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(54) Title: LTE ASSISTED PRACH TRANSMISSION IN 5G SYSTEMS

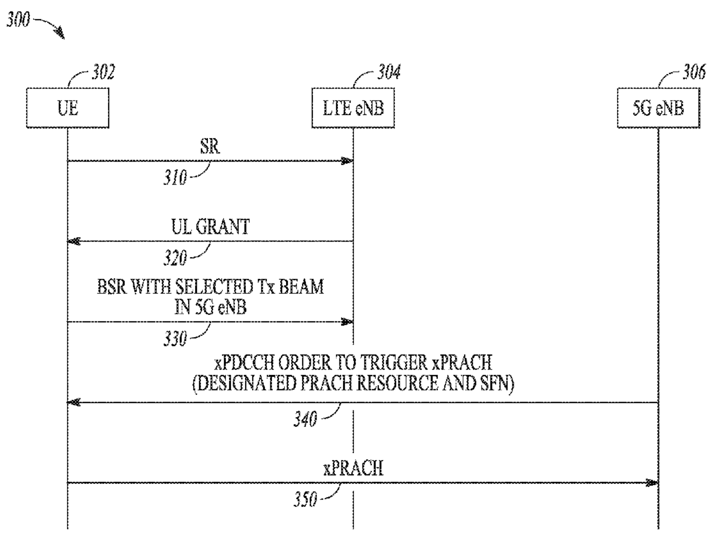

FIG. 3

(57) Abstract: Embodiments of 5G physical random access channel (xPRACH) transmission in 5G systems are generally described herein. A user equipment (UE) selects an evolved NodeB (eNB) transmit beam in a 5G eNB based on measurements of beamforming reference signals (BRS). The UE transmits a PRACH or scheduling request (SR) on a dedicated resource allocated by a long-term evolution (LTE) eNB. The UE transmits a report indicating the selected eNB transmit beam in the 5G eNB via a physical uplink shared channel (PUSCH) or physical uplink control channel (PUCCH) in the LTE eNB. The UE receives a physical downlink control channel (PDCCH) order from the LTE eNB or a 5G PDCCH (xPDCCH) order from the 5G eNB for triggering a 5G PRACH (xPRACH) transmission in the 5G eNB. The UE transmits xPRACH on a resource indicated in the received PDCCH in the LTE eNB or xPDCCH order in the 5G eNB.

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LTE ASSISTED PRACH TRANSMISSION IN 5G SYSTEMS

PRIORITY CLAIM

[0001] This application claims priority under 35 U.S.C. § 119 to United States Provisional Patent Application Serial No. 62/271,008, filed December 22, 2015, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] Embodiments pertain to wireless communications. Some embodiments relate to physical random access channel transmission and radio access network layer 1 (RAN1) in fifth generation (5G) systems.

BACKGROUND

[0003] In a cellular network, a user equipment (UE) needs to communicate with an evolved NodeB (eNB), for example, to receive control or traffic data. A physical random access channel (PRACH) is a physical contention-based uplink channel that is used for transmissions of initial access or non-real-time dedicated control or traffic data, and that has a limited-size data field.

[0004] Thus, there are general needs for systems and methods for physical random access channel transmission in a cellular network.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 is a data flow diagram of a method for initial contention based random access in a long term evolution (LTE) network in accordance with some embodiments.

[0006] FIG. 2 is a flow chart of a method, implemented at a user equipment (UE), for LTE assisted 5G physical random access channel (xPRACH) transmission in accordance with some embodiments.

[0007] FIG. 3 is a data flow diagram of a first method for LTE assisted xPRACH transmission using scheduling request (SR) in accordance with some embodiments.

[0008] FIG. 4 is a data flow diagram of a second method for LTE assisted xPRACH transmission using SR in accordance with some embodiments.

[0009] FIG. 5 is a block diagram of a subframe structure for xPRACH transmission in accordance with some embodiments.

[0010] FIG. 6 is a block diagram of an xPRACH transmission timing when a physical downlink control channel (PDCCH) order from an LTE evolved NodeB (eNB) is used in accordance with some embodiments.

[0011] FIG. 7 is a block diagram of an xPRACH transmission timing when a 5G physical downlink control channel (xPDCCH) order from a 5G eNB is used in accordance with some embodiments.

[0012] FIG. 8 is a functional diagram of a wireless network in accordance with some embodiments.

[0013] FIG. 9 illustrates components of a communication device in accordance with some embodiments.

[0014] FIG. 10 illustrates a block diagram of a communication device in accordance with some embodiments.

[0015] FIG. 11 illustrates another block diagram of a communication device in accordance with some embodiments.

DETAILED DESCRIPTION

[0016] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.

[0017] FIG. 1 is a data flow diagram of a method 100 for initial contention based random access in a LTE network. As shown in FIG. 1, a UE 102 communicates with an eNB 104.

[0018] The method 100 begins at step 110, where the UE 102 transmits physical random access channel (PRACH) in the uplink by randomly selecting one preamble signature, which allows the eNB 104 to estimate the UE 102 transmission timing.

[0019] At step 120, the eNB 104 feedbacks the random access response (RAR), which carries timing advanced (TA) command information and uplink grant for subsequent uplink transmissions by the UE (e.g., at step 130). The UE 102 expects to receive the RAR within a predefined time window. The start and end times of the predefined time window are configured by the eNB 104 via system information block (SIB).

[0020] At step 125, the UE adjusts its uplink timing based on the TA command information and the uplink grant in the received RAR. At step 130, the UE sends a layer 2/ layer 3 (L2/L3) message using the TA command information and the uplink grant in the received RAR. At step 140, in response to the L2/L3 message, the eNB sends and the UE receives a contention resolution. After step 140, the method 100 ends.

[0021] Mobile communication has evolved significantly from early voice systems to highly sophisticated integrated communication platforms available in some metropolitan areas of the United States today. Fourth generation (4G) long term evolution (LTE) networks are deployed in many countries to provide service in various spectrum band allocations depending on spectrum regime.

Some aspects of the subject technology relate to fifth generation (5G) wireless communications technology.

[0022] For mid-band (e.g., carrier frequency between 6 gigahertz (GHz) and 30 GHz) and high-band (e.g., carrier frequency beyond 30 GHz), beamforming is one key technology to improve the signal quality and reduce the inter user interference by directing the narrow radiate beaming toward the target user equipment (UE). For mid and high-band system, the path loss caused by weather like rain or fog, or object blocking, can severely deteriorate the signal strength between the evolved NodeB (eNB) and the UE, and damage the performance of the communications. Beam forming gain can fully or partially compensate this path loss, and thereby improve coverage range.

[0023] In some implementations, during initial access, the UE transmits a repeated 5G physical random access channel (xPRACH) for uplink synchronization using a selected UE receive (Rx) beam acquired during initial beam acquisition stage. The UE Rx beam may be selected based on received power or signal level at the UE. This is primarily due to the assumption of downlink and uplink reciprocity for Time Division Duplex (TDD) system. Subsequently, the eNB, in some cases, employs eNB Rx beam scanning to ensure robust reception.

[0024] In some implementations, for non-stand-alone deployment in a 5G system, an LTE eNB, a 5G eNB, or any other eNB is served as an anchor or coverage eNB and centimeter wave (cmWave) or millimeter wave (mmWave) is served as a booster eNB. With assistance from the LTE eNB, the UE may report the selected eNB transmit (Tx) beam using the LTE link between the LTE eNB and the UE. Based on this information, the eNB may apply the reported Tx beam as the Rx beam (due to downlink and uplink reciprocity) to detect the xPRACH signal. In accordance with the above, some aspects of the subject technology alleviate the need of Rx beam scanning and, thereby, simplify the design of xPRACH.

[0025] The subject technology provides, among other things, techniques for LTE assisted xPRACH transmission in 5G systems. Some aspects of the subject technology include: techniques for LTE assisted xPRACH transmission in the 5G eNB, techniques for the UE to trigger xPRACH transmission in the 5G eNB and to report eNB Tx beam information, or techniques for the eNB to inform the UE to transmit xPRACH in the 5G eNB.

[0026] FIG. 2 is a flow chart of a method 200, implemented at a UE, for LTE assisted xPRACH transmission. The UE implementing the method 200 may be the UE 102 or a different UE.

[0027] The method 200 begins at step 210, where the UE measures a beamforming reference signal (BRS) to select an eNB Tx beam (e.g., based on received power or signal level at the UE).

[0028] At step 220, for at least initial access, the UE triggers xPRACH transmission in the 5G eNB using LTE PRACH or SR in the LTE eNB.

[0029] At step 230, the UE reports the selected eNB Tx beam provided in the 5G eNB via physical uplink shared channel (PUSCH) or physical uplink control channel (PUCCH) in the LTE eNB. In some cases, the selected Tx beam is represented in a form of a unique identifier that correlates the selected Tx beam with a transmission point known to the LTE eNB and the 5G eNB.

[0030] At step 240, the UE receives a physical downlink control channel (PDCCH) order from the LTE eNB or a 5G PDCCH (xPDCCH) order from the 5G eNB for triggering xPRACH transmission in the 5G eNB.

[0031] At step 250, the UE transmits xPRACH on a designated resource (e.g., preamble and time/frequency resource). In some cases, the resource is indicated in the PDCCH or xPDCCH order in the 5G eNB. According to some implementations, the xPRACH resource includes at least an xPRACH preamble and an allocated time and frequency resource. After step 250, the method 200 ends.

[0032] In accordance with the method 200, in some cases, system information (e.g., BRS transmit power and xPRACH configuration for 5G eNB) is signaled to the UE via radio resource control (RRC) signaling in the LTE cell. For initial access, according to some embodiments, an additional step is used to signal the 5G eNB system information from the LTE eNB to the UE.

[0033] FIG. 3 is a data flow diagram of a first method 300 for LTE assisted xPRACH transmission using scheduling request (SR). As shown, the process 300 involves a UE 302, an LTE eNB 304, and a 5G eNB 306. While the LTE eNB 304 and the 5G eNB 306 are illustrated as residing on different machines, the LTE eNB 304 and the 5G eNB 306 reside on the same machine according to some embodiments.

[0034] As shown in FIG. 3, the process 300 begins at step 310, when the UE 302 uses SR to trigger the LTE eNB 304 to provide an uplink (UL) grant and to trigger the xPRACH transmission in the 5G eNB 306. At step 320, the LTE eNB 304 provides the UL grant to the UE 302. At step 330, the UE 302 reports, to the LTE eNB 304, the selected eNB Tx beam together with a buffer status report (BSR) via PUSCH or medium access control (MAC) protocol data unit (PDU). At step 340, the 5G eNB 306, which may be at the same machine as the LTE eNB 304, uses xPDCCH in order to trigger xPRACH transmission at the 5G eNB 306. The xPRACH transmission includes, in some cases, a designated xPRACH resource and/or a system frame number (SFN), if the 5G eNB 306 is already RRC configured at the UE 302. Otherwise, before sending the xPDCCH order, the UE 302 is RRC configured with the 5G eNB 306. SFN may be acquired from the LTE eNB 304 if the 5G eNB 306 is SFN aligned with the LTE eNB. Upon successful decoding of the xPDCCH order, the UE 302 can transmit an xPRACH on the designated resource on the 5G eNB 306, as shown in step 350. After step 350, the method 300 ends.

[0035] In some cases, in order to reduce latency of SR and uplink transmission, low latency uplink transmission is used. In some aspects, SR is combined with BSR and information for the selected eNB Tx beam in the 5G eNB in step 310 of FIG. 3. The uplink transmission may then be contention based or use a dedicated resource allocated by the LTE eNB 304 for contention-free transmission.

[0036] FIG. 4 is a data flow diagram of a second method 400 for LTE assisted xPRACH transmission using SR. The method 400 is implemented with the UE 302, the LTE eNB 304, and the 5G eNB 306.

