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(71) **Applicant: INTEL IP CORPORATION** [US/US]; 2200 Mission College Blvd., Santa Clara, California 95054 (US).

(72) **Inventors; and**
(71) **Applicants** *(for BZ only)*: **CHANG, Wenting** [CN/CN]; 8F, Raycom Infotech Park A, No2, Kexueyuan South Road, Beijing 100190 (CN). **ZHU, Yuan** [CN/CN]; Room 605, Building 16, Mo Li Yuan, Bei Yuan Jia Yuan, Chaoyang, Beijing 100013 (CN). **ZHANG, Yushu** [CN/CN]; Raycom Building A 8F No.2, Kexueyuan South Road, Zhong Guan Cun, Haidian District, Beijing 100190 (CN). **NIU, Huaning** [CN/US]; 1308 Knollview Drive, Milpitas, California 95035 (US). **LI, Qinghua** [CN/US]; 5117 Chiltern Lane, San Ramon, California 94582 (US).

(74) **Agent: CHINA PATENT AGENT (H.K.) LTD.**; 22/F., Great Eagle Center, 23 Harbour Road, Wanchai, Hong Kong (CN).

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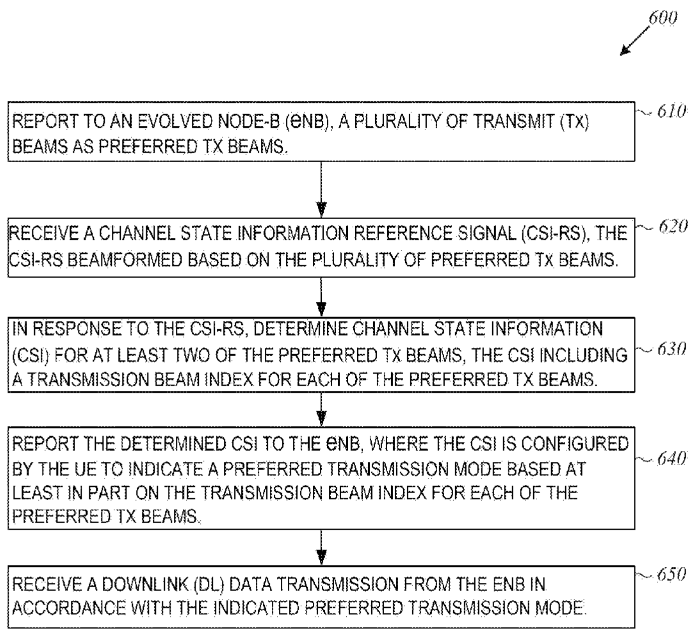

FIG. 6

(57) **Abstract:** User Equipment (UE) and base station (eNB) apparatus and methodology for CQI reporting for flexible transmission mode switching. The UE includes memory and processing circuitry configured to generate a reporting message for an Evolved Node-B (eNB), the reporting message indicating a plurality oftransmit (Tx) beams as preferred Tx beams. In response to a channel state information reference signal (CSI-RS), the processing circuitry determines channel state information (CSI) for at least two of the preferred Tx beams, the CSI-RS beamformed based on the plurality of preferred Tx beams, and the CSI including a transmission beam index for each of the preferred Tx beams. The determined CSI is reported to the eNB, where the CSI is configured by the UE to indicate a preferred transmission mode base at least in part on the transmission beam index for each of the preferred Tx beams.

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CQI REPORTING FOR FLEXIBLE TRANSMISSION MODE SWITCHING

TECHNICAL FIELD

[0001] Embodiments pertain to wireless communications. Some embodiments relate to wireless networks including 3GPP (Third Generation Partnership Project) networks, 3GPP LTE (Long Term Evolution) networks, 3GPP LTE-A (LTE Advanced) networks, and 5G networks, although the scope of the embodiments is not limited in this respect. Some embodiments relate to channel quality indicator (CQI) derivation and reporting for flexible transmission mode switching.

BACKGROUND

[0002] With the increase in different types of devices communicating with various network devices, usage of 3GPP LTE systems has increased. Over the last several years, cellular communication have developed from low-data-rate voice and text-messaging applications to high-data-rate applications, such as high definition (HD) audio and video streaming, full-featured Internet connectivity, with myriad useful applications, all of which have made a significant impact on the public's daily lives. Fifth generation (5G) wireless systems are forthcoming, and are expected to enable even greater speed, connectivity, and usability.

[0003] One area of development for 5G systems is improving communication bandwidth for higher data rates than is currently available. However, communication paths used in high-frequency-band communication tend to propagate in a more line-of-sight fashion, and may be more susceptible to path loss due to obstructions, such as natural topography, trees, buildings and other structures, and vehicles, for example. To address these challenges, the utilization of beamforming and multiple-input, multiple-output (MIMO) techniques have been proposed. Additionally, as the user equipment (UE) moves and/or rotates with use, the surrounding environment changes and the number, as well as the conditions, of channel clusters that can be used for communication with an Evolved Node-B (eNB) also changes.

[0004] A practical solution is needed for flexible transmission mode switching.

BRIEF DESCRIPTION OF THE FIGURES

[0005] In the figures, which are not necessarily drawn to scale, like numerals may describe similar components in different views. Like numerals having different letter suffixes may represent different instances of similar components. Some embodiments are illustrated by way of example, and not limitation, in the following figures of the accompanying drawings.

[0006] FIG. 1 is a functional diagram of a 3GPP network in accordance with some embodiments.

[0007] FIG. 2 is a block diagram of a User Equipment (UE) in accordance with some embodiments.

[0008] FIG. 3 is a block diagram of an Evolved Node-B (eNB) in accordance with some embodiments.

[0009] FIGS. 4A-4B illustrate examples of multiple beam transmission scenarios utilizing an eNB and a UE in accordance with some embodiments.

[0010] FIG. 5A is a diagram illustrating channel state information (CSI) derivation and reporting for flexible transmission mode switching, in accordance with some embodiments.

[0011] FIG. 5B illustrates CSI derivation and reporting based on downlink control information (DCI), in accordance with some embodiments.

