parameter; processing a transmission from an Evolved Node-B (eNB) carrying an indicator of one or more UE Rx beams to be used for Physical Downlink Control Channel (PDCCH) transmission; and selecting one or more of the number M of UE Rx beams for PDCCH reception, in accordance with the indicator of one or more UE Rx beams.

[00154] In example 12, the method of example11, wherein the received beamforming reference signal parameter is a signal strength parameter.

[00155] In example 13, the method of either of claims 11 or 12, wherein the indicator indicates use of an optimum beam of the number M of UE Rx beams.

[00156] In example 14, the method of any of claims 11 through 13, wherein the indicator indicates use of a number B of the optimum beams of the number M of UE Rx beams.

[00157] In example 15, the method of example14, wherein B is one of: 2, 3, or 4.

[00158] In example 16, the method of any of claims 11 through 15, wherein the indicator indicates use of one of: an omni-directional beam, or a pseudo-omni-directional beam.

[00159] In example 17, the method of any of claims 11 through 16, wherein the transmission is a first transmission, comprising: processing a second transmission from the eNB carrying a second indicator of one or more UE Rx beams to be used for PDCCH transmission, the second transmission being processed one or more subframes after the first transmission; and selecting one or more of the number M of UE Rx beams for PDCCH reception, in accordance with the second indicator of one or more UE Rx beams.

[00160] In example 18, the method of any of claims 11 through 17, comprising: processing a PDCCH transmission having a Downlink Control Information (DCI), wherein the DCI carries a beam switching command indicator for selecting one or more of the number M of UE Rx beams for Physical Downlink Shared Channel (PDSCH) reception.

[00161] In example 19, the method of any of claims 11 through 18, comprising: generating a Physical Uplink Control Channel (PUCCH) transmission having an Uplink Control Information (UCI), wherein the UCI carries at least one of: a beam switching request indicator, or a preferred beam indicator.

[00162] Example 20 provides machine readable storage media having machine executable instructions stored thereon that, when executed, cause one or more processors to perform a method according to any of claims 11 through 19.

[00163] Example 21 provides an apparatus of a User Equipment (UE) operable to communicate with an Evolved Node B (eNB) on a wireless network, comprising: means for identifying a number M of UE Receive (Rx) beams as being associated with optimum performance relative to a received beamforming reference signal parameter; means for processing a transmission from the eNB carrying an indicator of one or more UE Rx beams to be used for Physical Downlink Control Channel (PDCCH) transmission; and means for selecting one or more of the number M of UE Rx beams for PDCCH reception, in accordance with the indicator of one or more UE Rx beams.

[00164] In example 22, the apparatus of example21, wherein the received beamforming reference signal parameter is a signal strength parameter.

[00165] In example 23, the apparatus of either of claims 21 or 22, wherein the indicator indicates use of an optimum beam of the number M of UE Rx beams.

[00166] In example 24, the apparatus of any of claims 21 through 23, wherein the indicator indicates use of a number B of the optimum beams of the number M of UE Rx beams.

[00167] In example 25, the apparatus of example24, wherein B is one of: 2, 3, or 4.

[00168] In example 26, the apparatus of any of claims 21 through 25, wherein the indicator indicates use of one of: an omni-directional beam, or a pseudo-omni-directional beam.

[00169] In example 27, the apparatus of any of claims 21 through 26, wherein the transmission is a first transmission, comprising: means for processing a second transmission from the eNB carrying a second indicator of one or more UE Rx beams to be used for PDCCH transmission, the second transmission being processed one or more subframes after the first transmission; and means for selecting one or more of the number M of UE Rx beams for PDCCH reception, in accordance with the second indicator of one or more UE Rx beams.

[00170] In example 28, the apparatus of any of claims 21through 27, comprising: means for processing a PDCCH transmission having a Downlink Control Information (DCI), wherein the DCI carries a beam switching command indicator for selecting one or more of the number M of UE Rx beams for Physical Downlink Shared Channel (PDSCH) reception.

[00171] In example 29, the apparatus of any of claims 21 through 28, comprising: means for generating a Physical Uplink Control Channel (PUCCH) transmission having an Uplink Control Information (UCI), wherein the UCI carries at least one of: a beam switching request indicator, or a preferred beam indicator.

[00172] Example 30 provides machine readable storage media having machine executable instructions that, when executed, cause one or more processors of a User Equipment (UE) operable to communicate with an Evolved Node-B (eNB) on a wireless network to perform an operation comprising: identify a number M of UE Receive (Rx) beams as being associated with optimum performance relative to a received beamforming reference signal parameter; process a transmission from the eNB carrying an indicator of one or more UE Rx beams to be used for Physical Downlink Control Channel (PDCCH) transmission; and select one or more of the number M of UE Rx beams for PDCCH reception, in accordance with the indicator of one or more UE Rx beams.

[00173] In example 31, the machine readable storage media of example30, wherein the received beamforming reference signal parameter is a signal strength parameter.

[00174] In example 32, the machine readable storage media of either of claims 30 or 31, wherein the indicator indicates use of an optimum beam of the number M of UE Rx beams.

[00175] In example 33, the machine readable storage media of any of claims 30 through 32, wherein the indicator indicates use of a number B of the optimum beams of the number M of UE Rx beams.

[00176] In example 34, the machine readable storage media of example33, wherein B is one of: 2, 3, or 4.

[00177] In example 35, the machine readable storage media of any of claims 30 through 34, wherein the indicator indicates use of one of: an omni-directional beam, or a pseudo-omni-directional beam.

[00178] In example 36, the machine readable storage media of any of claims 30 through 35, wherein the transmission is a first transmission, the operation comprising: process a second transmission from the eNB carrying a second indicator of one or more UE Rx beams to be used for PDCCH transmission, the second transmission being processed one or more subframes after the first transmission; and select one or more of the number M of UE Rx beams for PDCCH reception, in accordance with the second indicator of one or more UE Rx beams.

[00179] In example 37, the machine readable storage media of any of claims 30 through 36, the operation comprising: process a PDCCH transmission having a Downlink Control Information (DCI), wherein the DCI carries a beam switching command indicator for selecting one or more of the number M of UE Rx beams for Physical Downlink Shared Channel (PDSCH) reception.

[00180] In example 38, the machine readable storage media of any of claims 30 through 37, the operation comprising: generate a Physical Uplink Control Channel (PUCCH) transmission having an Uplink Control Information (UCI), wherein the UCI carries at least one of: a beam switching request indicator, or a preferred beam indicator.

[00181] Example 39 provides an apparatus of a User Equipment (UE) operable to communicate with an Evolved Node B (eNB) on a wireless network, comprising: one or more processors to: process a request for measurement of a Reference Signal (RS) selected from one of: a mobility RS, or a beamformed Channel State Information RS (CSI-RS); calculate at least one of a Reference Signal Received Power (RSRP) or a Reference Signal Received Quality (RSRQ) of the RS; and generate a measurement report of at least one of the RSRP or the RSRQ of the RS, and an interface for receiving the request for measurement of

the RS and the RS from a receiving circuitry, and for sending the measurement report to a transmission circuitry.

[00182] In example 40, the apparatus of example39, wherein the measurement report comprises one or more sub-reports.

[00183] In example 41, the apparatus of example40, wherein at least one of the sub-reports comprises at least one of an RSRP or an RSRQ of a first RS, and at least one of an RSRP or an RSRQ of a second RS.

[00184] In example 42, the apparatus of any of claims 39 through 41, wherein the one or more processors are to: process a search space (SS) configuration transmission associating one or more configured RSes with one or more respectively corresponding Demodulation Reference Signal (DMRS) ports.