[0037] The method 400 begins at step 410, where the UE 302 transmits, to the LTE eNB 304, SR together with BSR and the selected eNB Tx beam in the 5G eNB. Step 420 corresponds to step 340 of FIG. 3, where the 5G eNB 306 uses xPDCCH in order to trigger xPRACH transmission at the 5G eNB 306. The xPRACH transmission includes, in some cases, a designated xPRACH resource and/or a system frame number (SFN), if the 5G eNB 306 is already RRC configured at the UE 302. Otherwise, before sending the xPDCCH order, the UE 302 is RRC configured with the 5G eNB 306. SFN may be acquired from the LTE eNB 304 if the 5G eNB 306 is SFN aligned with the LTE eNB. Upon successful decoding of the xPDCCH order, the UE 302 can transmit an xPRACH on the designated resource on the 5G eNB 306, as shown in step 430, which corresponds to step 350 of FIG. 3. After step 430, the method 400 ends.

[0038] According to one example, the UE 302 performs measurements (e.g., finds beams) on the 5G carrier and, when the UE 302 finds a beam that satisfies a measurement criterion, the UE 302 triggers a measurement report of the beam. Since the UE 302 has no uplink timing alignment on the 5G carrier, the UE 302 sends the measurement report of the beam through an uplink which is time-aligned (e.g., via the uplink on the LTE eNB 304 for which UE's timing advance timer is not expired). The LTE eNB 304 then exchanges the measurement report of the beam/UE information with the 5G eNB 306. The 5G eNB 306 takes the beam information into account to schedule downlink control and data on the 5G carrier to the UE 302. (Assuming that the UE 302 already has 5G system information such as xPDCCH configuration, etc.). In a first step, the 5G eNB 306 sends an order to the UE 302 on the xPDCCH to transmit a random access preamble on the 5G carrier in designed time/frequency resources. The 5G eNB 306 then estimates the timing advance information and then sends the timing advanced (TA) command to the UE for adjusting its uplink timing on the 5G carrier.

[0039] If the 5G eNB 306 has downlink data to transmit to the UE 302, it uses the downlink of the LTE eNB 304 or it determines (based on existing measurements or requesting a new report) the selected beam and sends an xPDCCH order to the UE 302 to send xPRACH on the 5G carrier.

[0040] If the UE 302 has uplink data to transmit to the network, the UE 302 can use the uplink of the LTE eNB 304. If the 5G eNB 306 already has the selected beam information from the UE 302, then the 5G eNB 306 sends an xPDCCH order and the UE 302 can send xPRACH to become uplink time-aligned on the 5G carrier and use 5G to transmit uplink data. The UE 302 measures and sends measurement reports about the best beam (via LTE uplink), and then the 5G eNB 306 sends an xPDCCH order and the UE 302 becomes time-aligned (via xPRACH) and uses 5G to transmit uplink data.

[0041] According to some examples, dedicated resources can be configured on LTE uplink for a UE 302 to use for indicating 5G-related information to the LTE eNB 304. For example, the UE 302 uses the dedicated resources to indicate to the LTE eNB 304 that it has found a new beam that satisfies some measurement criterion or to indicate a beam is now as effective as previously, or to indicate to the LTE eNB 304 that it has uplink data that it wishes to transfer on 5G carrier (so that the LTE eNB 304 configures 5G measurement/ reporting).

[0042] The UE 302 in RRC_CONNECTED mode with an LTE PCell (e.g., LTE eNB 304) performs inter-radio access technology (RAT) measurements according to a measurement configuration provided by the LTE PCell. The UE 302 may be configured with such a measurement configuration for the 5G. The UE may report inter-RAT radio resource management (RRM) measurements according to the specified measurement configuration for the 5G. In one example, the BRS report is sent to the LTE PCell as part of an RRM measurement reporting event.

[0043] Techniques for the UE 302 to trigger xPRACH transmission in the 5G eNB 306, for example, as discussed in step 220 of FIG. 2, are discussed below.

[0044] According to one embodiment, PRACH in the LTE eNB 304 can be used to trigger xPRACH transmission in the 5G eNB 306. In particular, dedicated PRACH resources in LTE eNB 304 can be reserved for this purpose. Upon successful detection of PRACH on the dedicated resource, eNB can inform UE to transmit the xPRACH in 5G cell on a designated resource.

[0045] The PRACH resource for normal communication and for triggering xPRACH transmission in the 5G eNB 306 may be multiplexed in a time division multiplexing (TDM), frequency division multiplexing (FDM) and/or code division multiplexing (CDM) manner or a combination of the above options. In one option, one or a plurality of signatures can be reserved for LTE PRACH to trigger xPRACH transmission in the 5G eNB 306. In another option, one or more frequency resources can be allocated for LTE PRACH to trigger xPRACH transmission in the 5G eNB 306.

[0046] In another option, one or more time resources can be allocated for LTE PRACH to trigger xPRACH transmission in the 5G eNB 306. For instance, PRACH for normal application can be transmitted in subframe 0, 2, 4, 6, 8 within one frame while PRACH used to trigger xPRACH transmission in the 5G eNB 306 can be transmitted in subframe 1, 3, 5, 7, 9.

[0047] In yet another option, a combination of TDM and/or FDM and/or CDM based multiplexed schemes can be used to separate the resource for normal and triggering xPRACH transmission in the 5G eNB.

[0048] According to another embodiment, SR can be used to trigger xPRACH transmission in the 5G eNB 306. In particular, dedicated SR resource can be configured by the 5G eNB 306 or the LTE eNB 304 via UE-dedicated Radio Resource Control (RRC) signaling. When the UE intends to transmit the xPRACH in the 5G eNB 306, it can use the dedicated SR for SR transmission. After successful detection of the SR on the dedicated SR resource, the 5G eNB 306 may trigger the xPRACH transmission using PDCCH order in LTE eNB 304 or xPDCCH order in the 5G eNB 306.

[0049] According to another embodiment, a new Logical Channel ID in the Medium Access Control (MAC) layer may be defined in LTE for UE to trigger xPRACH transmission in 5G cell. Further, corresponding MAC control element which may include the selected (by the UE 302) Tx beam report in 5G cell may be defined. This MAC control element may be transmitted in msg3 in the LTE RACH procedure or transmitted together with buffer status report (BSR) for uplink data transmission triggered by SR. For both cases, using dedicated resource on PRACH and SR can be avoided for triggering xPRACH transmission in 5G cell.

[0050] As set forth above, the UE 302 may report the best eNB Tx beam to facilitate eNB to detect the xPRACH signal enabling to avoid Rx beam scanning. The best eNB Tx beam can be acquired in the 5G eNB 306 during an initial beam acquisition stage by exploiting beamforming reference signal (BRS). The report may be transmitted in a MAC control element as mentioned above, or may be transmitted together with data via physical uplink shared channel (PUSCH) in LTE anchor cell. In the latter case, it could incur PUSCH transmission latency in the LTE cell. In this case, the selected eNB Tx beam may be changed during this time period.

[0051] In another embodiment, the report for the selected eNB Tx beam may be transmitted as part of a regular inter-RAT measurement procedure. In a first step, the LTE eNB 304 transmits to the UE a measurement configuration for the 5G. The UE 302 then performs BRS measurements according to this configuration. Based on the reporting criteria configured in the UE 302 by the eNB for the 5G, the UE 302 reports these BRS measurements to the LTE cell using, e.g., the RRC protocol. If a suitable 5G eNB 306 is identified, the LTE eNB 304 then configures the UE 302, for example, via RRC for a subsequent UE xPRACH transmission in the 5G RAT. This xPRACH may be contention-based or contention-free. In the latter case, the LTE eNB 304 can trigger the xPRACH by a PDCCH order as described herein.

[0052] In another embodiment, the report for the selected eNB beam may be transmitted in the physical uplink control channel (PUCCH) in the LTE eNB 304. This may be beneficial in cases when the information size for the selected Tx beam report is limited. A new PUCCH format for carrying this report can be defined or PUCCH format 2 can be used for this purpose. Resource and/or timing for this PUCCH based report can be pre-configured via RRC signaling or dynamically scheduled by a PDCCH order.

[0053] In another embodiment, when the UE 302 is RRC-connected with active UL allocations, the UE can piggyback the xPRACH triggering information, together with the BRS report in LTE PUSCH transmission.

[0054] In another embodiment, if the UE 302 supports the Rel-14 low latency feature with shortened transmission time interval (TTI), the xPRACH triggering information, together with best beam, or BRS report can go through the low latency TTI to reduce the delay.

[0055] Techniques for an LTE eNB or a 5G eNB to trigger the UE to transmit xPRACH in the 5G eNB, as used, for example, in conjunction with step 240 of FIG. 2, are discussed below.

[0056] For contention-free xPRACH transmission, the LTE eNB 304 or the 5G eNB 306 may allocate a designated xPRACH resource to the UE 302 using either PDCCH order in the LTE eNB 304 or xPDCCH order in the 5G eNB 306. The xPRACH resource may include time and frequency resource used for the xPRACH transmission and an xPRACH preamble signature.

[0057] Upon successful decoding of PDCCH or xPDCCH, the UE 302 can transmit the xPRACH on the designated resource. Further, system frame number (SFN) of the 5G eNB 306 may be indicated in a DCI via PDCCH from the LTE eNB 304 or xPDCCH from the 5G eNB 306.

[0058] FIG. 5 is a block diagram of a subframe structure 500 for xPRACH transmission. As shown, the subframe structure 500 can include an xPDCCH block 510, guard period (GP) blocks 520 and 550, xPUSCH blocks 530 and 560, a cyclic prefix (CP) and xPRACH preamble 540, and xPUCCH block 570.

[0059] The subframe structure 500 for the xPRACH transmission can be based on a self-contained subframe structure, where the xPDCCH block 510 can be transmitted at the beginning of the subframe and xPUCCH block 570 can be transmitted at the last part of the subframe.

[0060] As shown in FIG. 5, a GP 520 can be inserted after xPDCCH 510 in order to accommodate the downlink (DL) to uplink (UL) and UL to DL switching time and round-trip propagation delay. Further, xPUSCH blocks 530 and 560 and the xPRACH block 530 can be multiplexed in a frequency-division (FDM) manner. An additional GP block 550 may be inserted after the xPRACH block 540 to avoid collision between the xPRACH block 540 and xPUCCH block 570 transmissions. Note that a repeated xPRACH transmission may be needed to allow the eNB to train the eNB Rx beam, for example, in cases when DL/UL reciprocity may not be guaranteed.

[0061] In another embodiment, the xPRACH block 540 can be time-division multiplexed (TDM) with xPUSCH blocks 530 and 560. In the case of eNB needing to train the eNB Rx beam, the TDM approach does not sacrifice the xPUSCH receiving beamforming gain.

[0062] Examples to signal the frequency resource for the xPRACH transmission and xPRACH preamble signature are provided below.

[0063] In one example, the frequency resource of xPRACH transmission and xPRACH preamble signature are predefined or configured semi-statically by the higher layers via UE specific or cell specific RRC signaling from LTE primary cell or indicated via 5G master information block (xMIB), 5G system information block (xSIB) and/or UE specific RRC signaling from 5G cell. For instance, the frequency resource is configured in the xSIB while xPRACH preamble signature is configured by high layer signaling, for example, RRC signaling.

[0064] In another example, the frequency resource of xPRACH transmission and xPRACH preamble signature can be dynamically indicated in a DCI via PDCCH from the LTE eNB or xPDCCH from the 5G eNB. In one example, xPRACH preamble signature may be indicated in the DCI format used for contention free random access.

[0065] As mentioned above, other xPRACH configurations (similar to the PRACH configuration as defined in LTE), for instance, xPRACH root sequence index, initial received target power, power ramping level can be configured semi-statically by the higher layers via RRC signaling from LTE primary cell.

[0066] Several implementations for the transmission timing of xPRACH transmission are provided below.

[0067] In one implementation, when the PDCCH order from LTE cell is used to trigger the transmission, xPRACH transmission timing is aligned with a next available subframe which can be used for the 5G primary synchronization signal (xPSS) and/or the 5G secondary synchronization signal (xSSS) in the 5G eNB.