[0012] FIGS. 6-8 are flow diagrams illustrating example functionalities for CQI derivation and/or reporting according to some embodiments.

[0013] FIG. 9 illustrates a block diagram of a communication device such as an eNB or a UE, in accordance with some embodiments.

DETAILED DESCRIPTION

[0014] 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.

[0015] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. A number of examples are described in the context of 3GPP communication systems and components thereof. It will be understood that principles of the embodiments are applicable in other types of communication systems, such as Wi-Fi or Wi-Max networks, Bluetooth or other personal-area networks, Zigbee or other home-area networks, wireless mesh networks, and the like, without limitation, unless expressly limited by a corresponding claim. Given the benefit of the present disclosure, persons skilled in the relevant technologies will be able to engineer suitable variations to implement principles of the embodiments in other types of communication systems. Various diverse embodiments may incorporate structural, logical, electrical, process, and other differences. 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 presently-known, and after-arising, equivalents of those claims.

[0016] FIG. 1 is a functional diagram of a 3GPP network in accordance with some embodiments. The network comprises a radio access network (RAN) (e.g., as depicted, the E-UTRAN or evolved universal terrestrial radio access network) 101 and the core network 120 (e.g., shown as an evolved packet core (EPC)) coupled together through an S1 interface 115. For convenience and brevity sake, only a portion of the core network 120, as well as the RAN 101, is shown.

[0017] The core network 120 includes a mobility management entity (MME) 122, a serving gateway (serving GW) 124, and packet data network gateway (PDN GW) 126. The RAN 101 includes Evolved Node-B's (eNB)

104 (which may operate as base stations) for communicating with User Equipment (UE) 102. The eNBs 104 may include macro eNBs and low power (LP) eNBs. In accordance with some embodiments, the eNB 104 may transmit a downlink control message to the UE 102 to indicate an allocation of physical uplink control channel (PUCCH) channel resources. The UE 102 may receive the downlink control message from the eNB 104, and may transmit an uplink control message to the eNB 104 in at least a portion of the PUCCH channel resources. These embodiments will be described in more detail below.

[0018] The MME 122 is similar in function to the control plane of legacy Serving GPRS Support Nodes (SGSN). The MME 122 manages mobility aspects in access such as gateway selection and tracking area list management. The serving GW 124 terminates the interface toward the RAN 101, and routes data packets between the RAN 101 and the core network 120. In addition, it may be a local mobility anchor point for inter-eNB handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement. The serving GW 124 and the MME 122 may be implemented in one physical node or separate physical nodes. The PDN GW 126 terminates a SGi interface toward the packet data network (PDN). The PDN GW 126 routes data packets between the EPC 120 and the external PDN, and may be a key node for policy enforcement and charging data collection. It may also provide an anchor point for mobility with non-LTE accesses. The external PDN can be any kind of IP network, as well as an IP Multimedia Subsystem (IMS) domain. The PDN GW 126 and the serving GW 124 may be implemented in one physical node or separated physical nodes.

[0019] The eNB 104 (macro and micro) terminate the air interface protocol and may be the first point of contact for a UE 102. In some embodiments, an eNB 104 may fulfill various logical functions for the RAN 101 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, UE 102 may be configured to communicate with an eNB 104 over a multipath fading channel in accordance with an Orthogonal Frequency Division Multiple Access (OFDMA) communication technique. The OFDM signals may comprise a plurality of orthogonal subcarriers.

[0020] The S1 interface 115 is the interface that separates the RAN 101 and the EPC 120. It is split into two parts: the S1-U, which carries traffic data between the eNB 104 and the serving GW 124, and the S1-MME, which is a signaling interface between the eNB 104 and the MME 122. The X2 interface is the interface between eNB 104. The X2 interface comprises two parts, the X2-C and X2-U. The X2-C is the control plane interface between the eNB 104, while the X2-U is the user plane interface between the eNB 104.

[0021] With cellular networks, LP cells are typically used to extend coverage to indoor areas where outdoor signals do not reach well, or to add network capacity in areas with very dense phone usage, such as train stations. As used herein, the term low power (LP) eNB refers to any suitable relatively low power eNB for implementing a narrower cell (narrower than a macro cell) such as a femtocell, a picocell, or a micro cell. Femtocell eNBs are typically provided by a mobile network operator to its residential or enterprise customers. A femtocell is typically the size of a residential gateway or smaller and generally connects to the user's broadband line. Once plugged in, the femtocell connects to the mobile operator's mobile network and provides extra coverage in a range of typically 30 to 50 meters for residential femtocells. Thus, a LP eNB might be a femtocell eNB since it is coupled through the PDN GW 126. Similarly, a picocell is a wireless communication system typically covering a small area, such as in-building (offices, shopping malls, train stations, etc.), or more recently in-aircraft. A picocell eNB can generally connect through the X2 link to another eNB such as a macro eNB through its base station controller (BSC) functionality. Thus, LP eNB may be implemented with a picocell eNB since it is coupled to a macro eNB via an X2 interface. Picocell eNBs or other LP eNBs may incorporate some or all functionality of a macro eNB. In some cases, this may be referred to as an access point base station or enterprise femtocell.

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

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

[0024] The PDCCH uses CCEs (control channel elements) to convey the control information. Before being mapped to resource elements, the

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

[0025] In accordance with an example embodiment, the UE 102 can be configured for switching between single beam and dual beam transmission based on, e.g., channel quality of one or more channel clusters between the eNB 104 and the UE 102. More specifically and as explained below, the UE can be equipped with multiple antenna panels (e.g., 210A – 210D), which enables the UE to improve the signal quality with wider angle of arrival (AoA) or increase the data rate by providing a high-rank transmission through beam aggregation.