[00185] In example 43, the apparatus of example42, wherein the one or more processors are to: generate one or more measurement reports respectively corresponding to the one or more configured RSes.

[00186] In example 44, the apparatus of either of claims 41 or 42, wherein the SS configuration transmission identifies a pattern of subframes for which RSRP or RSRQ of the one or more configured RSes is to be measured.

[00187] Example 45 provides a User Equipment (UE) device comprising an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate with another device, and a touch-screen display, the UE device including the apparatus of any of claims 39 through 44.

[00188] Example 46 provides a method comprising: processing, for a User Equipment (UE), a request for measurement of a Reference Signal (RS) selected from one of: a mobility RS, or a beamformed Channel State Information RS (CSI-RS); calculating at least one of a Reference Signal Received Power (RSRP) or a Reference Signal Received Quality (RSRQ) of the RS; and generating a measurement report of at least one of the RSRP or the RSRQ of the RS.

[00189] In example 47, the method of example46, wherein the measurement report comprises one or more sub-reports.

[00190] In example 48, the method of example47, wherein at least one of the sub-reports comprises at least one of an RSRP or an RSRQ of a first RS, and at least one of an RSRP or an RSRQ of a second RS.

[00191] In example 49, the method of any of claims 46 through 48, the operation comprising: processing a search space (SS) configuration transmission associating one or

more configured RSes with one or more respectively corresponding Demodulation Reference Signal (DMRS) ports.

[00192] In example 50, the method of example49, the operation comprising: generating one or more measurement reports respectively corresponding to the one or more configured RSes.

[00193] In example 51, the method of either of claims 49 or 50, wherein the SS configuration transmission identifies a pattern of subframes for which RSRP or RSRQ of the one or more configured RSes is to be measured.

[00194] Example 52 provides machine readable storage media having machine executable instructions stored thereon that, when executed, cause one or more processors to perform a method according to any of claims 46 through 51.

[00195] Example 53 provides an apparatus of a User Equipment (UE) operable to communicate with an Evolved Node B (eNB) on a wireless network, comprising: means for processing a request for measurement of a Reference Signal (RS) selected from one of: a mobility RS, or a beamformed Channel State Information RS (CSI-RS); means for calculating at least one of a Reference Signal Received Power (RSRP) or a Reference Signal Received Quality (RSRQ) of the RS; and means for generating a measurement report of at least one of the RSRP or the RSRQ of the RS.

[00196] In example 54, the apparatus of example53, wherein the measurement report comprises one or more sub-reports.

[00197] In example 55, the apparatus of example54, wherein at least one of the sub-reports comprises at least one of an RSRP or an RSRQ of a first RS, and at least one of an RSRP or an RSRQ of a second RS.

[00198] In example 56, the apparatus of any of claims 53 through 55, the operation comprising: means for processing a search space (SS) configuration transmission associating one or more configured RSes with one or more respectively corresponding Demodulation Reference Signal (DMRS) ports.

[00199] In example 57, the apparatus of example56, the operation comprising: means for generating one or more measurement reports respectively corresponding to the one or more configured RSes.

[00200] In example 58, the apparatus of either of claims 56 or 57, wherein the SS configuration transmission identifies a pattern of subframes for which RSRP or RSRQ of the one or more configured RSes is to be measured.

[00201] Example 59 provides machine readable storage media having machine executable instructions that, when executed, cause one or more processors of a User Equipment (UE) operable to communicate with an Evolved Node-B (eNB) on a wireless network to perform an operation comprising: process a request for measurement of a Reference Signal (RS) selected from one of: a mobility RS, or a beamformed Channel State Information RS (CSI-RS); calculate at least one of a Reference Signal Received Power (RSRP) or a Reference Signal Received Quality (RSRQ) of the RS; and generate a measurement report of at least one of the RSRP or the RSRQ of the RS.

[00202] In example 60, the machine readable storage media of example59, wherein the measurement report comprises one or more sub-reports.

[00203] In example 61, the machine readable storage media of example60, wherein at least one of the sub-reports comprises at least one of an RSRP or an RSRQ of a first RS, and at least one of an RSRP or an RSRQ of a second RS.

[00204] In example 62, the machine readable storage media of any of claims 59 through 61, the operation comprising: process a search space (SS) configuration transmission associating one or more configured RSes with one or more respectively corresponding Demodulation Reference Signal (DMRS) ports.

[00205] In example 63, the machine readable storage media of example62, the operation comprising: generate one or more measurement reports respectively corresponding to the one or more configured RSes.

[00206] In example 64, the machine readable storage media of either of claims 62 or 63, wherein the SS configuration transmission identifies a pattern of subframes for which RSRP or RSRQ of the one or more configured RSes is to be measured.

[00207] In example 65, the apparatus of any of claims 1 through 9, and 39 through 44, wherein the one or more processors comprise a baseband processor.

[00208] In example 66, the apparatus of any of claims 1 through 9, and 39 through 44, comprising a memory for storing instructions, the memory being coupled to the one or more processors.

[00209] In example 67, the apparatus of any of claims 1 through 9, and 39 through 44, comprising a transceiver circuitry for at least one of: generating transmissions, encoding transmissions, processing transmissions, or decoding transmissions.

[00210] In example 68, the apparatus of any of claims 1 through 9, and 39 through 44, comprising a transceiver circuitry for generating transmissions and processing transmissions.

[00211] form, after preliminary QR and before filing]

[00212] An abstract is provided that will allow the reader to ascertain the nature and gist of the technical disclosure. The abstract is submitted with the understanding that it will not be used to limit 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

We claim:

1. An apparatus of a User Equipment (UE) operable to communicate with an Evolved Node-B (eNB) on a wireless network, comprising:
   one or more processors to:
      identify a number M of UE Receive (Rx) beams as being associated with optimum performance relative to a received beamforming reference signal parameter;
      process a transmission from the eNB carrying an indicator of one or more UE Rx beams to be used for Physical Downlink Control Channel (PDCCH) transmission; and
      select one or more of the number M of UE Rx beams for PDCCH reception, in accordance with the indicator of one or more UE Rx beams, and
   an interface for receiving the transmission from a receiving circuitry.

2. The apparatus of claim 1,
   wherein the received beamforming reference signal parameter is a signal strength parameter.

3. The apparatus of either of claims 1 or 2,
   wherein the indicator indicates use of an optimum beam of the number M of UE Rx beams.

4. The apparatus of either of claims 1 or 2,
   wherein the indicator indicates use of a number B of the optimum beams of the number M of UE Rx beams.

5. The apparatus of claim 4,
   wherein B is one of: 2, 3, or 4.

6. The apparatus of either of claims 1 or 2,
   wherein the indicator indicates use of one of: an omni-directional beam, or a pseudo-omni-directional beam.

7. Machine readable storage media having machine executable instructions that, when executed, cause one or more processors of a User Equipment (UE) operable to communicate with an Evolved Node-B (eNB) on a wireless network to perform an operation comprising:

identify a number M of UE Receive (Rx) beams as being associated with optimum performance relative to a received beamforming reference signal parameter;

process a transmission from the eNB carrying an indicator of one or more UE Rx beams to be used for Physical Downlink Control Channel (PDCCH) transmission; and

select one or more of the number M of UE Rx beams for PDCCH reception, in accordance with the indicator of one or more UE Rx beams.

8. The machine readable storage media of claim 7,

wherein the received beamforming reference signal parameter is a signal strength parameter.