[0068] FIG. 6 is a block diagram of an xPRACH transmission timing when a physical downlink control channel (PDCCH) order from an LTE evolved NodeB (eNB) is used to trigger the xPRACH transmission. In this example, PDCCH order in the LTE eNB is used to schedule the xPRACH transmission in the 5G cell. Further, xPRACH transmission is aligned with xPSS/xSSS subframe and the gap between xPSS/xSSS and xPRACH is seven subframes (subframe 5 through subframe 12) in the 5G cell. The frame boundary for the LTE eNB and the 5G eNB may or may not be aligned depending on deployment scenarios and operation modes. For example, in a carrier aggregation scenario where the 5G cell is configured as a secondary cell of an LTE primary cell, the network may provide some level of alignment between the two cells.

[0069] In another implementation, in the case when the xPDCCH order from the 5G eNB is used to trigger the xPRACH transmission, the xPRACH transmission timing can be aligned with the subframe allocated for the transmission of the xPDCCH order.

[0070] FIG. 7 is a block diagram of an xPRACH transmission timing when a 5G physical downlink control channel (xPDCCH) order from a 5G eNB is used. In this example, the xPDCCH order in the 5G eNB can be used to trigger the xPRACH transmission in the 5G eNB. Further, the gap between xPDCCH order and xPRACH transmission is seven subframes (between subframe 5 and subframe 12). However, a gap of a length different from seven subframes may be used.

[0071] Implementations to indicate the aforementioned gap are discussed below.

[0072] In one implementation, a fixed gap can be defined between the subframes used for transmission of xPSS/xSSS or xPDCCH order and xPRACH transmission. Alternatively, the gap can be explicitly signaled in a DCI format to allow dynamic scheduling of the xPRACH transmission.

[0073] In another implementation, a fixed gap may be defined and additional delay can be signaled in the downlink control information (DCI) format to allow certain flexibility. For instance, a fixed gap of five subframes is defined, and a one bit field in the DCI format may indicate whether an additional subframe delay is applied on the transmission of xPRACH.

[0074] FIG. 8 shows an example of a portion of an end-to-end network architecture of a Long Term Evolution (LTE) network 800 with various components of the network in accordance with some embodiments. As used herein, an LTE network refers to both LTE and LTE Advanced (LTE-A) networks as well as other versions of LTE networks to be developed. The network 800 may comprise a radio access network (RAN) (e.g., as depicted, the E-UTRAN or evolved universal terrestrial radio access network) 801 and core network 820 (e.g., shown as an evolved packet core (EPC)) coupled together through an S1 interface 815. For convenience and brevity, only a portion of the core network 820, as well as the RAN 801, is shown in the example. The network 800 includes the UE 802, which is configured to select an eNB Tx beam in a 5G eNB based on BRS measurements; transmit a PRACH or SR on a dedicated resource allocated by a LTE eNB; transmit a report indicating the selected eNB Tx beam in the 5G eNB via a PUSCH or PUCCH in the LTE eNB; receive a PDCCH order from the LTE eNB or a xPDCCH order from the 5G eNB for triggering a xPRACH transmission in the 5G eNB; and transmit xPRACH on a resource indicated in the received PDCCH or xPDCCH order in the 5G eNB.

[0075] The core network 820 may include a mobility management entity (MME) 822, serving gateway (serving GW) 824, and packet data network gateway (PDN GW) 826. The RAN 801 may include evolved node Bs (eNBs) 804 (which may operate as base stations) for communicating with user equipment (UE) 802. The eNBs 804 may include macro eNBs 804a and low power (LP) eNBs 804b. The UEs 802 may correspond to the UE 102 or the UE 302. The eNBs 804 may correspond to the eNB 104, the LTE eNB 304, or the 5G eMB 306.

[0076] The MME 822 may be similar in function to the control plane of legacy Serving GPRS Support Nodes (SGSN). The MME 822 may manage mobility aspects in access such as gateway selection and tracking area list management. The serving GW 824 may terminate the interface toward the RAN 801, and route data packets between the RAN 801 and the core network 820. In addition, the serving GW 824 may be a local mobility anchor point for inter-eNB handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement. The serving GW 824 and the MME 822 may be implemented in one physical node or separate physical nodes.

[0077] The PDN GW 826 may terminate a SGi interface toward the packet data network (PDN). The PDN GW 826 may route data packets between the EPC 820 and the external PDN, and may perform policy enforcement and charging data collection. The PDN GW 826 may also provide an anchor point for mobility devices with non-LTE access. The external PDN can be any kind of IP network, as well as an IP Multimedia Subsystem (IMS) domain. The PDN

GW 826 and the serving GW 824 may be implemented in a single physical node or separate physical nodes.

[0078] The eNBs 804 (macro and micro) may terminate the air interface protocol and may be the first point of contact for a UE 802. In some embodiments, an eNB 804 may fulfill various logical functions for the RAN 801 including, but not limited to, RNC (radio network controller functions) such as radio bearer management, uplink and downlink dynamic radio resource management and data packet scheduling, and mobility management. In accordance with embodiments, UEs 802 may be configured to communicate orthogonal frequency division multiplexed (OFDM) communication signals with an eNB 804 over a multicarrier communication channel in accordance with an OFDMA communication technique. The OFDM signals may comprise a plurality of orthogonal subcarriers.

[0079] The S1 interface 815 may be the interface that separates the RAN 801 and the EPC 820. It may be split into two parts: the S1-U, which may carry traffic data between the eNBs 804 and the serving GW 824, and the S1-MME, which may be a signaling interface between the eNBs 804 and the MME 822. The X2 interface may be the interface between eNBs 804. The X2 interface may comprise two parts, the X2-C and X2-U. The X2-C may be the control plane interface between the eNBs 804, while the X2-U may be the user plane interface between the eNBs 804.

[0080] With cellular networks, LP cells 804b may be typically used to extend coverage to indoor areas where outdoor signals do not reach well, or to add network capacity in areas with dense usage. In particular, it may be desirable to enhance the coverage of a wireless communication system using cells of different sizes, macrocells, microcells, picocells, and femtocells, to boost system performance. The cells of different sizes may operate on the same frequency band, or may operate on different frequency bands with each cell operating in a different frequency band or only cells of different sizes operating on different frequency bands. As used herein, the term LP eNB refers to any suitable relatively LP eNB for implementing a smaller cell (smaller than a macro cell) such as a femtocell, a picocell, or a microcell. Femtocell eNBs may be typically provided by a mobile network operator to its residential or enterprise customers.

A femtocell may be typically the size of a residential gateway or smaller and generally connect to a broadband line. The femtocell may connect to the mobile operator's mobile network and provide extra coverage in a range of typically 30 to 50 meters. Thus, a LP eNB 804b might be a femtocell eNB since it is coupled through the PDN GW 826. Similarly, a picocell may be a wireless communication system typically covering a small area, such as in-building (offices, shopping malls, train stations, etc.), or more recently in-aircraft. A picocell eNB may generally connect through the X2 link to another eNB such as a macro eNB through its base station controller (BSC) functionality. Thus, LP eNB may be implemented with a picocell eNB since it may be coupled to a macro eNB 804a via an X2 interface. Picocell eNBs or other LP eNBs LP eNB 804b may incorporate some or all functionality of a macro eNB LP eNB 804a. In some cases, this may be referred to as an access point base station or enterprise femtocell.

[0081] In some embodiments, the UE 802 may communicate with an access point (AP) 804c. The AP 804c may use only the unlicensed spectrum (e.g., WiFi bands) to communicate with the UE 802. The AP 804c may communicate with the macro eNB 804A (or LP eNB 804B) through an Xw interface. In some embodiments, the AP 804c may communicate with the UE 802 independent of communication between the UE 802 and the macro eNB 804A. In other embodiments, the AP 804c may be controlled by the macro eNB 804A and use LWA, as described in more detail below.

[0082] Communication over an LTE network may be split up into 10ms frames, each of which may contain ten 1ms subframes. Each subframe of the frame, in turn, may contain two slots of 0.5ms. Each subframe may be used for uplink (UL) communications from the UE to the eNB or downlink (DL) communications from the eNB to the UE. In one embodiment, the eNB may allocate a greater number of DL communications than UL communications in a particular frame. The eNB may schedule transmissions over a variety of frequency bands (f_1 and f_2). The allocation of resources in subframes used in one frequency band and may differ from those in another frequency band. Each slot of the subframe may contain 6-7 OFDM symbols, depending on the system used. In one embodiment, the subframe may contain 12 subcarriers. A downlink resource grid may be used for downlink transmissions from an eNB to a UE, while an uplink resource grid may be used for uplink transmissions from a UE to an eNB or from a UE to another UE. The resource grid may be a time-frequency grid, which is the physical resource in the downlink in each slot. The smallest time-frequency unit in a resource grid may be denoted as a resource element (RE). Each column and each row of the resource grid may correspond to one OFDM symbol and one OFDM subcarrier, respectively. The resource grid may contain resource blocks (RBs) that describe the mapping of physical channels to resource elements and physical RBs (PRBs). A PRB may be the smallest unit of resources that can be allocated to a UE. A resource block may be 180 kHz wide in frequency and 1 slot long in time. In frequency, resource blocks may be either 12 x 15 kHz subcarriers or 24 x 7.5 kHz subcarriers wide. For most channels and signals, 12 subcarriers may be used per resource block, dependent on the system bandwidth. In Frequency Division Duplexed (FDD) mode, both the uplink and downlink frames may be 10ms and frequency (full-duplex) or time (half-duplex) separated. In Time Division Duplexed (TDD), the uplink and downlink subframes may be transmitted on the same frequency and are multiplexed in the time domain. The duration of the resource grid 400 in the time domain corresponds to one subframe or two resource blocks. Each resource grid may comprise 12 (subcarriers) *14 (symbols) =168 resource elements.

[0083] Each OFDM symbol may contain a cyclic prefix (CP) which may be used to effectively eliminate Inter Symbol Interference (ISI), and a Fast Fourier Transform (FFT) period. The duration of the CP may be determined by the highest anticipated degree of delay spread. Although distortion from the preceding OFDM symbol may exist within the CP, with a CP of sufficient duration, preceding OFDM symbols do not enter the FFT period. Once the FFT period signal is received and digitized, the receiver may ignore the signal in the CP.

[0084] There may be several different physical downlink channels that are conveyed using such resource blocks, including the physical downlink control channel (PDCCH) and the physical downlink shared channel (PDSCH). Each subframe may be partitioned into the PDCCH and the PDSCH. The PDCCH may normally occupy the first two symbols of each subframe and carries, among other things, information about the transport format and resource allocations related to the PDSCH channel, as well as H-ARQ information related to the uplink shared channel. The PDSCH may carry user data and higher layer signaling to a UE and occupy the remainder of the subframe. Typically, downlink scheduling (assigning control and shared channel resource blocks to UEs within a cell) may be performed at the eNB based on channel quality information provided from the UEs to the eNB, and then the downlink resource assignment information may be sent to each UE on the PDCCH used for (assigned to) the UE. The PDCCH may contain downlink control information (DCI) in one of a number of formats that indicate to the UE how to find and decode data, transmitted on PDSCH in the same subframe, from the resource grid. The DCI format may provide details such as number of resource blocks, resource allocation type, modulation scheme, transport block, redundancy version, coding rate etc. Each DCI format may have a cyclic redundancy code (CRC) and be scrambled with a Radio Network Temporary Identifier (RNTI) that identifies the target UE for which the PDSCH is intended. Use of the UE-specific RNTI may limit decoding of the DCI format (and hence the corresponding PDSCH) to only the intended UE.

[0085] Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. FIG. 9 illustrates components of a UE in accordance with some embodiments. At least some of the components shown may be used in an eNB or MME, for example, such as the UE 802 or eNB 804 shown in FIG. 8, the UE 102 or eNB 104 of FIG. 1, or the UE 302, the LTE eNB 304, or the 5G eNB 306 of FIGS. 3 and 4. The UE 900 and other components may be configured to use the synchronization signals as described herein. The UE 900 may be one of the UEs 902 shown in FIG. 1 and may be a stationary, non-mobile device or may be a mobile device. In some embodiments, the UE 900 may include application circuitry 902, baseband circuitry 904, Radio Frequency (RF) circuitry 906, front-end module (FEM) circuitry 908 and one or more antennas 910, coupled together at least as shown. At least some of the baseband circuitry 904, RF circuitry 906, and FEM circuitry 908 may form a transceiver. In some embodiments, other network elements, such as the eNB may contain some or all of the components shown in FIG. 9.