[0026] Along with the movement and/or rotation of the UE and the resulting change of surrounding environment, the preferred transmission may be switched between single beam transmission (e.g., rank 1 or 2) and dual beam transmission (e.g., rank 2, 3, or 4). For example, when at least two strong channel clusters are available during the link between the eNB and the UE, dual beam transmission with higher rank can be will be preferred so as to achieve higher data rate. In instances when only one strong channel cluster is feasible (e.g., under line of sight (LoS) scenario), a single beam can be provided due to spatial deficiency. Since the eNB uses channel state information (CSI) 160 to assess the conditions of the communication channel clusters for a beam, the CSI 160 (e.g., the channel quality indicator, or CQI) can be used by the UE to indicate to the eNB a preferred transmission mode. Additionally, the eNB 104 can provide an indicator 180 to the UE, specifying whether CSI 160 for a single transmit beam or for multiple transmit beams is required. In another embodiment, the eNB 104 can provide an indicator 170 to the UE, specifying a derivation method for one or more CSI characteristics (such as a CQI). For example, the derivation indicator 170 can specify whether mutual interference between at least two transmit beams should be taken into account when determining the CQI, or whether the CQI should be determined by the UE 102 without taking the mutual interference into account. In this regard, CQI reporting can be used to achieve flexible transmission mode switching, where a preferred transmission mode (e.g., single or dual beam transmission) can be indicated by the UE or by the eNB.

[0027] As used herein, the term circuitry may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group), or memory (shared, dedicated, or group) that executes one or more software or firmware programs, a combinational logic circuit, or other suitable hardware components that provide the described functionality. In some embodiments, the circuitry may be implemented in, or functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware. Embodiments described herein may be implemented into a system using any suitably configured hardware or software.

[0028] FIG. 2 is a functional diagram of a User Equipment (UE) in accordance with some embodiments. The UE 200 may be suitable for use as a UE 102 as depicted in FIG. 1. In some embodiments, the UE 200 may include application circuitry 202, baseband circuitry 204, Radio Frequency (RF) circuitry 206, front-end module (FEM) circuitry 208, and multiple antennas 210A-210D, coupled together at least as shown. In some embodiments, other circuitry or arrangements may include one or more elements or components of the application circuitry 202, the baseband circuitry 204, the RF circuitry 206 or the FEM circuitry 208, and may also include other elements or components in some cases. As an example, “processing circuitry” may include one or more elements or components, some or all of which may be included in the application circuitry 202 or the baseband circuitry 204. As another example, “transceiver circuitry” may include one or more elements or components, some or all of which may be included in the RF circuitry 206 or the FEM circuitry 208. These examples are not limiting, however, as the processing circuitry or the transceiver circuitry may also include other elements or components in some cases.

[0029] The application circuitry 202 may include one or more application processors. For example, the application circuitry 202 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications or operating systems to run on the system.

[0030] The baseband circuitry 204 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 204 may include one or more baseband processors or control logic to process baseband signals received from a receive signal path of the RF circuitry 206 and to generate baseband signals for a transmit signal path of the RF circuitry 206. Baseband processing circuity 204 may interface with the application circuitry 202 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 206. For example, in some embodiments, the baseband circuitry 204 may include a second generation (2G) baseband processor 204a, third generation (3G) baseband processor 204b, fourth generation (4G) baseband processor 204c, or other baseband processor(s) 204d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 204 (e.g., one or more of baseband processors 204a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 206. 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 204 may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 204 may include Low Density Parity Check (LDPC) encoder/decoder functionality, optionally along-side other techniques such as, for example, block codes, convolutional codes, turbo codes, or the like, which may be used to support legacy protocols. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

[0031] In some embodiments, the baseband circuitry 204 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (EUTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), or radio resource control (RRC) elements. A central processing unit (CPU) 204e of the baseband circuitry 204 may be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP or RRC layers. In some embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (DSP) 204f. The audio DSP(s) 204f 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 204 and the application circuitry 202 may be implemented together such as, for example, on a system on chip (SOC).

[0032] In some embodiments, the baseband circuitry 204 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 204 may support communication with an evolved universal terrestrial radio access network (EUTRAN) or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 204 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[0033] RF circuitry 206 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 206 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 206 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 208 and provide baseband signals to the baseband circuitry 204. RF circuitry 206 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 204 and provide RF output signals to the FEM circuitry 208 for transmission.

[0034] In some embodiments, the RF circuitry 206 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 206 may include mixer circuitry 206a, amplifier circuitry 206b and filter circuitry 206c. The transmit signal path of the RF circuitry 206 may include filter circuitry 206c and mixer circuitry 206a. RF circuitry 206 may also include synthesizer circuitry 206d for synthesizing a frequency for use by the mixer circuitry 206a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 206a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 208 based on the synthesized frequency provided by synthesizer circuitry 206d. The amplifier circuitry 206b may be configured to amplify the down-converted signals and the filter circuitry 206c 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 204 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 206a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect. In some embodiments, the mixer circuitry 206a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 206d to generate RF output signals for the FEM circuitry 208. The baseband signals may be provided by the baseband circuitry 204 and may be filtered by filter circuitry 206c. The filter circuitry 206c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

[0035] In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion or upconversion respectively. In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a 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 206a of the receive signal path and the mixer circuitry 206a may be arranged for direct downconversion or direct upconversion, respectively. In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a of the transmit signal path may be configured for super-heterodyne operation.

[0036] 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 206 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 204 may include a digital baseband interface to communicate with the RF circuitry 206. 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.

[0037] In some embodiments, the synthesizer circuitry 206d 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 206d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider. The synthesizer circuitry 206d may be configured to synthesize an output frequency for use by the mixer circuitry 206a of the RF circuitry 206 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 206d may be a fractional N/N+1 synthesizer. In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry 204 or the applications processor 202 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 202.

[0038] Synthesizer circuitry 206d of the RF circuitry 206 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.

[0039] In some embodiments, synthesizer circuitry 206d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency may be a LO frequency (fLO). In some embodiments, the RF circuitry 206 may include an IQ/polar converter.

[0040] FEM circuitry 208 may include a receive signal path, which may include circuitry configured to operate on RF signals received from one or more of the antennas 210A-D, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 206 for further processing. FEM circuitry 208 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 206 for transmission by one or more of the one or more antennas 210A-D.

[0041] In some embodiments, the FEM circuitry 208 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 206). The transmit signal path of the FEM circuitry 208 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 206), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 210. In some embodiments, the UE 200 may include additional elements such as, for example, memory/storage, display, camera, sensor, or input/output (I/O) interface.