9. The machine readable storage media of either of claims 7 or 8,

wherein the indicator indicates use of an optimum beam of the number M of UE Rx beams.

10. The machine readable storage media of either of claims 7 or 8,

wherein the indicator indicates use of a number B of the optimum beams of the number M of UE Rx beams.

11. The machine readable storage media of claim 10,

wherein B is one of: 2, 3, or 4.

12. The machine readable storage media of either of claims 7 or 8,

wherein the indicator indicates use of one of: an omni-directional beam, or a pseudo-omni-directional beam.

13. An apparatus of a User Equipment (UE) operable to communicate with an Evolved Node-B (eNB) on a wireless network, comprising:

one or more processors to:

process a request for measurement of a Reference Signal (RS) selected from one of: a mobility RS, or a beamformed Channel State Information RS (CSI-RS);

calculate at least one of a Reference Signal Received Power (RSRP) or a Reference Signal Received Quality (RSRQ) of the RS; and

generate a measurement report of at least one of the RSRP or the RSRQ of the RS, and

an interface for receiving the request for measurement of the RS and the RS from a receiving circuitry, and for sending the measurement report to a transmission circuitry.

14. The apparatus of claim 13,

wherein the measurement report comprises one or more sub-reports.

15. The apparatus of claim 14,

wherein at least one of the sub-reports comprises at least one of an RSRP or an RSRQ of a first RS, and at least one of an RSRP or an RSRQ of a second RS.

16. The apparatus of any of claims 13 through 15, wherein the one or more processors are to:

process a search space (SS) configuration transmission associating one or more configured RSes with one or more respectively corresponding Demodulation Reference Signal (DMRS) ports.

17. The apparatus of claim 16, wherein the one or more processors are to:

generate one or more measurement reports respectively corresponding to the one or more configured RSes.

18. The apparatus of claim 16,

wherein the SS configuration transmission identifies a pattern of subframes for which RSRP or RSRQ of the one or more configured RSes is to be measured.

19. Machine readable storage media having machine executable instructions that, when executed, cause one or more processors of a User Equipment (UE) operable to communicate with an Evolved Node-B (eNB) on a wireless network to perform an operation comprising:

process a request for measurement of a Reference Signal (RS) selected from one of: a mobility RS, or a beamformed Channel State Information RS (CSI-RS);

calculate at least one of a Reference Signal Received Power (RSRP) or a Reference Signal Received Quality (RSRQ) of the RS; and

generate a measurement report of at least one of the RSRP or the RSRQ of the RS.

20. The machine readable storage media of claim 19,

wherein the measurement report comprises one or more sub-reports.

21. The machine readable storage media of claim 20,

wherein at least one of the sub-reports comprises at least one of an RSRP or an RSRQ of a first RS, and at least one of an RSRP or an RSRQ of a second RS.

22. The machine readable storage media of any of claims 19 through 21, the operation comprising:

process a search space (SS) configuration transmission associating one or more configured RSes with one or more respectively corresponding Demodulation Reference Signal (DMRS) ports.

23. The machine readable storage media of claim 22, the operation comprising:

generate one or more measurement reports respectively corresponding to the one or more configured RSes.

24. The machine readable storage media of claim 22,

wherein the SS configuration transmission identifies a pattern of subframes for which RSRP or RSRQ of the one or more configured RSes is to be measured.