Other of the network elements, such as the MME, may contain an interface, such as the S1 interface, to communicate with the eNB over a wired connection regarding the UE.

[0086] The application or processing 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 and/or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications and/or operating systems to run on the system.

[0087] 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 and/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 second generation (2G) baseband processor 904a, third generation (3G) baseband processor 904b, fourth generation (4G) baseband processor 904c, and/or other baseband processor(s) 904d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 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. 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 FFT, precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 904 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

[0088] In some embodiments, the baseband circuitry 904 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (E-UTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), and/or radio resource control (RRC) elements. A central processing unit (CPU) 904e of the baseband circuitry 904 may be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP and/or RRC layers. In some embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (DSP) 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).

[0089] 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) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 904 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry. In some embodiments, the device can be configured to operate in accordance with communication standards or other protocols or standards, including Institute of Electrical and Electronic

Engineers (IEEE) 802.16 wireless technology (WiMax), IEEE 802.11 wireless technology (WiFi) including IEEE 802.11 ad, which operates in the 60 GHz millimeter wave spectrum, various other wireless technologies such as global system for mobile communications (GSM), enhanced data rates for GSM evolution (EDGE), GSM EDGE radio access network (GERAN), universal mobile telecommunications system (UMTS), UMTS terrestrial radio access network (UTRAN), or other 2G, 3G, 4G, 5G, etc. technologies either already developed or to be developed.

[0090] 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.

[0091] In some embodiments, the RF circuitry 906 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 906 may include mixer circuitry 906a, amplifier circuitry 906b and filter circuitry 906c. 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.

[0092] 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. The filter circuitry 906c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

[0093] 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/or 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/or 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.

[0094] 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.

[0095] 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.

[0096] 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.

[0097] 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.

[0098] 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.

[0099] 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.

[00100] 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 (f_{LO}). In some embodiments, the RF circuitry 906 may include an IQ/polar converter.

[00101] 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.

[00102] 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 a low-noise amplifier (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.

[00103] In some embodiments, the UE 900 may include additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface as described in more detail below. In some embodiments, the UE 900 described herein may be part of a portable wireless communication device, such as a personal digital assistant (PDA), a laptop or portable computer with wireless communication capability, a web tablet, a wireless telephone, a smartphone, a wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, a medical device (e.g., a heart rate monitor, a blood pressure monitor, etc.), or other device that may receive and/or transmit information wirelessly. In some embodiments, the UE 900 may include one or more user interfaces designed to enable user interaction with the system and/or peripheral component interfaces designed to enable peripheral component interaction with the system. For example, the UE 900 may include one or more of a keyboard, a keypad, a touchpad, a display, a sensor, a non-volatile memory port, a universal serial bus (USB) port, an audio jack, a power supply interface, one or more antennas, a graphics processor, an application processor, a speaker, a microphone, and other I/O components. The display may be an LCD or LED screen including a touch screen. The sensor may include a gyro sensor, an accelerometer, a proximity sensor, an ambient light sensor, and a positioning unit. The positioning unit may communicate with components of a positioning network, e.g., a global positioning system (GPS) satellite.

[00104] The antennas 910 may comprise one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, patch antennas, loop antennas, microstrip antennas or other types of antennas suitable for transmission of RF signals. In some multiple-input multiple-output (MIMO) embodiments, the antennas 910 may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result.

[00105] Although the UE 900 is illustrated 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, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For example, some elements may comprise one or more microprocessors, DSPs, field-programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), radio-frequency integrated circuits (RFICs) and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements may refer to one or more processes operating on one or more processing elements.

[00106] Embodiments may be implemented in one or a combination of hardware, firmware and software. Embodiments may also be implemented as instructions stored on a computer-readable storage device, which may be read and executed by at least one processor to perform the operations described herein. A computer-readable storage device may include any non-transitory mechanism for storing information in a form readable by a machine (e.g., a computer). For example, a computer-readable storage device may include read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and other storage devices and media. Some embodiments may include one or more processors and may be configured with instructions stored on a computer-readable storage device.

[00107] FIG. 10 is a block diagram of a communication device in accordance with some embodiments. The device may be a UE or eNB, for example, such as the UE 802 or eNB 804 shown in FIG. 8, the UE 102 or the eNB 104 shown in FIG. 1, or the UE 302, the LTE eNB 304, or the 5G eNB 306 shown in FIGS. 3-4, that may be configured to track the UE as described herein. The physical layer circuitry 1002 may perform various encoding and decoding functions that may include formation of baseband signals for transmission and decoding of received signals. The communication device 1000 may also include medium access control layer (MAC) circuitry 1004 for controlling access to the wireless medium. The communication device 1000 may also include processing circuitry 1006, such as one or more single-core or multi-core processors, and memory 1008 arranged to perform the operations described herein. The physical layer circuitry 1002, MAC circuitry 1004 and processing circuitry 1006 may handle various radio control functions that enable communication with one or more radio networks compatible with one or more radio technologies. The radio control functions may include signal modulation, encoding, decoding, radio frequency shifting, etc. For example, similar to the device shown in FIG. 2, in some embodiments, communication may be enabled with one or more of a WMAN, a WLAN, and a WPAN. In some embodiments, the communication device 1000 can be configured to operate in accordance with 3GPP standards or other protocols or standards, including WiMax, WiFi, WiGig, GSM, EDGE, GERAN, UMTS, UTRAN, or other 3G, 3G, 4G, 5G, etc. technologies either already developed or to be developed. The communication device 1000 may include transceiver circuitry 1012 to enable communication with other external devices wirelessly and interfaces 1014 to enable wired communication with other external devices. As another example, the transceiver circuitry 1012 may perform various transmission and reception functions such as conversion of signals between a baseband range and a Radio Frequency (RF) range.

[00108] The antennas 1001 may comprise one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, patch antennas, loop antennas, microstrip antennas or other types of antennas suitable for transmission of RF signals. In some MIMO embodiments, the antennas 1001 may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result.

[00109] Although the communication device 1000 is illustrated 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, such as processing elements including DSPs, and/or other hardware elements. For example, some elements may comprise one or more microprocessors, DSPs, FPGAs, ASICs, RFICs and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements may refer to one or more processes operating on one or more processing elements. Embodiments may be implemented in one or a combination of hardware, firmware and software. Embodiments may also be implemented as instructions stored on a computer-readable storage device, which may be read and executed by at least one processor to perform the operations described herein.

[00110] FIG. 11 illustrates another block diagram of a communication device 1100 in accordance with some embodiments. The communication device 1100 may correspond to the UE 102, the eNB 104, the UE 302, the LTE eNB 304, or the 5G eNB 306. In alternative embodiments, the communication device 1100 may operate as a standalone device or may be connected (e.g., networked) to other communication devices. In a networked deployment, the communication device 1100 may operate in the capacity of a server communication device, a client communication device, or both in server-client network environments. In an example, the communication device 1100 may act as a peer communication device in peer-to-peer (P2P) (or other distributed) network environment. The communication device 1100 may be a UE, eNB, PC, a tablet PC, a STB, a PDA, a mobile telephone, a smart phone, a web appliance, a network router, switch or bridge, or any communication device capable of executing instructions (sequential or otherwise) that specify actions to be taken by that communication device. Further, while only a single communication device is illustrated, the term "communication device" shall also be taken to include any collection of communication devices that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein, such as cloud computing, software as a service (SaaS), other computer cluster configurations.

[00111] Examples, as described herein, may include, or may operate on, logic or a number of components, modules, or mechanisms. Modules are tangible entities (e.g., hardware) capable of performing specified operations and may be configured or arranged in a certain manner. In an example, circuits may be arranged (e.g., internally or with respect to external entities such as other circuits) in a specified manner as a module. In an example, the whole or part of one or more computer systems (e.g., a standalone, client or server computer system) or one or more hardware processors may be configured by firmware or software (e.g., instructions, an application portion, or an application) as a module that operates to perform specified operations. In an example, the software may reside on a communication device readable medium. In an example, the software, when executed by the underlying hardware of the module, causes the hardware to perform the specified operations.

[00112] Accordingly, the term "module" is understood to encompass a tangible entity, be that an entity that is physically constructed, specifically configured (e.g., hardwired), or temporarily (e.g., transitorily) configured (e.g., programmed) to operate in a specified manner or to perform part or all of any operation described herein. Considering examples in which modules are temporarily configured, each of the modules need not be instantiated at any one moment in time. For example, where the modules comprise a general-purpose hardware processor configured using software, the general-purpose hardware processor may be configured as respective different modules at different times. Software may accordingly configure a hardware processor, for example, to constitute a particular module at one instance of time and to constitute a different module at a different instance of time.

[00113] Communication device (e.g., computer system) 1100 may include a hardware processor 1102 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 1104 and a static memory 1106, some or all of which may communicate with each other via an interlink (e.g., bus) 1108. The communication device 1100 may further include a display unit 1110, an alphanumeric input device 1112 (e.g., a keyboard), and a user interface (UI) navigation device 1114 (e.g., a mouse). In an example, the display unit 1110, input device 1112 and UI navigation device 1114 may be a touch screen display. The communication device 1100 may additionally include a storage device (e.g., drive unit) 1116, a signal generation device 1118 (e.g., a speaker), a network interface device 1120, and one or more sensors 1121, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The communication device 1100 may include an output controller 1128, such as a serial (e.g., universal serial bus (USB), parallel, or other wired or wireless (e.g., infrared (IR), near field communication (NFC), etc.) connection to communicate or control one or more peripheral devices (e.g., a printer, card reader, etc.).

[00114] The storage device 1116 may include a communication device readable medium 1122 on which is stored one or more sets of data structures or instructions 1124 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 1124 may also reside, completely or at least partially, within the main memory 1104, within static memory 1106, or within the hardware processor 1102 during execution thereof by the communication device 1100. In an example, one or any combination of the hardware processor 1102, the main memory 1104, the static memory 1106, or the storage device 1116 may constitute communication device readable media.

[00115] While the communication device readable medium 1122 is illustrated as a single medium, the term "communication device readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) configured to store the one or more instructions 1124.

[00116] The term "communication device readable medium" may include any medium that is capable of storing, encoding, or carrying instructions for execution by the communication device 1100 and that cause the communication device 1100 to perform any one or more of the techniques of the present disclosure, or that is capable of storing, encoding or carrying data structures used by or associated with such instructions. Non-limiting communication device readable medium examples may include solid-state memories, and optical and magnetic media. Specific examples of communication device readable media may include: non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; Random Access Memory (RAM); and CD-ROM and DVD-ROM disks. In some examples, communication device readable media may include non-transitory communication device readable media. In some examples, communication device readable media may include communication device readable media that is not a transitory propagating signal.

[00117] The instructions 1124 may further be transmitted or received over a communications network 1126 using a transmission medium via the network interface device 1120 utilizing any one of a number of transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communication networks may include a local area network (LAN), a wide area network (WAN), a packet data network (e.g., the Internet), mobile telephone networks (e.g., cellular networks), Plain Old Telephone (POTS) networks, and wireless data networks (e.g., Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards known as Wi-Fi®, IEEE 802.16 family of standards known as WiMax®), IEEE 802.15.4 family of standards, a Long Term Evolution (LTE) family of standards, a Universal Mobile Telecommunications System (UMTS) family of standards, peer-to-peer (P2P) networks, among others. In an example, the network interface device 1120 may include one or more physical jacks (e.g., Ethernet, coaxial, or phone jacks) or one or more antennas to connect to the communications network 1126. In an example, the network interface device 1120 may include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), MIMO, or multiple-input single-output (MISO) techniques. In some examples, the network interface device 1120 may wirelessly communicate using Multiple User MIMO techniques. The term “transmission medium” shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution by the communication device 1100, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

[00118] The subject technology is described below in conjunction with various examples.