[0042] FIG. 3 is a functional diagram of an Evolved Node-B (eNB) in accordance with some embodiments. It should be noted that in some embodiments, the eNB 300 may be a stationary non-mobile device. The eNB 300 may be suitable for use as an eNB 104 as depicted in FIG. 1. The components of eNB 300 may be included in a single device or a plurality of devices. The eNB 300 may include physical layer (PHY) circuitry 302 and a transceiver 305, one or both of which may enable transmission and reception of signals to and from the UE 200, other eNBs, other UEs or other devices using one or more antennas 301A-B. As an example, the physical layer circuitry 302 may perform various encoding and decoding functions that may include formation of baseband signals for transmission and decoding of received signals. For example, physical layer circuitry 302 may include LDPC encoder/decoder functionality, optionally along-side other techniques such as, for example, block codes, convolutional codes, turbo codes, or the like, which may be used to support legacy protocols. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments. As another example, the transceiver 305 may perform various transmission and reception functions such as conversion of signals between a baseband range and a Radio Frequency (RF) range. Accordingly, the physical layer circuitry 302 and the transceiver 305 may be separate components or may be part of a combined component. In addition, some of the described functionality related to transmission and reception of signals may be performed by a combination that may include one, any or all of the physical layer circuitry 302, the transceiver 305, and other components or layers. The eNB 300 may also include medium access control layer (MAC) circuitry 304 for controlling access to the wireless medium. The eNB 300 may also include processing circuitry 306 and memory 308 arranged to perform the operations described herein. The eNB 300 may also include one or more interfaces 310, which may enable communication with other components, including other eNB 104 (FIG. 1), components in the EPC 120 (FIG. 1) or other network components. In addition, the interfaces 310 may enable communication with other components that may not be shown in FIG. 1, including components external to the network. The interfaces 310 may be wired or wireless or a combination thereof.

[0043] The antennas 210A-D (in the UE) and 301A-B (in the eNB) 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 210A-D, 301A-B may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result.

[0044] In some embodiments, the UE 200 or the eNB 300 may be a mobile device and may be a portable wireless communication device, such as a personal digital assistant (PDA), a laptop or portable computer with wireless communication capability, a web tablet, a wireless telephone, a smartphone, a wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, a wearable device such as a medical device (e.g., a heart rate monitor, a blood pressure monitor, etc.), or other device that may receive or transmit information wirelessly. In some embodiments, the UE 200 or eNB 300 may be configured to operate in accordance with 3GPP standards, although the scope of the embodiments is not limited in this respect. Mobile devices or other devices in some embodiments may be configured to operate according to other protocols or standards, including IEEE 802.11 or other IEEE standards. In some embodiments, the UE 200, eNB 300 or other device may include one or more of a keyboard, a display, a non-volatile memory port, multiple antennas, a graphics processor, an application processor, speakers, and other mobile device elements. The display may be an LCD screen including a touch screen.

[0045] Although the UE 200 and the eNB 300 are each 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), 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.

[0046] 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.

[0047] It should be noted that in some embodiments, an apparatus used by the UE 200 or eNB 300 may include various components of the UE 200 or the eNB 300 as shown in FIGs. 2-3. Accordingly, techniques and operations described herein that refer to the UE 200 (or 102) may be applicable to an apparatus for a UE. In addition, techniques and operations described herein that refer to the eNB 300 (or 104) may be applicable to an apparatus for an eNB.

[0048] FIGS. 4A-4B illustrate examples of multiple beam transmission scenarios utilizing an eNB and a UE in accordance with some embodiments. Although the example scenarios depicted in FIGS. 4A-4B may illustrate some aspects of techniques disclosed herein, it will be understood that embodiments are not limited by such example scenarios. Embodiments are not limited to the number or type of components shown in FIGS. 4A-4B and are also not limited to the number or arrangement of transmitted beams shown in FIGS. 4A-4B.

[0049] Referring to FIG. 4A, eNB 104 has multiple antennas (e.g., two antennas 410), which may be used in various groupings, and with various signal modifications for each grouping, to effectively produce a plurality of antenna ports 405 (e.g., P1-P4). In various embodiments within the framework of the illustrated example, each antenna port P1-P4 may be defined for one or more of the antennas 410. Each antenna port P1-P4 may correspond to a different transmission signal direction. Using the different antenna ports, eNB 104 may transmit multiple layers with codebook-based or non-codebook-based precoding techniques. According to some embodiments, each antenna port corresponds to a beam antenna port-specific CSI-RS signals transmitted via the respective antenna port. In other embodiments, there may be more, or fewer, antenna ports available at the eNB than the four antenna ports as illustrated in FIG. 4A.

[0050] On the UE side, there are a plurality of receive antennas 415. As illustrated in the example of FIG. 4A, the UE has two receive antennas. The multiple receive antennas may be used selectively to create receive beam forming. Receive beam forming may be used advantageously to increase the receive antenna gain for the direction(s) on which desired signals are received, and to suppress interference from neighboring cells, provided of course that the interference is received along different directions than the desired signals.

[0051] Some aspects of the embodiments are directed to achieving flexible transmission mode switching. Each of the antennas 410 (or 415) can have one or two of the antenna ports 405 associated with it, allowing for up to two layers of transmission per antenna. A single antenna can, therefore, provide single beam transmission with a rank of one (i.e., a single antenna port is used per antenna) or a rank of two (two antenna ports are used per antenna). Dual beam transmission can be provided by two antennas with a transmission rank of two (using one port for each of two antennas), three or four (using two ports for each of two antennas). As illustrated in FIG. 4A, two transmission (Tx) beams are used, utilizing the two antennas of eNB104 and a transmission rank of four (i.e., all four ports 405 are being used). In one embodiment, the eNB104 can indicate a preference for a single or dual beam transmission to the UE (e.g., as explained in reference to FIG. 5B). In this scenario, the UE can report back CSI (e.g., CQI) for a plurality of Tx beams (e.g., the two Tx beams seen in FIG. 4A). In another embodiment, the UE can indicate a preference for a single or dual beam transmission to the eNB (e.g., as explained in reference to FIG. 5A).