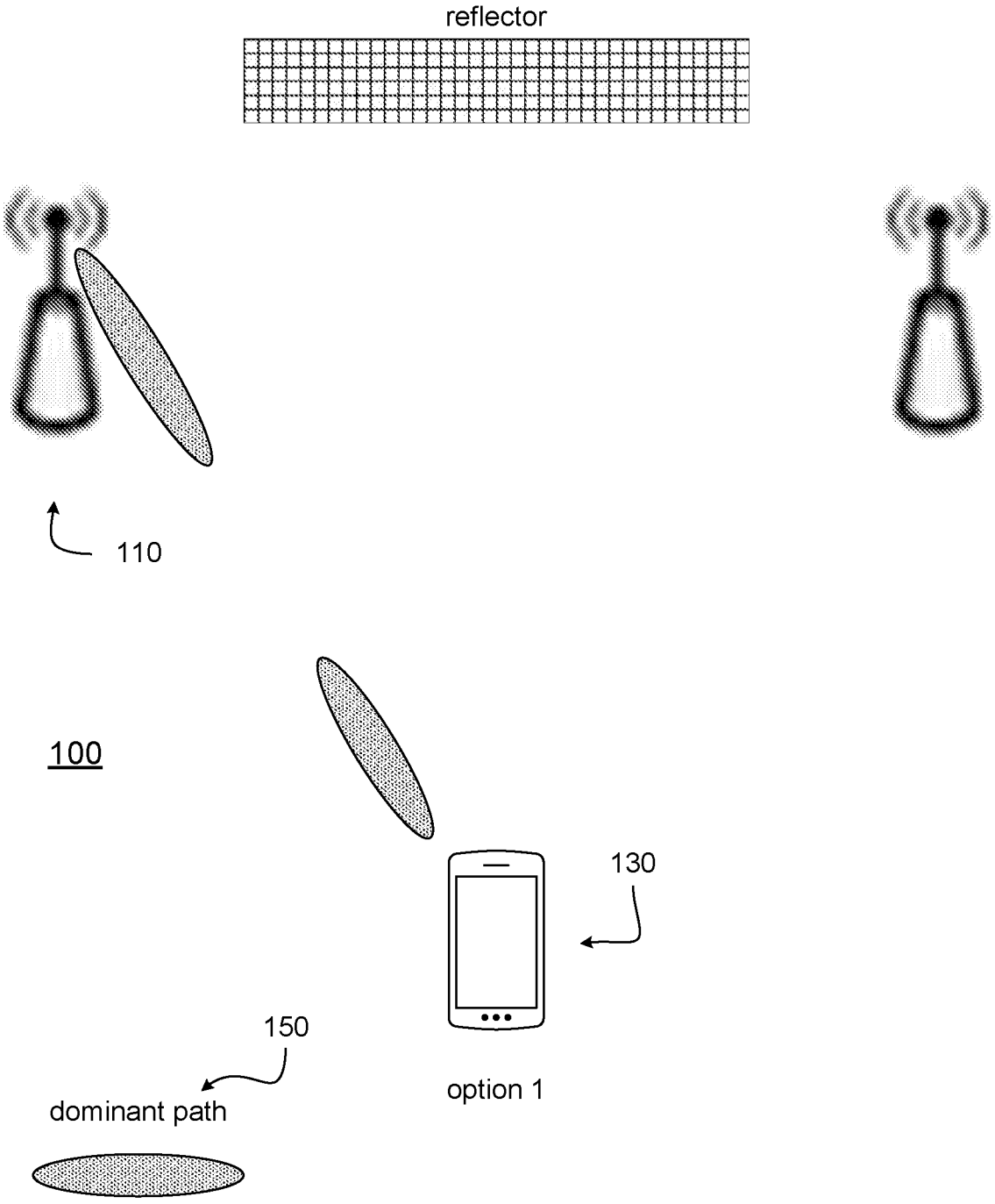


Fig. 1

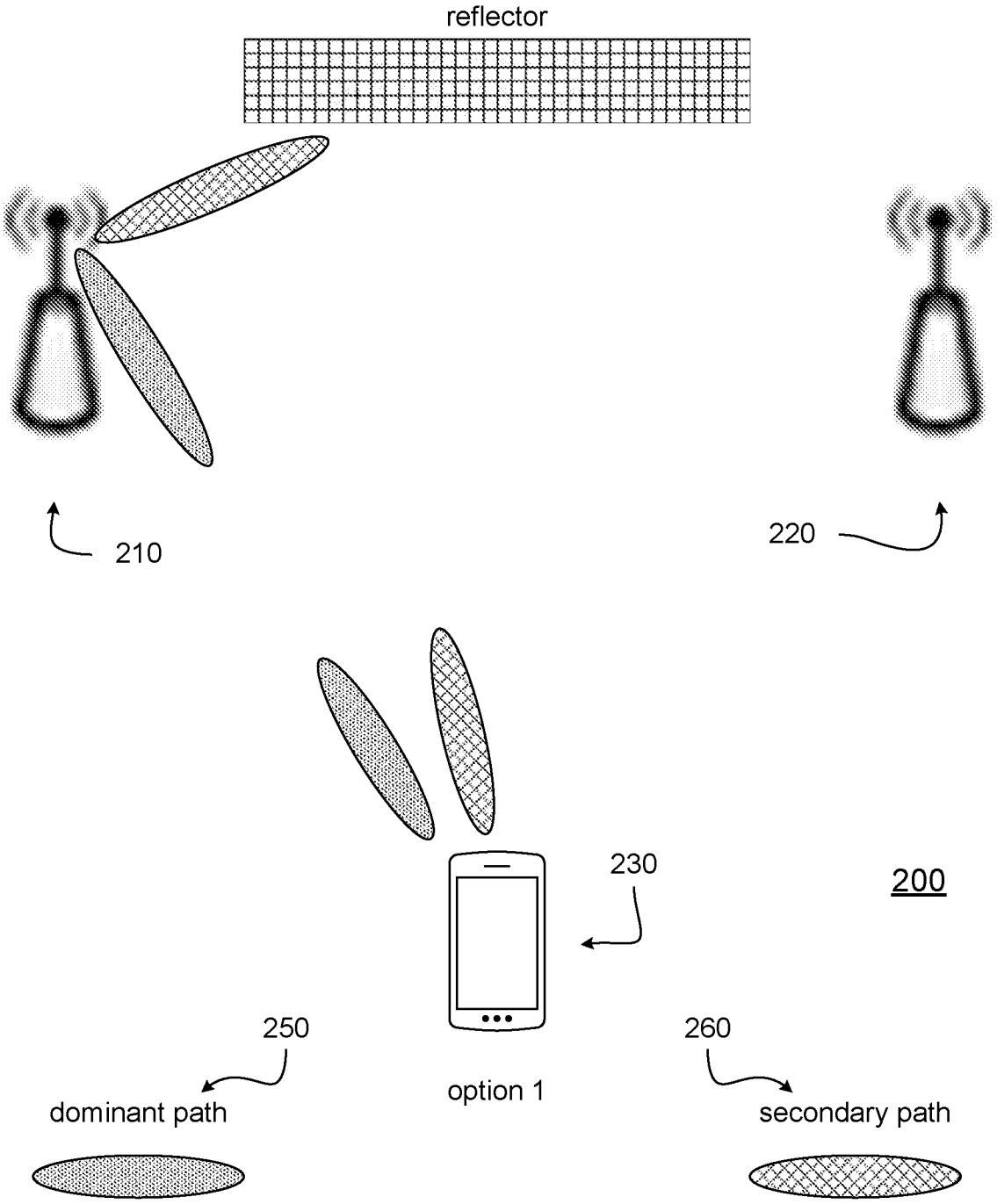

reflector
210
220
230
200
250
260
dominant path
option 1
secondary path

Fig. 2

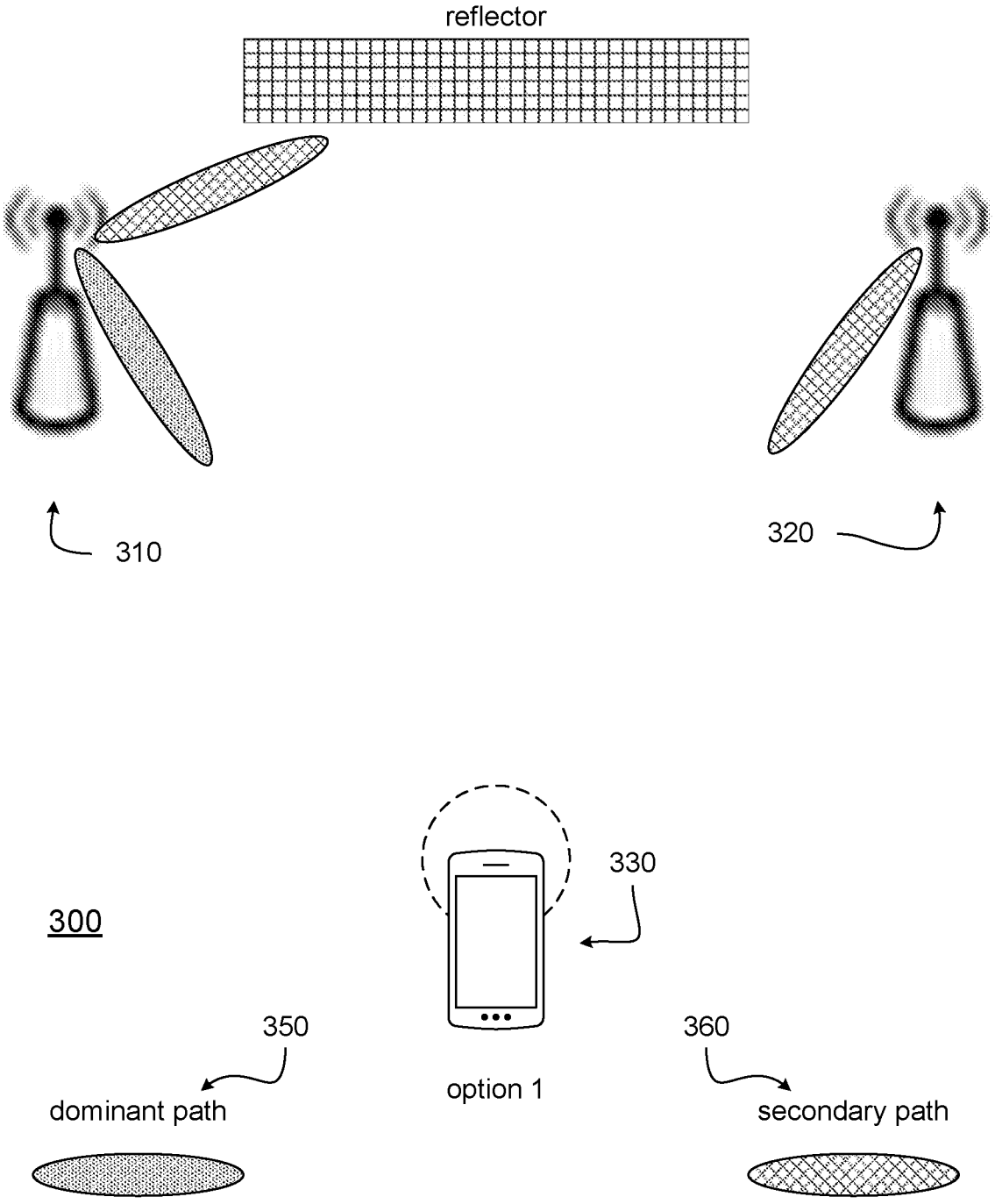

reflector
310
320
300
330
350
dominant path
option 1
360
secondary path

Fig. 3

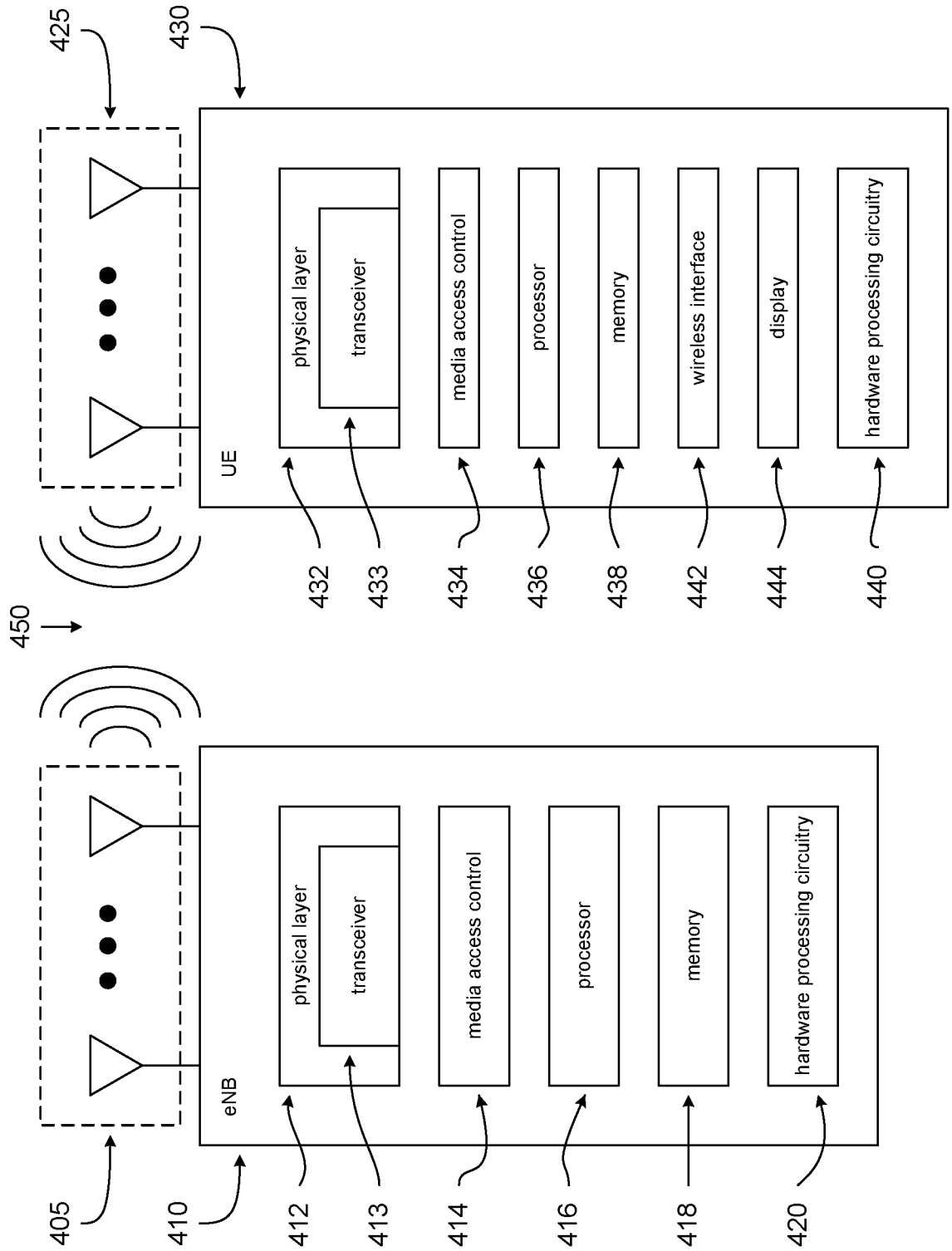

405
410
412
413
414
416
418
420
eNB
physical layer
transceiver
media access control
processor
memory
hardware processing circuitry
450
425
430
UE
physical layer
transceiver
media access control
processor
memory
wireless interface
display
hardware processing circuitry
432
433
434
436
438
442
444
440