[00119] Example 1 is an apparatus of a user equipment (UE), the apparatus comprising: processing circuitry and memory, the processing circuitry to configure the UE to: select an evolved NodeB (eNB) transmit (Tx) beam in a 5G evolved NodeB (eNB) based on measurements of one or more beamforming reference signals (BRS); signal for transmission of a physical random access channel (PRACH) or scheduling request (SR) on a dedicated resource allocated by a long term evolution (LTE) eNB; signal for transmission of a report indicating the selected eNB Tx beam in the 5G eNB via a physical uplink shared channel (PUSCH) or physical uplink control channel (PUCCH) in the LTE eNB; facilitate receiving a physical downlink control channel (PDCCH) order from the LTE eNB or a 5G physical downlink control channel (xPDCCH) order from the 5G eNB for triggering a 5G physical random access channel (xPRACH) transmission in the 5G eNB; and signal for transmission of xPRACH on a resource indicated in the received PDCCH or xPDCCH order in the 5G eNB.

[00120] In Example 2, the subject matter of Example 1 optionally includes that the processing circuitry is further to configure the UE to: measure received power or signal level from the one or more BRS, wherein the one or more BRSs are received by the transceiver circuitry.

[00121] In Example 3, the subject matter of any of Examples 1-2 optionally includes that the eNB Tx beam is selected based on received power or signal level at the UE.

[00122] In Example 4, the subject matter of any of Examples 1-3 optionally includes that the PRACH on the dedicated resource allocated by the LTE eNB is used to trigger xPRACH transmission in the 5G eNB.

[00123] In Example 5, the subject matter of any of Examples 1-4 optionally includes that the transmitted PRACH is used to trigger xPRACH transmissions in the 5G eNB, and wherein the transmitted PRACH for normal application and triggering xPRACH transmission is multiplexed using one or more of time division multiplexing (TDM), frequency division multiplexing (FDM), or code division multiplexing (CDM).

[00124] In Example 6, the subject matter of any of Examples 1-5 optionally includes that the SR is configured by the LTE eNB via UE dedicated radio resource control (RRC) signaling.

[00125] In Example 7, the subject matter of any of Examples 1-6 optionally includes that a logical channel identifier (ID) in a medium access control (MAC) layer is defined for the UE to trigger xPRACH transmission to the 5G eNB, and wherein a MAC control element including the report indicating the selected eNB Tx beam in the 5G eNB is defined, the processing circuitry further to configure the UE to: transmit the MAC control element either in a Message 3 (msg3) in a random access channel (RACH) procedure or together with a buffer status report (BSR) for uplink data triggered by the SR.

[00126] In Example 8, the subject matter of Example 7 optionally includes that the processing circuitry is to configure the UE to transmit the report indicating the selected eNB Tx within the MAC control element or together with data via the PUSCH in the LTE eNB.

[00127] In Example 9, the subject matter of any of Examples 1-8 optionally includes that the processing circuitry is further to configure the UE to: enter into an radio resource control (RRC) connected mode with active uplink (UL) allocations; and configure the transceiver circuitry to transmit xPRACH triggering information together with the report indicating the selected eNB Tx beam.

[00128] In Example 10, the subject matter of any of Examples 1-9 optionally includes that a system frame number (SFN) of the 5G eNB in a downlink control information (DCI) via the PDCCH order from the LTE eNB or the xPDCCH order from the 5G eNB.

[00129] In Example 11, the subject matter of any of Examples 1-10 optionally includes that the received PDCCH order is for allocating a designated xPRACH resource to the UE, and wherein xPRACH transmission timing is aligned with a next available subframe which is used for 5G primary synchronization signal (xPSS) or 5G secondary synchronization signal (xSSS).

[00130] In Example 12, the subject matter of any of any of Examples 1-11 optionally includes that the received xPDCCH order is for allocating a designated xPRACH resource to the UE, and wherein xPRACH transmission timing is aligned with the subframe allocated for the transmission of the xPDCCH order.

[00131] In Example 13, the subject matter of any of Examples 1-12 optionally includes that the processing circuitry comprises a baseband processor.

[00132] In Example 14, the subject matter of any of Examples 1-12 optionally includes that, the apparatus further comprises transceiver circuitry coupled with an antenna for communicating with the LTE eNB and the 5G eNB.

[00133] In Example 15, the subject matter of Example 14 optionally includes that the processing circuitry and the transceiver circuitry are coupled with the memory and an interface circuitry, the memory and the interface circuitry to provide a user interface.

[00134] Example 16 is a computer-readable storage medium that stores instructions for execution by one or more processors to perform operations to configure a user equipment (UE) to: select an evolved NodeB (eNB) transmit (Tx) beam in a 5G evolved NodeB (eNB) based on measurements of one or more beamforming reference signals (BRS); signal for transmission of a physical random access channel (PRACH) or scheduling request (SR) on a dedicated resource allocated by a long term evolution (LTE) eNB; signal for transmission of a report indicating the selected eNB Tx beam in the 5G eNB via a physical uplink shared channel (PUSCH) or physical uplink control channel (PUCCH) in the LTE eNB; facilitate receiving a physical downlink control channel (PDCCH) order from the LTE eNB or a 5G physical downlink control channel (xPDCCH) order from the 5G eNB for triggering a 5G physical random access channel (xPRACH) transmission in the 5G eNB; and signal for transmission of xPRACH on a resource indicated in the received PDCCH or xPDCCH order in the 5G eNB.

[00135] In Example 17, the subject matter of Example 16 optionally includes that the computer-readable medium further stores instructions for execution by the one or more processors to perform operations to configure the UE to: measure received power or signal level from the one or more BRS, wherein the one or more BRSs are received by the UE.

[00136] In Example 18, the subject matter of any of Examples 16-17 optionally includes that the eNB Tx beam is selected based on received power or signal level at the UE.

[00137] Example 19 is an apparatus of a long term evolution (LTE) evolved NodeB (eNB) that provides communication for the eNB, the apparatus comprising: processing circuitry, the processing circuitry to: detect a physical random access channel (PRACH) or scheduling request (SR) on a dedicated resource on the LTE eNB received from a user equipment (UE); decode a report, received from the UE, the report indicating a selected eNB Tx beam in the 5G eNB via a physical uplink shared channel (PUSCH) or physical uplink control channel (PUCCH); encode, for transmission to the UE, a physical downlink control channel (PDCCH) order from the LTE eNB or xPDCCH order from a 5G eNB for triggering a 5G physical random access channel (xPRACH) transmission in the 5G eNB and for triggering an xPRACH transmission from the UE on a resource indicated in the PDCCH order or xPDCCH order.

[00138] In Example 20, the subject matter of Example 19 optionally includes that the report indicating the selected eNB Tx beam is decoded as part of a regular inter-radio access technology (RAT) measurement procedure in the LTE eNB.

[00139] In Example 21, the subject matter of any of Examples 19-20 optionally includes that the processing circuitry is further to: allocate, to the UE by using the PDCCH order or the xPDCCH order, a designated xPRACH resource for communicating with the 5G eNB.

[00140] In Example 22, the subject matter of Example 21 optionally includes that a frequency resource of the xPRACH transmission and xPRACH preamble signature, for communication between the UE and the 5G eNB, are predefined or configured semi-statically via UE specific or LTE eNB specific radio resource control (RRC) signaling from the LTE eNB acting as a primary eNB or indicated via 5G mater information block (xMIB), 5G system information block (xSIB), or UE specific RRC signaling from the 5G eNB.

[00141] Example 23 is an apparatus of a user equipment (UE), the apparatus comprising: means for selecting an evolved NodeB (eNB) transmit (Tx) beam in a 5G evolved NodeB (eNB) based on measurements of one or more beamforming reference signals (BRS); means for signaling for transmission of a physical random access channel (PRACH) or scheduling request (SR) on a dedicated resource allocated by a long term evolution (LTE) eNB; means for signaling for transmission of a report indicating the selected eNB Tx beam in the 5G eNB via a physical uplink shared channel (PUSCH) or physical uplink control channel (PUCCH) in the LTE eNB; means for facilitating receiving a physical downlink control channel (PDCCH) order from the LTE eNB or a 5G physical downlink control channel (xPDCCH) order from the 5G eNB for triggering a 5G physical random access channel (xPRACH) transmission in the 5G eNB; and means for signaling for transmission of xPRACH on a resource indicated in the received PDCCH or xPDCCH order in the 5G eNB.

[00142] In Example 24, the subject matter of Example 23 optionally includes that the apparatus further comprises: means for measuring received power or signal level from the one or more BRS, wherein the one or more BRSs are received by the UE.

[00143] In Example 25, the subject matter of any of Examples 23-24 optionally includes that the eNB Tx beam is selected based on received power or signal level at the UE.

[00144] Although an embodiment has been described with reference to specific example embodiments, it will be evident that various modifications and changes may be made to these embodiments. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense. The accompanying drawings that form a part hereof show, by way of illustration, and not of limitation, specific embodiments in which the subject matter may be practiced. The embodiments illustrated are described in sufficient detail to enable those skilled in the art to practice the teachings disclosed herein. Other embodiments may be utilized and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. This Detailed Description, therefore, is not to be taken in a limiting sense, and the scope of various embodiments is defined only by the appended claims, along with the full range of equivalents to which such claims are entitled.

[00145] Although specific embodiments have been illustrated and described herein, it should be appreciated that any arrangement calculated to achieve the same purpose may be substituted for the specific embodiments shown. This disclosure is intended to cover any and all adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, will be apparent to those of skill in the art upon reviewing the above description.

[00146] In this document, the terms "a" or "an" are used, as is common in patent documents, to include one or more than one, independent of any other instances or usages of "at least one" or "one or more." In this document, the term "or" is used to refer to a nonexclusive or, such that "A or B" includes "A but not B," "B but not A," and "A and B," unless otherwise indicated. In this document, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Also, in the following claims, the terms "including" and "comprising" are open-ended, that is, a system, UE, article, composition, formulation, or process that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim. Moreover, in the following claims, the terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.

[00147] The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate embodiment.

CLAIMS

What is claimed is:

1. An apparatus of a user equipment (UE), the apparatus comprising:

processing circuitry and memory, the processing circuitry to configure the UE to:

select an evolved NodeB (eNB) transmit (Tx) beam in a 5G evolved NodeB (eNB) based on measurements of one or more beamforming reference signals (BRS);

signal for transmission of a physical random access channel (PRACH) or scheduling request (SR) on a dedicated resource allocated by a long term evolution (LTE) eNB;

signal for transmission of a report indicating the selected eNB Tx beam in the 5G eNB via a physical uplink shared channel (PUSCH) or physical uplink control channel (PUCCH) in the LTE eNB;

facilitate receiving a physical downlink control channel (PDCCH) order from the LTE eNB or a 5G physical downlink control channel (xPDCCH) order from the 5G eNB for triggering a 5G physical random access channel (xPRACH) transmission in the 5G eNB; and

signal for transmission of xPRACH on a resource indicated in the received PDCCH or xPDCCH order in the 5G eNB.

2. The apparatus of claim 1, the processing circuitry further to configure the UE to:

measure received power or signal level from the one or more BRS, wherein the one or more BRSs are received by the transceiver circuitry.

3. The apparatus of any of claims 1-2, wherein the eNB Tx beam is selected based on received power or signal level at the UE.

4. The apparatus of any of claims 1-2, wherein the PRACH on the dedicated resource allocated by the LTE eNB is used to trigger xPRACH transmission in the 5G eNB.

5. The apparatus of any of claims 1-2, wherein the transmitted PRACH is used to trigger xPRACH transmissions in the 5G eNB, and wherein the transmitted PRACH for normal application and triggering xPRACH transmission is multiplexed using one or more of time division multiplexing (TDM), frequency division multiplexing (FDM), or code division multiplexing (CDM).

6. The apparatus of any of claims 1-2, wherein the SR is configured by the LTE eNB via UE dedicated radio resource control (RRC) signaling.

7. The apparatus of any of claims 1-2, wherein a logical channel identifier (ID) in a medium access control (MAC) layer is defined for the UE to trigger xPRACH transmission to the 5G eNB, and wherein a MAC control element including the report indicating the selected eNB Tx beam in the 5G eNB is defined, the processing circuitry further to configure the UE to:

transmit the MAC control element either in a Message 3 (msg3) in a random access channel (RACH) procedure or together with a buffer status report (BSR) for uplink data triggered by the SR.

8. The apparatus of claim 7, wherein the processing circuitry is to configure the UE to transmit the report indicating the selected eNB Tx within the MAC control element or together with data via the PUSCH in the LTE eNB.