[0052] Additionally and in instances when dual beam transmission is selected (by the eNB or the UE), the UE can apply different derivation methods when determining the CQI (e.g., CQI can be derived using mutual interference of the received beams or not taking into account such mutual interference). The eNB can also indicate a preference of a desired CQI derivation method (e.g., as explained herein below).

[0053] In the example scenario in FIG. 4B, the eNB 104 may transmit a signal on multiple beams 420-440, any or all of which may be received at the UE 102. It should be noted that the number of beams or transmission angles as shown are not limiting. As the beams 420-440 may be directional, transmitted energy from the beams 420-440 may be concentrated in the direction shown. Therefore, the UE 102 may not necessarily receive a significant amount of energy from beam 440 in some cases, due to the relative location of the UE 102.

[0054] UE 102 may receive a significant amount of energy from the beams 420 and 430 as shown. As an example, the beams 405-420 may be transmitted using different reference signals, and the UE 102 may determine channel-state information (CSI) feedback or other information for beams 420 and 430. In some embodiments, each of beams 420-430 are configured as CSI reference signals (CSI-RS). In related embodiments, the CSI-RS signal is a part of the discovery reference signaling (DRS) configuration. The DRS configuration may serve to inform the UE 102 about the physical resources (e.g., subframes, subcarriers) on which the CSI-RS signal will be found. In related embodiments, the UE 102 is further informed about any scrambling sequences that are to be applied for CSI-RS.

[0055] In some embodiments, up to 2 MIMO layers may be transmitted within each beam by using different polarizations. More than 2 MIMO layers may be transmitted by using multiple beams. In related embodiments, the UE is configured to discover the available beams and report those discovered beams to the eNB prior to the MIMO data transmissions using suitable reporting messaging. Based on the reporting messaging, the eNB 104 may determine suitable beam directions for the MIMO layers to be used for data communications with the UE 102. In various embodiments, there may be up to 2, 4, 8, 16, 32, or more MIMO layers, depending on the number of MIMO layers that are supported by the eNB 104 and UE 102. In a given scenario, the number of MIMO layers that may actually be used will depend on the quality of the signaling received at the UE 102, and the availability of reflected beams arriving at diverse angles at the UE 102, such that the UE 102 may discriminate the data carried on the separate beams.

[0056] In the example scenario in FIG. 4B, the UE 102 may determine angles or other information (such as CSI feedback, including channel-quality indicator (CQI) or other) for the beams 420 and 430. The UE 102 may also determine such information when received at other angles, such as the illustrated beam 440. The beam 440 is demarcated using a dotted line configuration to indicate that it may not necessarily be transmitted at the indicated angle, but that the UE 102 may determine the beam direction of beam 440 using such techniques as receive beam-forming. This situation may occur, for example, when a transmitted beam reflects from an object in the vicinity of the UE 102, and arrives at the UE 102 according to its reflected, rather than incident, angle.

[0057] In some embodiments, the UE 102 may transmit one or more channel state information (CSI) messages to the eNB 104 as reporting messaging. Embodiments are not limited to dedicated CSI messaging, however, as the UE 102 may include relevant reporting information in control messages or other types of messages that may or may not be dedicated for communication of the CSI-type information.

[0058] As an example, the first signal received from the first eNB 104 may include a first directional beam 420 based at least partly on a first CSI-RS signal and a second directional beam 430 based at least partly on a second CSI-RS signal. The UE 102 may determine a rank indicator (RI) for the first CSI-RS and an RI for the second CSI-RS, and may transmit both RIs in the CSI messages. In some embodiments, the UE 102 may also determine a CQI, a precoding matrix indicator (PMI), receive angles or other information for one or both of the first and second signals. Such information may be included, along with one or more RIs, in the one or more CSI messages. In some embodiments, the UE 102 performs reference signal receive power (RSRP) measurement, received signal strength indication (RSSI) measurement, reference signal receive quality (RSRQ) measurement, or some combination of these using CSI-RS signals.

[0059] As an example, the first signal received from the eNB 104 may include a first directional beam based at least partly on a first CSI-RS signal and a second directional beam based at least partly on a second CSI-RS signal. The UE 102 may determine a first CSI measurement for the first directional beam and a second CSI measurement for the second directional beam based on the received CSI-RS. The CSI measurements can include a channel-quality indicator (CQI), a rank indicator (RI) and a precoding matrix indicator (PMI). The CQI can be used by the eNB transmitter to select one of several modulation alphabets and code rate combinations. The RI can be used to inform the transmitter about the number of useful transmission layers for a current MIMO channel, and the PMI can be used to indicate the codebook index of the precoding matrix (depending on the number of transmit antennas) that is applied at the transmitter. The code rate used by the eNB may be based on the CQI. The PMI may be a vector that is calculated by the cell station and reported to the eNB.

[0060] In this regard, the CQI may be an indication of the downlink mobile radio channel quality as experienced by the UE. The CQI allows the UE to propose to an eNB an optimum modulation scheme and coding rate to use for a given radio link quality so that the resulting transport block error rate would not exceed a certain value, such as 10%. In some embodiments, the UE may report a wideband CQI value which refers to the channel quality of the system bandwidth. The UE may also report a sub-band CQI value per sub-band of a certain number of resource blocks which may be configured by higher layers.

[0061] The PMI within the CSI may indicate an optimum precoding matrix to be used by the eNB for a given radio condition. The PMI value can refers to a codebook table. The network configures the number of resource blocks that are represented by a PMI report. In some embodiments, to cover the system bandwidth, multiple PMI reports may be provided. PMI reports may also be provided for closed loop spatial multiplexing, multi-user MIMO and closed-loop rank 1 precoding MIMO modes.

[0062] In accordance with an example embodiment, the UE can control transmission modes (e.g., single or dual beam transmission) by providing an indication (or preference) for a transmission mode in the CSI reported to the eNB (as explained herein below). In yet another example, the transmission mode selection can be controlled by the eNB, and the eNB can indicate a preference that CSI information is needed for multiple (e.g., 2) transmit beams.