Fig. 4

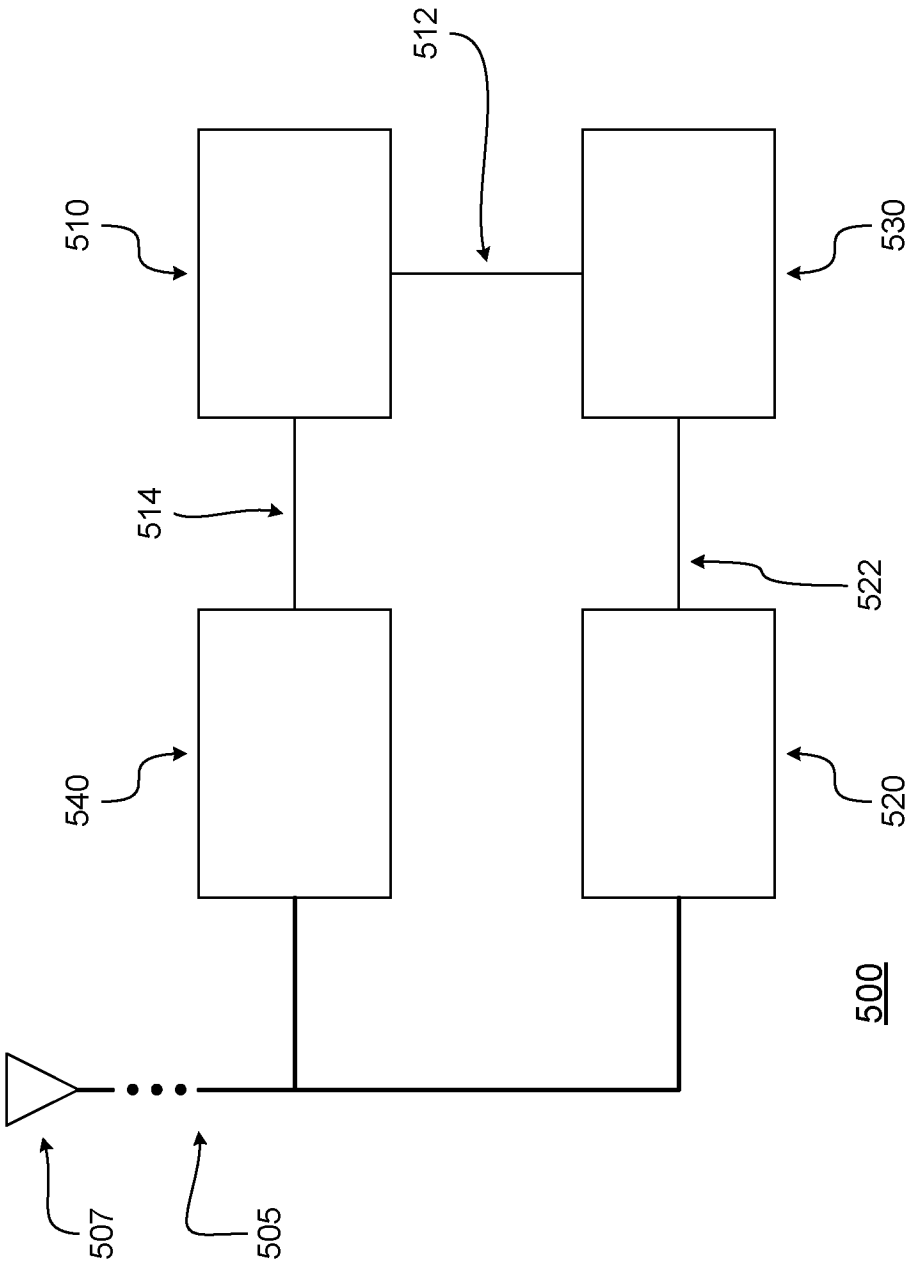


Fig. 5

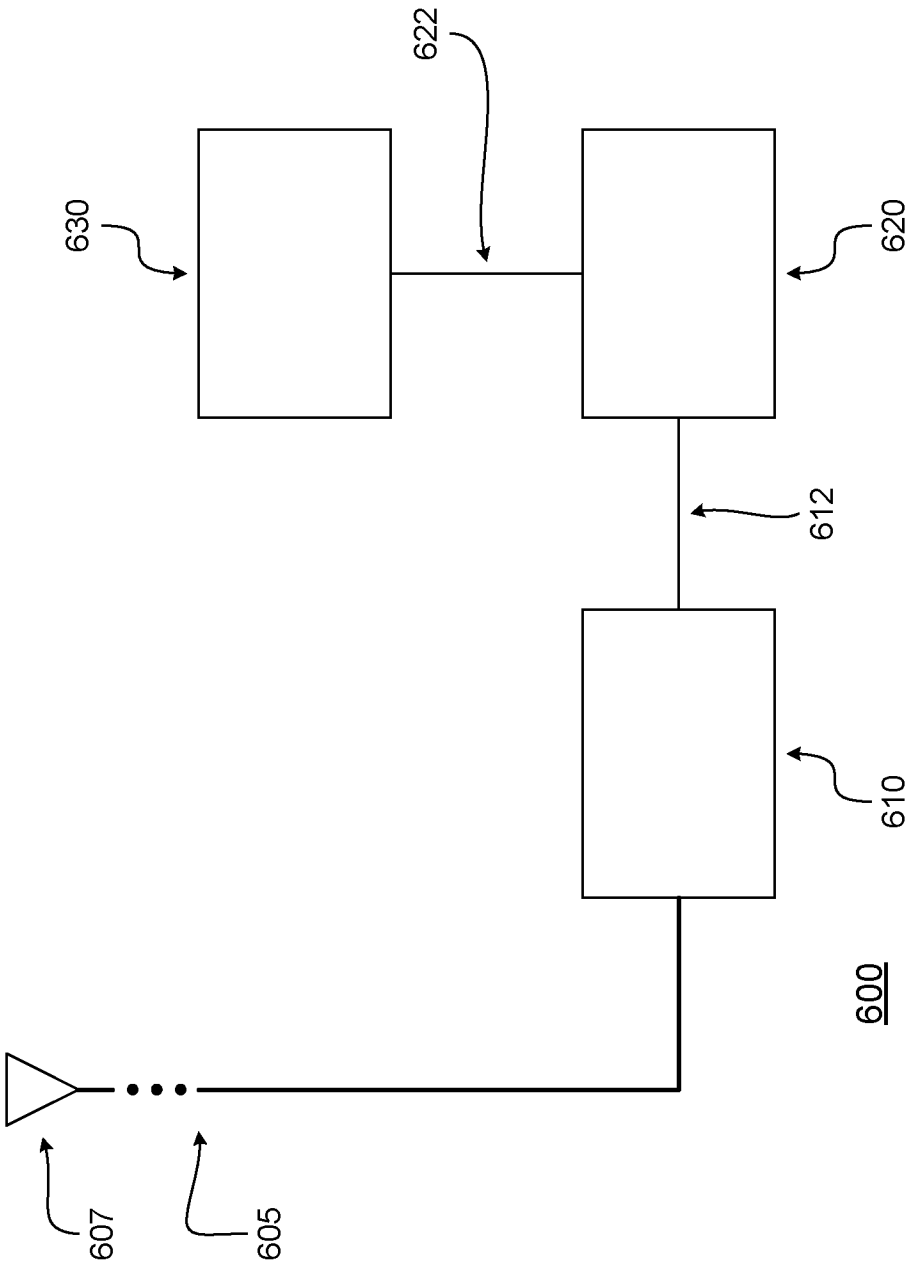


Fig. 6

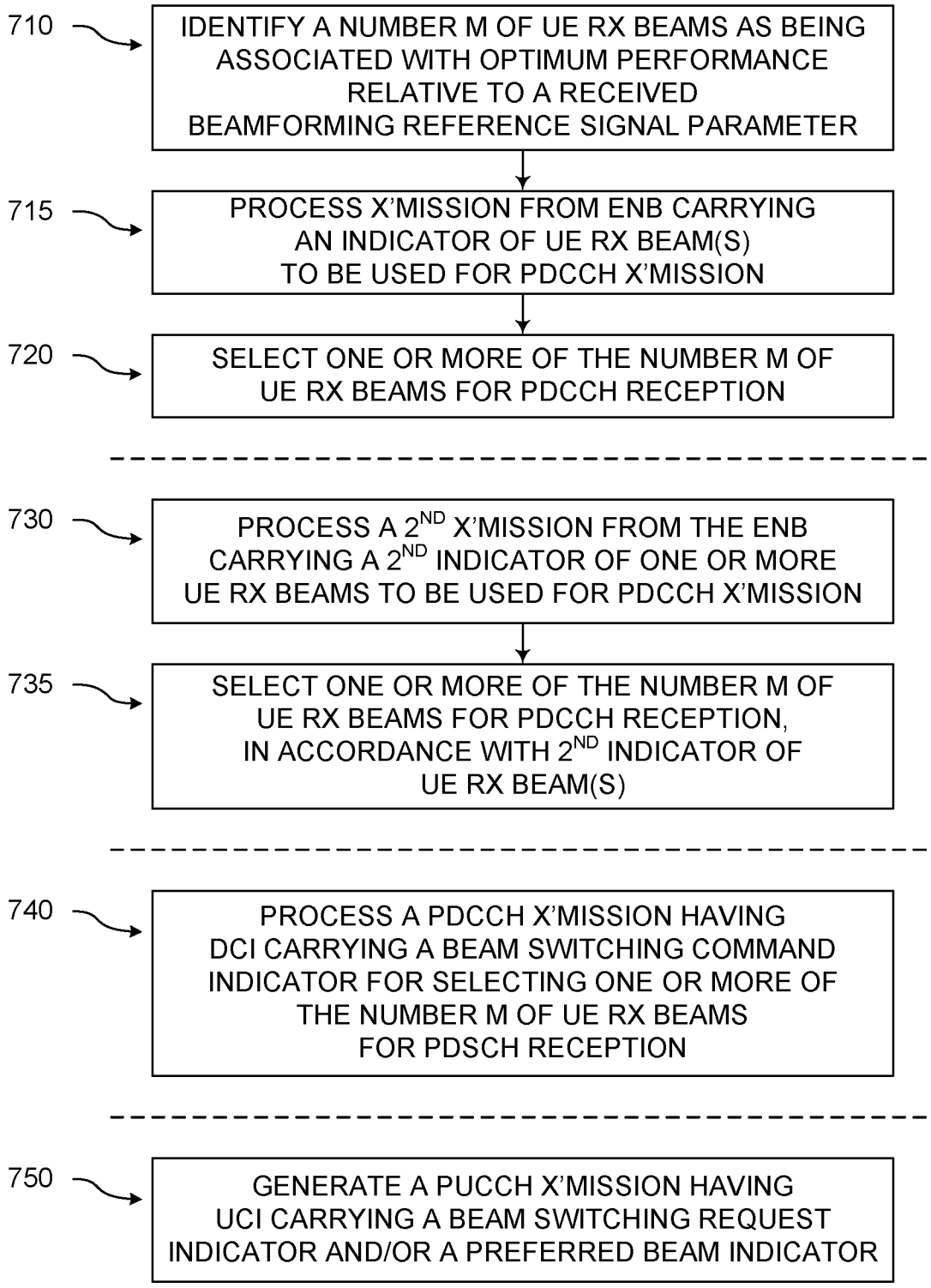

710
IDENTIFY A NUMBER M OF UE RX BEAMS AS BEING ASSOCIATED WITH OPTIMUM PERFORMANCE RELATIVE TO A RECEIVED BEAMFORMING REFERENCE SIGNAL PARAMETER
715
PROCESS X'MISSION FROM ENB CARRYING AN INDICATOR OF UE RX BEAM(S) TO BE USED FOR PDCCH X'MISSION
720
SELECT ONE OR MORE OF THE NUMBER M OF UE RX BEAMS FOR PDCCH RECEPTION
730
PROCESS A 2ND X'MISSION FROM THE ENB CARRYING A 2ND INDICATOR OF ONE OR MORE UE RX BEAMS TO BE USED FOR PDCCH X'MISSION
735
SELECT ONE OR MORE OF THE NUMBER M OF UE RX BEAMS FOR PDCCH RECEPTION, IN ACCORDANCE WITH 2ND INDICATOR OF UE RX BEAM(S)
740