9. The apparatus of any of claims 1-2, the processing circuitry further to configure the UE to:

enter into an radio resource control (RRC) connected mode with active uplink (UL) allocations; and

configure the transceiver circuitry to transmit xPRACH triggering information together with the report indicating the selected eNB Tx beam.

10. The apparatus of any of claims 1-2, wherein a system frame number (SFN) of the 5G eNB in a downlink control information (DCI) via the PDCCH order from the LTE eNB or the xPDCCH order from the 5G eNB.

11. The apparatus of any of claims 1-2, wherein the received PDCCH order is for allocating a designated xPRACH resource to the UE, and wherein xPRACH transmission timing is aligned with a next available subframe which is used for 5G primary synchronization signal (xPSS) or 5G secondary synchronization signal (xSSS).

12. The apparatus of any of claims 1-2, wherein the received xPDCCH order is for allocating a designated xPRACH resource to the UE, and wherein xPRACH transmission timing is aligned with the subframe allocated for the transmission of the xPDCCH order.

13. The apparatus of any of claims 1-2, wherein the processing circuitry comprises a baseband processor.

14. The apparatus of any of claims 1-2, wherein the apparatus further comprises transceiver circuitry coupled with an antenna for communicating with the LTE eNB and the 5G eNB.

15. The apparatus of claim 14, wherein the processing circuitry and the transceiver circuitry are coupled with the memory and an interface circuitry, the memory and the interface circuitry to provide a user interface.

16. A computer-readable storage medium that stores instructions for execution by one or more processors to perform operations to configure a user equipment (UE) to:

select an evolved NodeB (eNB) transmit (Tx) beam in a 5G evolved NodeB (eNB) based on measurements of one or more beamforming reference signals (BRS);

signal for transmission of a physical random access channel (PRACH) or scheduling request (SR) on a dedicated resource allocated by a long term evolution (LTE) eNB;

signal for transmission of a report indicating the selected eNB Tx beam in the 5G eNB via a physical uplink shared channel (PUSCH) or physical uplink control channel (PUCCH) in the LTE eNB;

facilitate receiving a physical downlink control channel (PDCCH) order from the LTE eNB or a 5G physical downlink control channel (xPDCCH) order from the 5G eNB for triggering a 5G physical random access channel (xPRACH) transmission in the 5G eNB; and

signal for transmission of xPRACH on a resource indicated in the received PDCCH or xPDCCH order in the 5G eNB.

17. The computer-readable storage medium of claim 16, further storing instructions for execution by the one or more processors to perform operations to configure the UE to:

measure received power or signal level from the one or more BRS, wherein the one or more BRSs are received by the UE.

18. The computer-readable storage medium of claim 16, wherein the eNB Tx beam is selected based on received power or signal level at the UE.

19. An apparatus of a long term evolution (LTE) evolved NodeB (eNB) that provides communication for the eNB, the apparatus comprising:

processing circuitry, the processing circuitry to:

detect a physical random access channel (PRACH) or scheduling request (SR) on a dedicated resource on the LTE eNB received from a user equipment (UE);

decode a report, received from the UE, the report indicating a selected eNB Tx beam in the 5G eNB via a physical uplink shared channel (PUSCH) or physical uplink control channel (PUCCH);

encode, for transmission to the UE, a physical downlink control channel (PDCCH) order from the LTE eNB or xPDCCH order from a 5G eNB for triggering a 5G physical random access channel (xPRACH) transmission in the 5G eNB and for triggering an xPRACH transmission from the UE on a resource indicated in the PDCCH order or xPDCCH order.

20. The apparatus of claim 19, wherein the report indicating the selected eNB Tx beam is decoded as part of a regular inter-radio access technology (RAT) measurement procedure in the LTE eNB.

21. The apparatus of claim 19, the processing circuitry further to:

allocate, to the UE by using the PDCCH order or the xPDCCH order, a designated xPRACH resource for communicating with the 5G eNB.

22. The apparatus of claim 21, wherein a frequency resource of the xPRACH transmission and xPRACH preamble signature, for communication between the UE and the 5G eNB, are predefined or configured semi-statically via UE specific or LTE eNB specific radio resource control (RRC) signaling from the LTE eNB acting as a primary eNB or indicated via 5G mater information block (xMIB), 5G system information block (xSIB), or UE specific RRC signaling from the 5G eNB.

23. An apparatus of a user equipment (UE), the apparatus comprising:

means for selecting an evolved NodeB (eNB) transmit (Tx) beam in a 5G evolved NodeB (eNB) based on measurements of one or more beamforming reference signals (BRS);

means for signaling for transmission of a physical random access channel (PRACH) or scheduling request (SR) on a dedicated resource allocated by a long term evolution (LTE) eNB;

means for signaling for transmission of a report indicating the selected eNB Tx beam in the 5G eNB via a physical uplink shared channel (PUSCH) or physical uplink control channel (PUCCH) in the LTE eNB;

means for facilitating receiving a physical downlink control channel (PDCCH) order from the LTE eNB or a 5G physical downlink control channel (xPDCCH) order from the 5G eNB for triggering a 5G physical random access channel (xPRACH) transmission in the 5G eNB; and

means for signaling for transmission of xPRACH on a resource indicated in the received PDCCH or xPDCCH order in the 5G eNB.

24. The apparatus of claim 23, further comprising:

means for measuring received power or signal level from the one or more BRS, wherein the one or more BRSs are received by the UE.

25. The apparatus of claim 23, wherein the eNB Tx beam is selected based on received power or signal level at the UE.

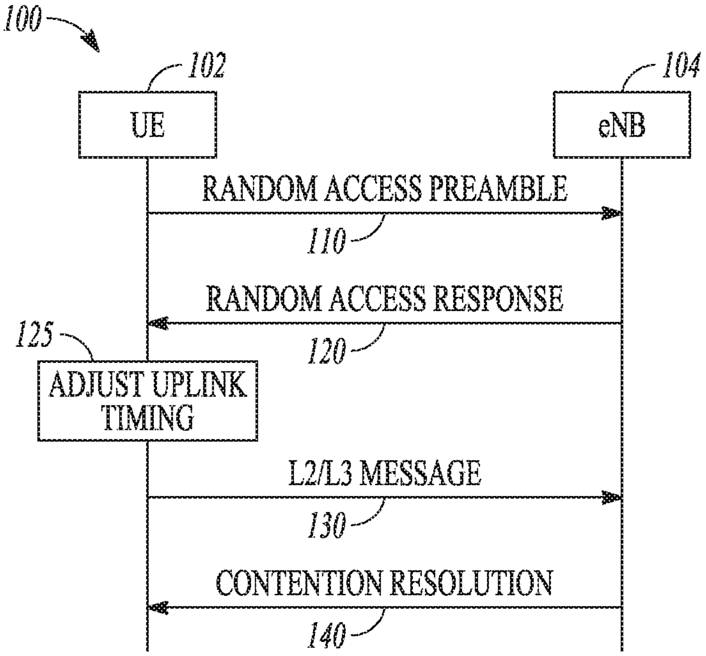
100
102
UE
104
eNB
RANDOM ACCESS PREAMBLE
110
RANDOM ACCESS RESPONSE
120
125
ADJUST UPLINK TIMING
L2/L3 MESSAGE
130
CONTENTION RESOLUTION
140

FIG. 1

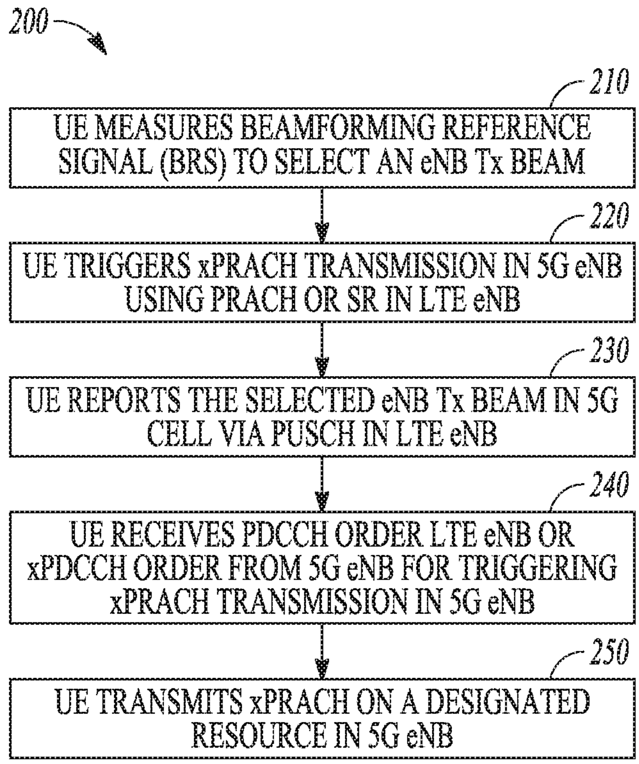
200
210
UE MEASURES BEAMFORMING REFERENCE SIGNAL (BRS) TO SELECT AN eNB Tx BEAM
220
UE TRIGGERS xPRACH TRANSMISSION IN 5G eNB USING PRACH OR SR IN LTE eNB
230
UE REPORTS THE SELECTED eNB Tx BEAM IN 5G CELL VIA PUSCH IN LTE eNB
240
UE RECEIVES PDCCH ORDER LTE eNB OR xPDCCH ORDER FROM 5G eNB FOR TRIGGERING xPRACH TRANSMISSION IN 5G eNB
250
UE TRANSMITS xPRACH ON A DESIGNATED RESOURCE IN 5G eNB

FIG. 2

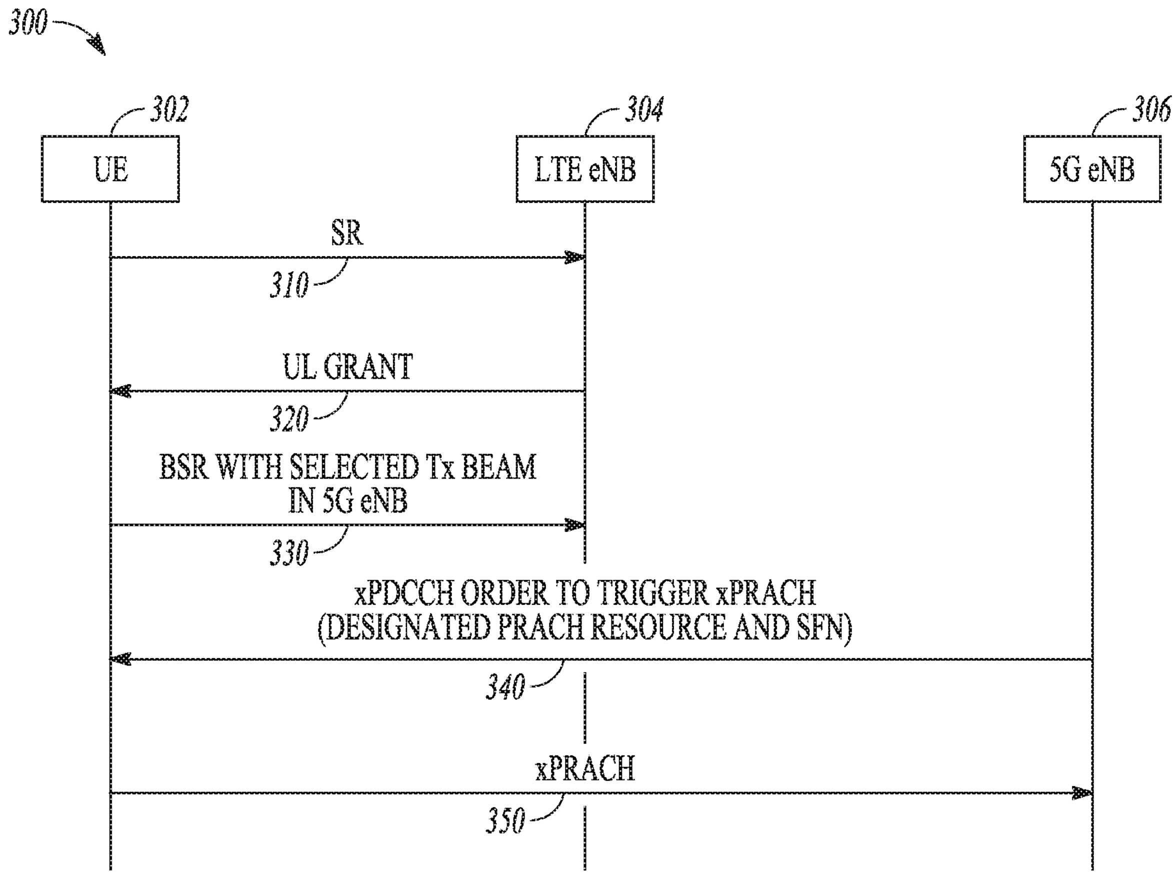
300
302
UE
304
LTE eNB
306
5G eNB
SR
310
UL GRANT
320
BSR WITH SELECTED Tx BEAM
IN 5G eNB
330
xPDCCH ORDER TO TRIGGER xPRACH
(DESIGNATED PRACH RESOURCE AND SFN)
340
xPRACH
350