[0063] FIG. 5A is a diagram illustrating channel state information (CSI) derivation and reporting for flexible transmission mode switching, in accordance with some embodiments. Referring to FIG. 5A, there is illustrated CSI derivation in a high frequency band system formed by the eNB and the UE. Transmit (Tx) and receive (Rx) beam forming can be used in such system so as to enlarge the cell coverage and/or improve the signal quality. Initially, the beamformed reference signals (RS) 510a are periodically transmitted to enable UE to acquire and maintain the preferred (optimal) Tx beam 515a, as well as candidate Tx beams 520a. The acquired optimal TX beam 515a and candidate Tx beams 520a are transmitted to the eNB. When the eNB intends to transmit data to the UE, the channel state information reference signal (CSI-RS) 525a, which can be beam formed based on the reported optimal Tx beam 515a and/or candidate beams 520a, is transmitted to the UE for channel quality measurement, so that eNB can determine the practical modulation and coding scheme, the number of streams, and best Tx beam at the current stage.

[0064] In some instances (e.g., due to movement of the UE), the wireless link between the eNB and the UE can change, and the transmission mode can be switched based on, e.g., such condition changes. For example, high rank transmission (such as dual beam transmission mode) can be supported, when there exist multiple strong channel clusters (e.g., at least two channel clusters), while low rank transmission is enabled when the spatial degree of freedom is deficient. In order to flexible switch between different ranks (e.g., between single and dual mode transmission), the following CQI reporting techniques can be used:

[0065] The CSI report sent from the UE to the eNB can contain Tx beam specific CSI information. More specifically and for two example Tx beams (e.g., one preferred/optimal and one candidate Tx beam), the CSI information can include implicit or explicit index Tx1 of one candidate Tx beam; the RI1, PMI1, and CQI1 of candidate beam Tx1; the implicit or explicit index Tx2 of the other candidate Tx beam; and the RI2, PMI2, CQI2 of candidate beam Tx2. The beam index can be an explicit or an implicit beam index. An explicit beam index can be the beam number as transmitted from the eNB (e.g., for a first of 48 possible beams, the explicit beam index will be 1). An implicit beam index can be associated with the antenna port number used to transmit the beam.

[0066] CSI REPORTING

[0067] In accordance with an example embodiment, the different transmission modes, including dual beam transmission and single beam transmission, can be distinguished via flexible CSI/CQI reporting, as follows:

[0068] (1) In instances when beam index Tx2 is different from beam index Tx1 (and/or any of the RI, PMI and CQI are different between the beams), then a preference for dual beam transmission is indicated by the UE to the eNB;

[0069] (2) In instances when Tx1, RI1, PMI1, and CQI1 are equal to Tx2, RI2, PMI2, CQI2, respectively, the UE can indicate a preference for a single beam transmission to the eNB; and

[0070] (3) As an alternative to (2), if beam index Tx2 is the same as beam index Tx1, while RI2, PMI2, and CQI2 are set to zero, a preference for a single beam transmission is indicated by the UE to the eNB.

[0071] The UE can use any of examples (1)-(3) above to report the beam index and the CSI information so as to indicate a preference for a single or dual beam transmission and trigger flexible transmission mode switching.

[0072] Referring again to FIG. 5A, CSI information 530a, 535a for, e.g., an optimal and a candidate beam, can be reported to the eNB. The beam index (and/or the CSI for each beam) can be different. Based on the different values, the UE can indicate to the eNB a preference for a dual beam transmission. Downlink data 540a can then be transmitted using two Tx beams 550a and 560a.

[0073] In another instance, the UE can set index Tx2, RI2, PMI2 and CQI2 to be equal to (even though they may be different from) Tx1, RI1, PMI1, and CQI1, thereby indicating a preference to the eNB for a single beam transmission.

[0074] In yet another instance, the UE can set RI2, PMI2 and CQI2 to be equal to zero, thereby indicating a preference to the eNB for a single beam transmission.

[0075] FIG. 5B illustrates CSI derivation and reporting based on downlink control information (DCI), in accordance with some embodiments. In another embodiment, selection of the transmission mode may be controlled by the eNB. For example, a new beam searching algorithm (BSA) value 520b can be added in the Downlink Control Information (DCI) 510b, sent by the eNB to the UE. For example, when the BSA value 520b is equal to a pre-defined (and known to the UE) value x, the dual-beam Channel State Information (CSI) report is required by the eNB for purposes of dual beam transmission. Similarly, when the BSA value 520b is equal to another pre-defined (and known to the UE) value y, single CSI report is required by the eNB for purposes of single beam transmission. In the particular example in FIG. 5B, the BSA value 520b indicates a preference for a dual beam transmission, and CSI information 530b and 540b (for Tx beams 1 and 2, respectively) is communicated back to the eNB.

[0076] CQI DERIVATION

[0077] In instances when dual beam transmission is used, the transmitted signals of two different beams will cause interference to each other at the UE. In this regard, whether or not CQI derivation takes into account the mutual interference should be consistent between (and known by both) the eNB and the UE.

[0078] In accordance with an example embodiment, the CQI derivation without taking the mutual interference into consideration, can be set as a default configuration (and can be known to both the eNB and the UE as the default configuration).

[0079] Without mutual interference, the CQI can be derived based on the following formula:

[0080] $$P_{sig} / (P_{\mathrm{intf}} + P_{\mathrm{noise}}),$$

[0081] where P_{sig} is the signal power, P_{intf} is the interference power, and P_{noise} is the noise power. Using this CQI derivation technique, the eNB can perform flexible centric scheduling, and the computation complexity of the UE during CQI derivation is simplified. For instance, if the eNB is equipped with two individual RF chains, the cell capacity can be optimized by deciding whether to transmit a single beam to two users or whether to transmit dual beams to one user.

[0082] In accordance with another example embodiment, the CQI derivation based on taking the mutual interference into consideration can be set as a default configuration.