PROCESS A PDCCH X'MISSION HAVING DCI CARRYING A BEAM SWITCHING COMMAND INDICATOR FOR SELECTING ONE OR MORE OF THE NUMBER M OF UE RX BEAMS FOR PDSCH RECEPTION
750
GENERATE A PUCCH X'MISSION HAVING UCI CARRYING A BEAM SWITCHING REQUEST INDICATOR AND/OR A PREFERRED BEAM INDICATOR
700

Fig. 7

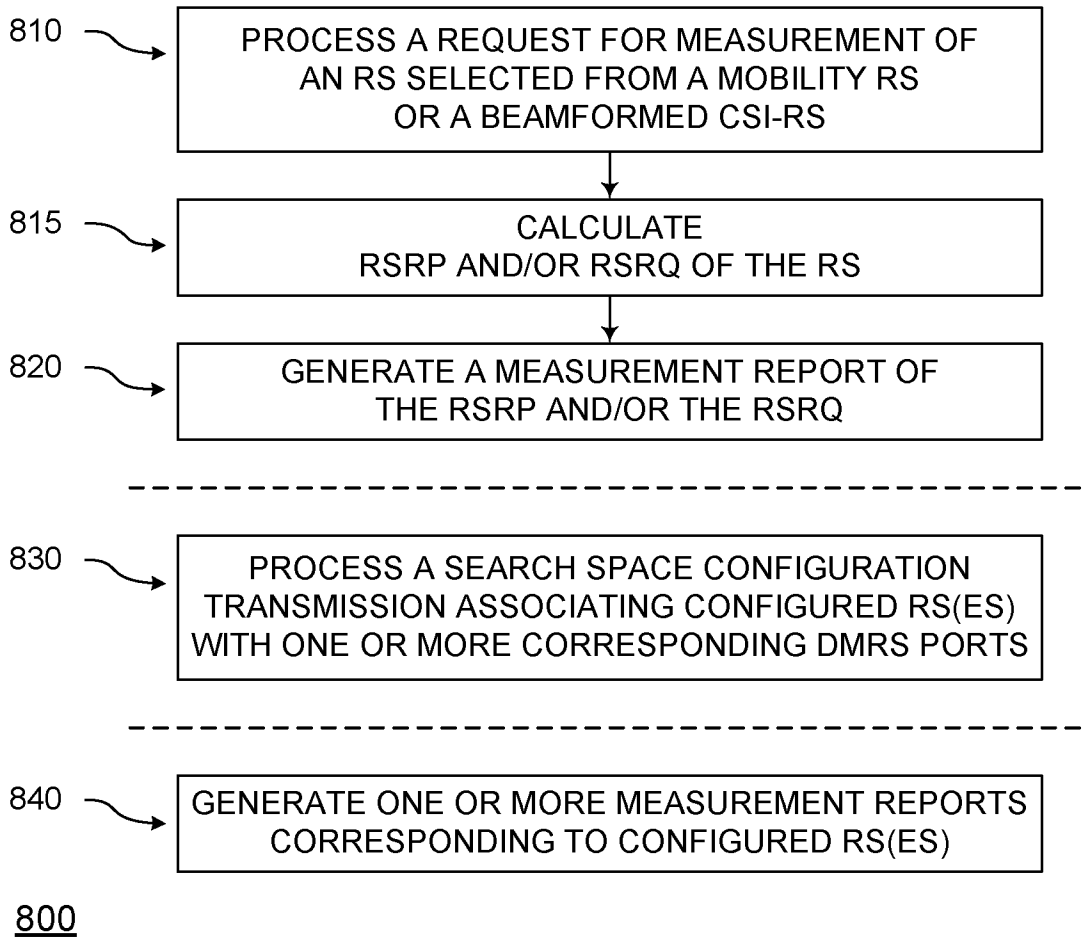

810
PROCESS A REQUEST FOR MEASUREMENT OF AN RS SELECTED FROM A MOBILITY RS OR A BEAMFORMED CSI-RS
815
CALCULATE RSRP AND/OR RSRQ OF THE RS
820
GENERATE A MEASUREMENT REPORT OF THE RSRP AND/OR THE RSRQ
830
PROCESS A SEARCH SPACE CONFIGURATION TRANSMISSION ASSOCIATING CONFIGURED RS(ES) WITH ONE OR MORE CORRESPONDING DMRS PORTS
840
GENERATE ONE OR MORE MEASUREMENT REPORTS CORRESPONDING TO CONFIGURED RS(ES)
800