FIG. 3

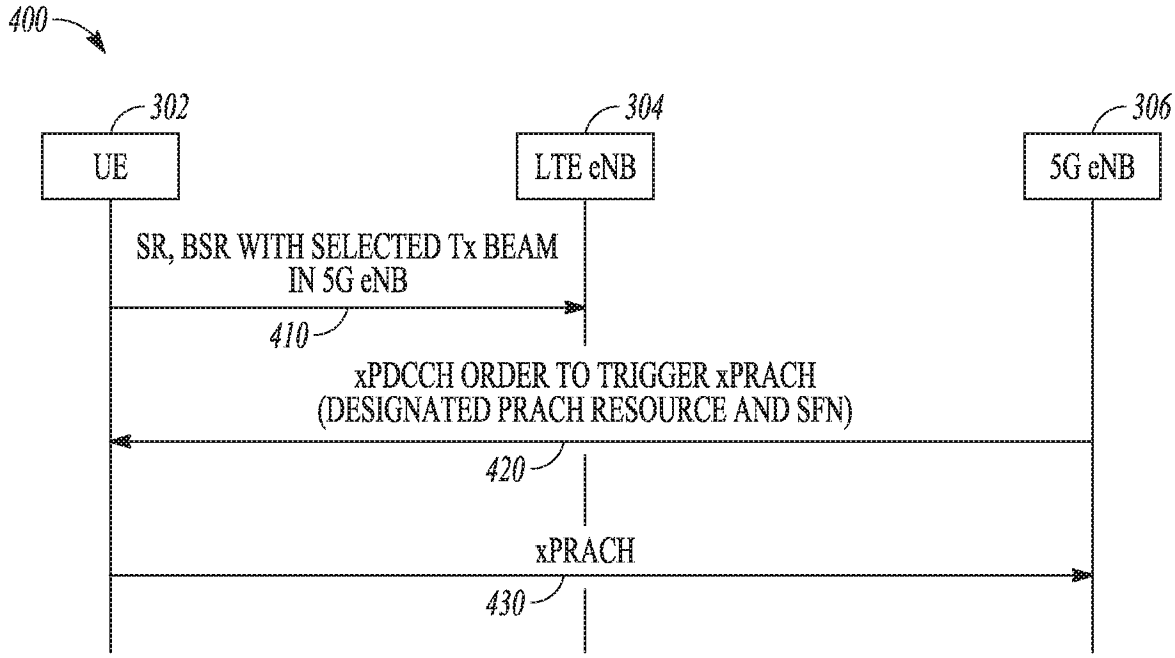
400
302
UE
304
LTE eNB
306
5G eNB
SR, BSR WITH SELECTED Tx BEAM IN 5G eNB
410
xPDCCH ORDER TO TRIGGER xPRACH (DESIGNATED PRACH RESOURCE AND SFN)
420
xPRACH
430

FIG. 4

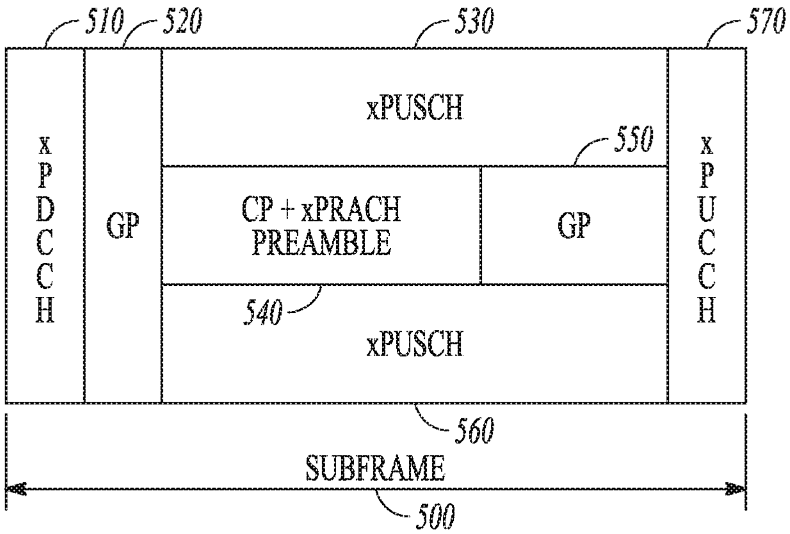
510
520
530
570
xPDCCH
GP
xPUSCH
550
CP + xPRACH PREAMBLE
GP
xPUCCH
540
xPUSCH
560
SUBFRAME
500

FIG. 5

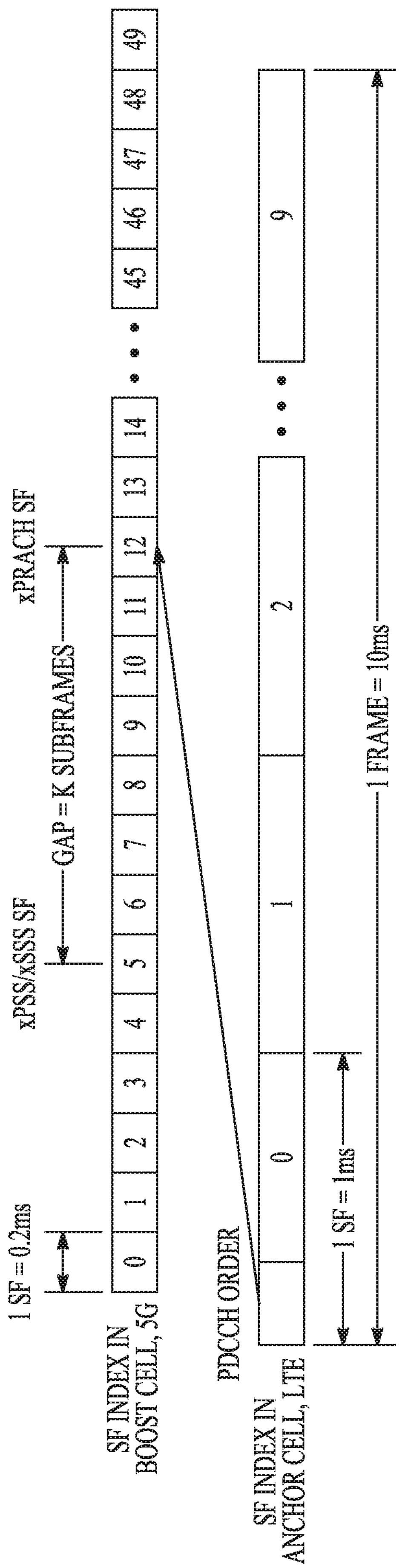
SF INDEX IN BOOST CELL, 5G
1 SF = 0.2ms
xPSS/xSSS SF
GAP = K SUBFRAMES
xPRACH SF
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
45 46 47 48 49
PDCCH ORDER
SF INDEX IN ANCHOR CELL, LTE
0 1 2 9
1 SF = 1ms
1 FRAME = 10ms

FIG. 6

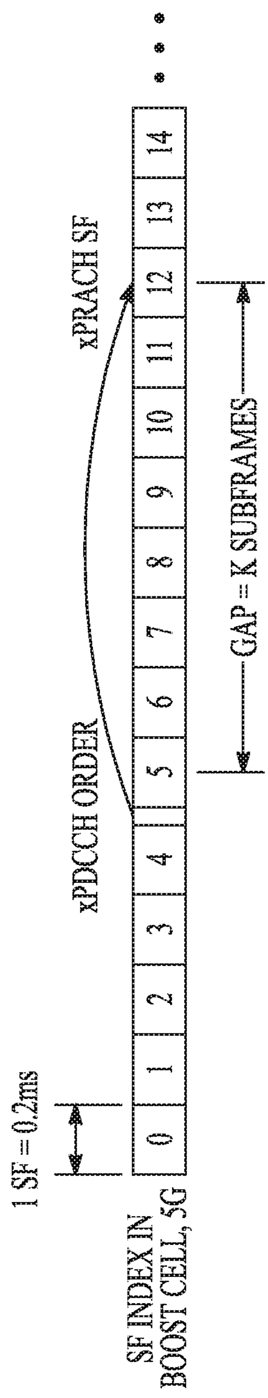
SF INDEX IN BOOST CELL, 5G
1 SF = 0.2ms
xPDCCH ORDER
xPRACH SF
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
GAP = K SUBFRAMES

FIG. 7

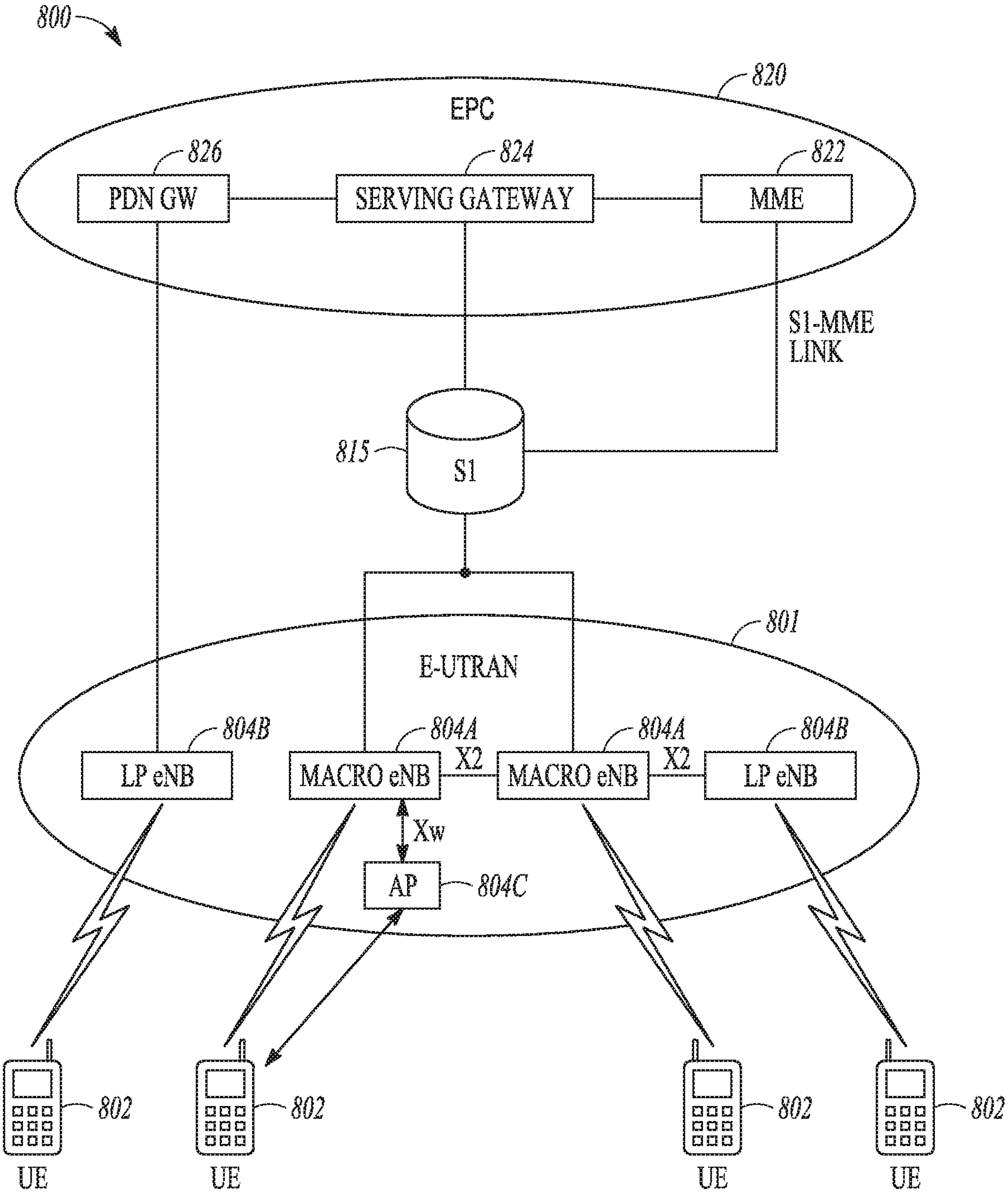
800
820
EPC
826
PDN GW
824
SERVING GATEWAY
822
MME
S1-MME
LINK
815
S1
801
E-UTRAN
804B
LP eNB
804A
MACRO eNB
X2
804A
MACRO eNB
X2
804B
LP eNB
Xw
AP
804C
802
UE
802
UE
802
UE
802
UE