[0083] If considering the mutual interference, an additional interference will be added, resulting in the following formula:

$P_{sig} / (P_{intf} + P_{mutual,intf} + P_{noise})$, where $P_{mutual,intf}$ is the additional mutual interference power. By taking into account the mutual interference, the eNB and the UE can optimize the Tx beam selection between dual beams. For example, in instances when two non-ideal backhaul eNBs are grouped to realize beam aggregation, this mechanism can reduce the overhead for information exchange.

[0084] In yet another embodiment, a 1-bit indicator can be configured by the eNB through the high layer signaling via, e.g., a master information block (MIB), a system information block (SIB), radio resource configuration (RRC) signaling, and/or downlink control information (DCI). This indicator can be used by the eNB to inform the UE to derive the CQI with taking the mutual interference into consideration, or not taking the mutual interference into consideration (e.g., based on the indicator bit value).

[0085] In yet another embodiment, the eNB can indicate a preference for the CQI derivation method (e.g., whether or not to account for mutual interference) based on the beam searching algorithm indicated by the BSA value (e.g., 520b in FIG. 5B) in the DCI. For example, if dual-beam CSI is required by the BSA, the UE can calculate the CQI based on the mutual interference from the dual beams.

[0086] FIGS. 6-8 are flow diagrams illustrating example functionalities for CQI derivation and/or reporting according to some embodiments. The example process in each flow diagram 600 and 800 may be performed by the UE 102, or by a UE device having a different architecture. The example process in flow diagram 700 may be performed by the eNB 104. Notably, the process in each flow diagram is a machine-implemented process that can operate autonomously (i.e., without user interaction). In addition, it is important to note that the process in each flow diagram is a richly-featured embodiment that may be realized as described; in addition, portions of the process may be implemented while others are excluded in various embodiments. The following Additional Notes and Examples section details various combinations, without limitation, that are contemplated. It should also be noted that in various embodiments, certain process operations may be performed in a different ordering than depicted in FIGS. 6-8.

[0087] Referring to FIG. 1-6, the example process 600 may be performed by the UE 102. More specifically, at 610, the UE102 reports to an Evolved Node-B (eNB) 104, a plurality of transmit (Tx) beams as preferred Tx beams (e.g., beams 515a, 520a). At 620, the UE 102 receives a channel state information reference signal (CSI-RS) 525a, the CSI-RS beamformed based on the plurality of preferred Tx beams. At 630, in response to the CSI-RS 525a, the UE 102 determines channel state information (CSI) for at least two of the preferred Tx beams (e.g., CSI 530a for a first beam and CSI 535a for a second beam), where the CSI includes a transmission beam index for each of the preferred Tx beams. At 640, the UE 102 reports the determined CSI (530a and 535a) to the eNB 104. The reported CSI can be configured by the UE to indicate a preferred transmission mode, based at least in part on the transmission beam index. For example, the following CSI reporting techniques can be used:

[0088] (1) In instances when beam index Tx2 is different from beam index Tx1 (and/or any of the RI, PMI and CQI are different between the beams), then a preference for dual beam transmission is indicated by the UE to the eNB (in this regard, a dual beam transmission mode can be determined solely based on the difference of the transmission beam indices);

[0089] (2) In instances when Tx1, RI1, PMI1, and CQI1 are equal to Tx2, RI2, PMI2, CQI2, respectively, the UE can indicate a preference for a single beam transmission to the eNB; and

[0090] (3) As an alternative to (2), if beam index Tx2 is the same as beam index Tx1, while RI2, PMI2, and CQI2 are set to zero, a preference for a single beam transmission is indicated by the UE to the eNB.

[0091] At 650, the UE 102 receives a downlink (DL) data transmission 540a from the eNB in accordance with the indicated preferred transmission mode.

[0092] Referring to FIGS. 1-5B and 7, the example process 700 may be performed by the eNB 104. More specifically, at 710, the eNB 104 receives from user equipment (UE) 102, a plurality of transmit (Tx) beams as preferred Tx beams (e.g., beams 515a, 520a). AT 720, the eNB 104 transmits to the UE 102 a channel state information reference signal (CSI-RS) 525a. The CSI-RS 525a is beamformed based on the plurality of preferred Tx beams (e.g., 515a and/or 520a). AT 730, the eNB 104 receives from the UE 102 channel state information (CSI) (530a, 535a) for at least two of the preferred Tx beams, the CSI including a transmission beam index for each of the Tx beams. At 740, the eNB determines a transmission mode based at least in part on the transmission beam indices in the CSI for the at least two of the preferred Tx beams. The transmission mode can be, for example, a single beam transmission mode or a dual beam transmission mode, as discussed in reference to FIG. 6 above. At 750, the eNB 104 initiates a downlink (DL) data (540a) transmission in accordance with the determined transmission mode.

[0093] Referring to FIG. 1-5B and 8, the example process 800 may be performed by the UE 102. More specifically, at 810, the UE102 receives from the eNB 104 a channel state information reference signal (CSI-RS) 525a, the CSI-RS 525a beamformed based on a plurality of preferred Tx beams (e.g., 515a, 520a). At 820, the UE 102 receives from the eNB 104 downlink control information (DCI) 510b. The DCI 510b includes an indicator (e.g., 520b) of a transmission mode. At 830, in response to the CSI-RS and based on the transmission mode, the UE 102 determines channel state information (CSI) for one or more of the preferred Tx beams (e.g., 530b, 540b). At 840, the UE 102 reports the determined CSI (530b, 540b) to the eNB 104. AT 850, the UE 102 receives a downlink (DL) data (e.g., 540a) transmission from the eNB 104 in accordance with the transmission mode, the transmission mode based on the determined CSI.

[0094] FIG. 9 illustrates a block diagram of a communication device such as an eNB or a UE, in accordance with some embodiments. In alternative embodiments, the communication device 900 may operate as a standalone device or may be connected (e.g., networked) to other communication devices. In a networked deployment, the communication device 900 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 900 may act as a peer communication device in peer-to-peer (P2P) (or other distributed) network environment. The communication device 900 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.

[0095] 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.

[0096] 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.