Fig. 8

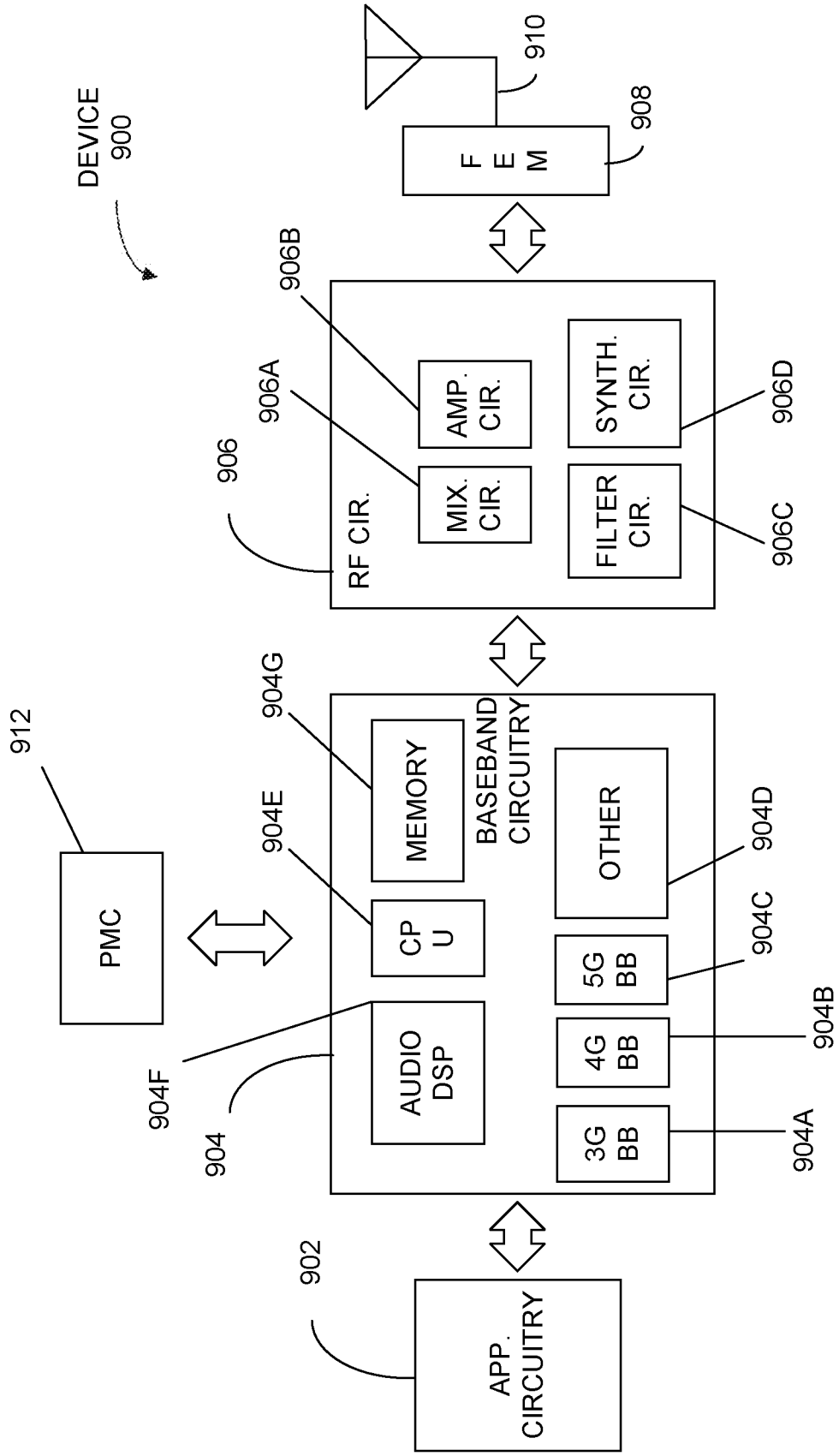

DEVICE
900
910
908
F E M
906B
906A
906
AMP. CIR.
MIX. CIR.
RF CIR.
SYNTH. CIR.
FILTER CIR.
906D
906C
904G
912
PMC
904E
MEMORY
CP U
BASEBAND CIRCUITRY
OTHER
904D
5G BB
904C
4G BB
904B
3G BB
904A
904F
AUDIO DSP
904
902
APP. CIRCUITRY

Fig. 9

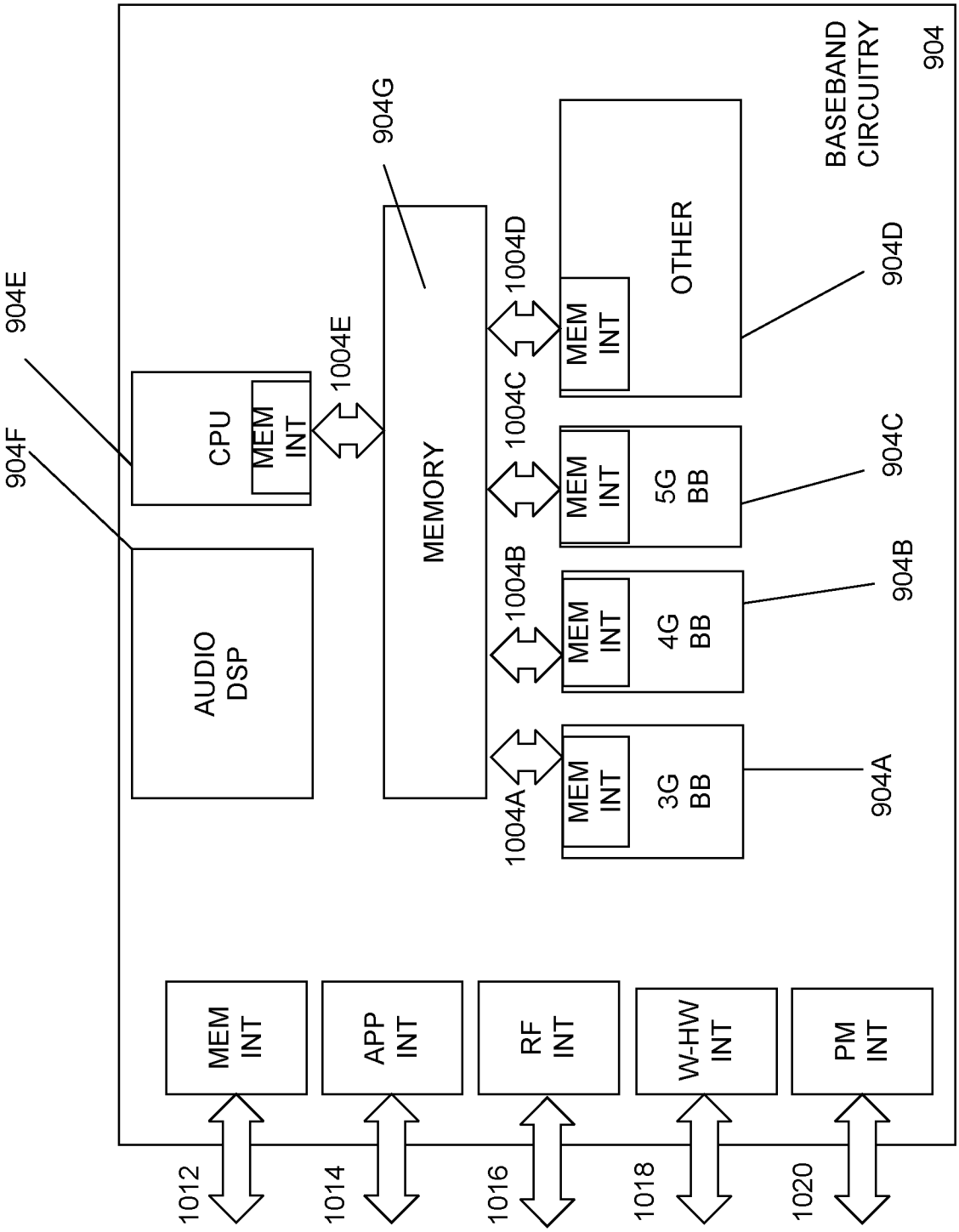

BASEBAND CIRCUITRY
904
904G
MEMORY
904E
CPU
MEM INT
1004E
904F
AUDIO DSP
1004D
OTHER
MEM INT
904D
1004C
5G BB
MEM INT
904C
1004B
4G BB
MEM INT
904B
1004A
3G BB
MEM INT
904A
MEM INT
APP INT
RF INT
W-HW INT
PM INT
1012
1014
1016
1018
1020

Fig. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/046635

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/06
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04B

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	ALCATEL: "Fast Beam Selection in Soft Handover", 3GPP DRAFT; R1-040195, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE, vol. RAN WG1, no. Malaga, Spain; 20040211, 11 February 2004 (2004-02-11), XP050098529, paragraph [2.FastBeamSelectioninSHO]; figure 1 -----	1-12

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 October 2017	02/01/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Bauer, Frédéric

1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/046635

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-12

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-12

   Claims 1-12 refer to selecting on of more beams with optimum performance using an indicator sent by an eNB and a beamforming reference signal parameter.

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2. claims: 13-24

   Claims 13-24 relate to generating a measurement report.