FIG. 8

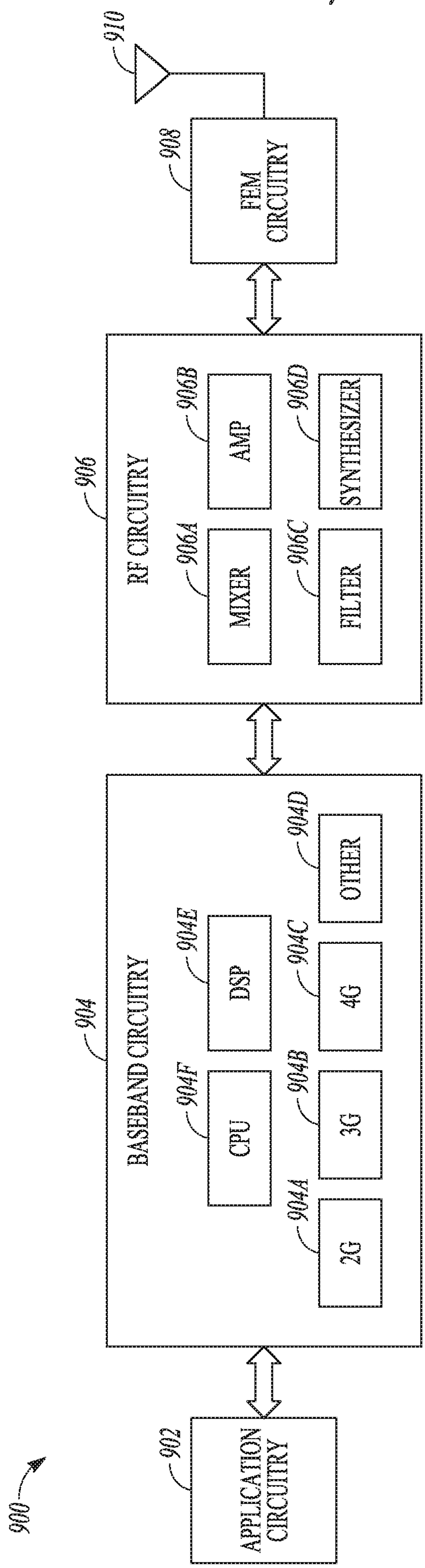
910
908
FEM CIRCUITRY
906
RF CIRCUITRY
906A
MIXER
906B
AMP
906C
FILTER
906D
SYNTHESIZER
904
BASEBAND CIRCUITRY
904F
CPU
904E
DSP
904A
2G
904B
3G
904C
4G
904D
OTHER
902
APPLICATION CIRCUITRY
900

FIG. 9

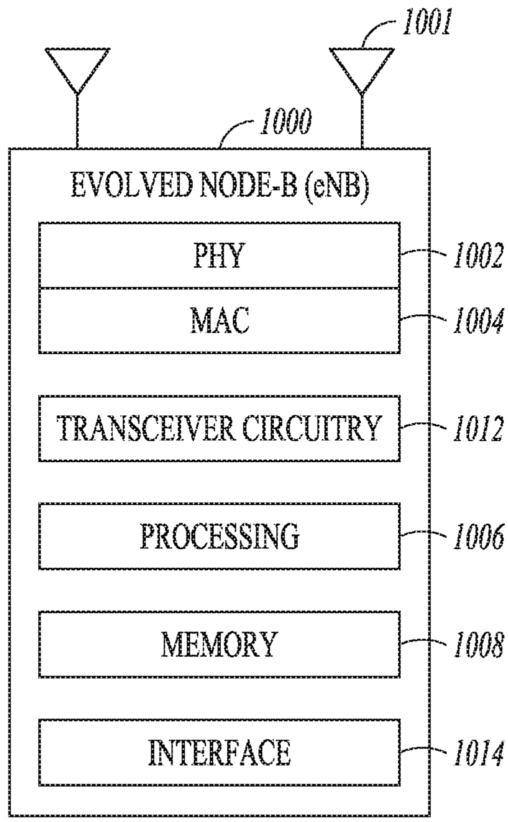
1001
1000
EVOLVED NODE-B (eNB)
PHY
1002
MAC
1004
TRANSCEIVER CIRCUITRY
1012
PROCESSING
1006
MEMORY
1008
INTERFACE
1014

FIG. 10

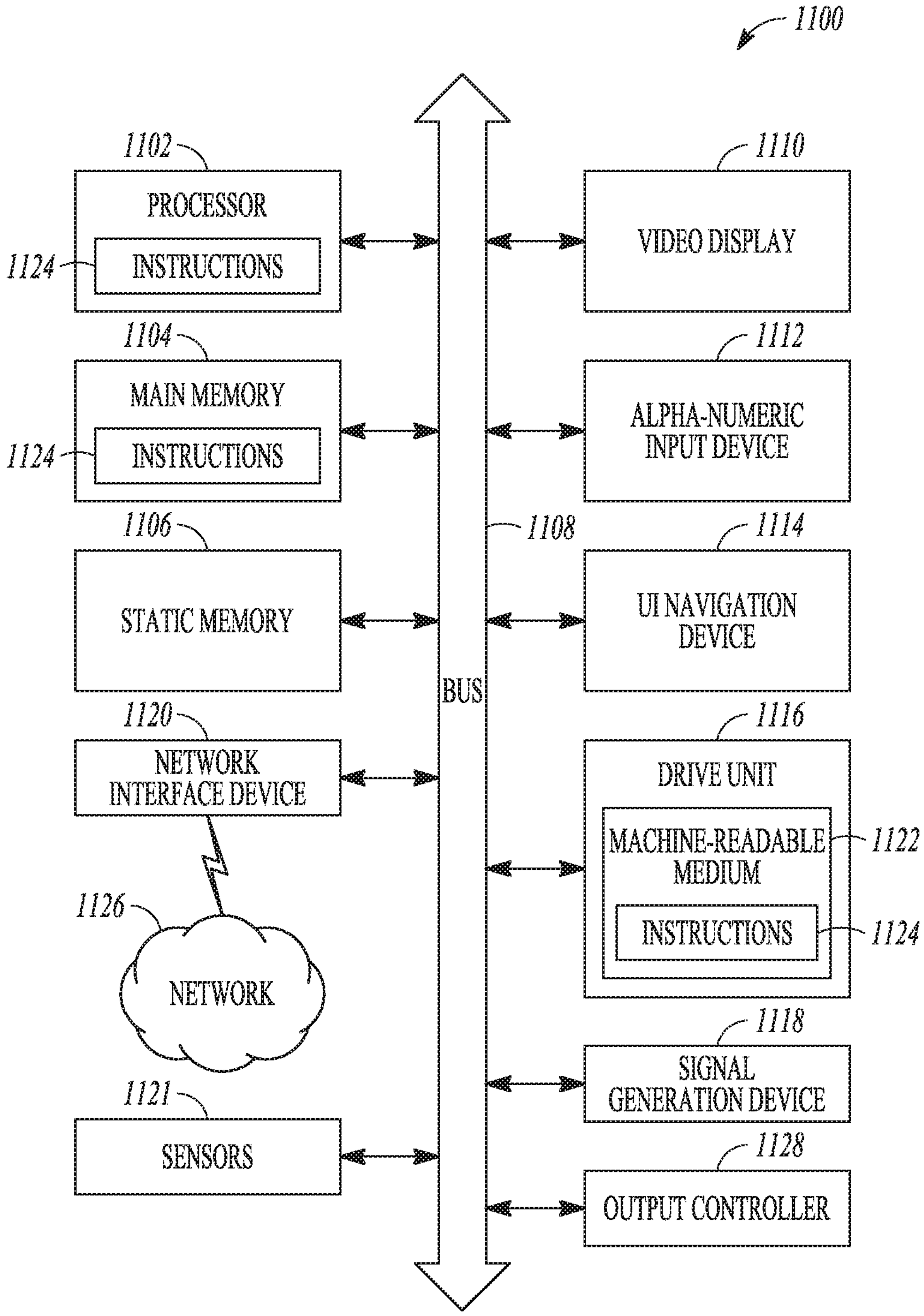
1100
1102
PROCESSOR
1124
INSTRUCTIONS
1104
MAIN MEMORY
1124
INSTRUCTIONS
1106
STATIC MEMORY
1120
NETWORK INTERFACE DEVICE
1126
NETWORK
1121
SENSORS
BUS
1108
1110
VIDEO DISPLAY
1112
ALPHA-NUMERIC INPUT DEVICE
1114
UI NAVIGATION DEVICE
1116
DRIVE UNIT
MACHINE-READABLE MEDIUM
1122
INSTRUCTIONS
1124
1118
SIGNAL GENERATION DEVICE
1128
OUTPUT CONTROLLER

FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/024264

A. CLASSIFICATION OF SUBJECT MATTER

H04L 5/00(2006.01)i, H04W 80/08(2009.01)i, H04W 80/04(2009.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04L 5/00; H04W 74/08; H04W 84/00; H01Q 3/00; H04B 7/08; H04W 80/08; H04W 80/04

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: 5G, LTE, assisted, eNB, beamforming, reference(BRS), PRACH(physical random access channel), SR(scheduling request), report, PUSCH, PUCCH, PDCCH order, xPDCCH(5G PDCCH) order, xPRACH(5G PRACH)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2015-147717 A1 (TELEFONAKTIEBOLAGET L M ERICSSON (PUBL)) 01 October 2015 See page 24, line 23 - page 26, line 7; and figure 12.	1-25
A	US 2013-0235834 A1 (TELEFONAKTIEBOLAGET L M ERICSSON (PUBL)) 12 September 2013 See paragraphs [0026]-[0096]; and figures 2-5.	1-25
A	US 2012-0026940 A1 (ALAN BARBIERI et al.) 02 February 2012 See paragraphs [0179]-[0188]; and figures 7, 8.	1-25
A	ALCATEL-LUCENT et al., 'Considerations on PRACH for LC-MTC', R2-152674, 3GPP TSG RAN WG2 Meeting #90, 15 May 2015 See section 3.	1-25
A	3GPP TS 36.300 V13.1.0, '3GPP; TSG RAN; E-UTRA and E-UTRAN; Overall description; Stage 2 (Release 13)', 24 September 2015 See pages 95-98.	1-25

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

* Special categories of cited documents:
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"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
07 September 2016 (07.09.2016)	**07 September 2016 (07.09.2016)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/024264

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2015-147717 A1	01/10/2015	US 2016-157267 A1	02/06/2016
US 2013-0235834 A1	12/09/2013	CN 101843007 A	22/09/2010
		CN 101843007 B	24/09/2014
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		US 8457647 B2	04/06/2013
		WO 2009-058065 A1	07/05/2009
US 2012-0026940 A1	02/02/2012	TW 201204141 A	16/01/2012
		WO 2011-115703 A1	22/09/2011