[0097] Communication device (e.g., computer system) 900 may include a hardware processor 902 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 904 and a static memory 906, some or all of which may communicate with each other via an interlink (e.g., bus) 908. The communication device 900 may further include a display unit 910, an alphanumeric input device 912 (e.g., a keyboard), and a user interface (UI) navigation device 914 (e.g., a mouse). In an example, the display unit 910, input device 912 and UI navigation device 914 may be a touch screen display. The communication device 900 may additionally include a storage device (e.g., drive unit) 916, a signal generation device 918 (e.g., a speaker), a network interface device 920, and one or more sensors 921, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The communication device 900 may include an output controller 928, 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.).

[0098] The storage device 916 may include a communication device readable medium 922 on which is stored one or more sets of data structures or instructions 924 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 924 may also reside, completely or at least partially, within the main memory 904, within static memory 906, or within the hardware processor 902 during execution thereof by the communication device 900. In an example, one or any combination of the hardware processor 902, the main memory 904, the static memory 906, or the storage device 916 may constitute communication device readable media.

[0099] While the communication device readable medium 922 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 924.

[00100] 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 900 and that cause the communication device 900 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.

[00101] The instructions 924 may further be transmitted or received over a communications network 926 using a transmission medium via the network interface device 920 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 920 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 926. In an example, the network interface device 920 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 920 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 900, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

[00102] Additional notes and examples:

[00103] Example 1 is an apparatus of user equipment (UE), the apparatus can include memory; and processing circuitry coupled to the memory, the processing circuitry configured to: generate a reporting message for an Evolved Node-B (eNB), the reporting message indicating a plurality of transmit (Tx) beams as preferred Tx beams; in response to a channel state information reference signal (CSI-RS), determine channel state information (CSI) for at least two of the preferred Tx beams, the CSI-RS beamformed based on the plurality of preferred Tx beams, and the CSI comprising a transmission beam index for each of the preferred Tx beams; report the determined CSI to the eNB, wherein the CSI is configured by the UE to indicate a preferred transmission mode base at least in part on the transmission beam index for each of the preferred Tx beams; and process a downlink (DL) data transmission from the eNB, the downlink data transmission associated with the indicated preferred transmission mode.

[00104] In Example 2, the subject matter of Example 1 optionally includes wherein the processing circuitry comprises baseband processing circuitry, and wherein the CSI for each of the at least two preferred Tx beams further comprises: a rank indicator (RI); a precoding matrix indicator (PMI); and a channel quality indicator (CQI).

[00105] In Example 3, the subject matter of any one or more of Examples 1–2 optionally include or 2, wherein the preferred transmission mode comprises: a single beam transmission mode, when the transmission beam index is the same for the preferred Tx beams; or a dual beam transmission mode, when the transmission beam index is different for the preferred Tx beams.

[00106] In Example 4, the subject matter of any one or more of Examples 1–3 optionally include or 2, wherein the plurality of preferred Tx beams comprises at least a first Tx beam and a second Tx beam.

[00107] In Example 5, the subject matter of Example 4 optionally includes wherein the CSI comprises a first CSI associated with the first Tx beam and a second CSI associated with the second Tx beam.

[00108] In Example 6, the subject matter of Example 5 optionally includes wherein the processing circuitry is further configured to: indicate the preferred transmission mode to the eNB by setting a transmission beam index, an RI, a PMI and a CQI in the second CSI to be equal to a corresponding transmission beam index, RI, PMI and CQI in the first CSI.

[00109] In Example 7, the subject matter of any one or more of Examples 5–6 optionally include wherein the processing circuitry is further configured to: indicate the preferred transmission mode to the eNB by setting RI, PMI and CQI in the second CSI to be equal to zero.

[00110] In Example 8, the subject matter of any one or more of Examples 6–7 optionally include or 7, wherein the indicated preferred transmission mode is a single beam transmission mode.

[00111] In Example 9, the subject matter of any one or more of Examples 5–8 optionally include wherein the processing circuitry is further configured to: obtain RI, PMI and CQI measurements for the first CSI and for the second CSI.

[00112] In Example 10, the subject matter of Example 9 optionally includes wherein the processing circuitry is further configured to: indicate a dual beam transmission mode to the eNB when the RI, PMI and CQI measurements for the first CSI are different from the RI, PMI, and CQI measurements for the second CSI.

[00113] In Example 11, the subject matter of any one or more of Examples 1–10 optionally include a transceiver; and an antenna assembly coupled to the transceiver, wherein the transceiver is configured to transmit and receive signal using the antenna assembly.

[00114] In Example 12, the subject matter of Example 11 optionally includes wherein the transceiver is further configured to: receive downlink control information (DCI) from the eNB, the DCI comprising a beam searching algorithm (BSA) value.

[00115] In Example 13, the subject matter of Example 12 optionally includes wherein the processing circuitry is further configured, based on the BSA value, to: report the CSI for only one of the preferred Tx beams for a single beam transmission mode; or report the CSI for the at least two preferred Tx beams for a dual beam transmission mode.

[00116] In Example 14, the subject matter of any one or more of Examples 9–13 optionally include or 10, wherein the processing circuitry is further configured to: using an indication from the eNB associated with a CQI derivation method, apply the indicated CQI derivation method to obtain the CQI measurements for the first CSI and for the second CSI.

[00117] In Example 15, the subject matter of Example 14 optionally includes wherein the CQI derivation method is based on one of: obtain the CQI measurements without accounting for interference between the first Tx beam and the second Tx beam at the UE and during a dual beam transmission from the eNB; or obtain the CQI measurements with accounting for interference between the first Tx beam and the second Tx beam at the UE and during the dual beam transmission from the eNB.

[00118] Example 16 is a method for flexible transmission mode switching, comprising: by a user equipment (UE): reporting to an Evolved Node-B (eNB), a plurality of transmit (Tx) beams as preferred Tx beams; receiving a channel state information reference signal (CSI-RS), the CSI-RS beamformed based on the plurality of preferred Tx beams; in response to the CSI-RS, determining channel state information (CSI) for at least two of the preferred Tx beams, the CSI comprising a transmission beam index for each of the preferred Tx beams; reporting the determined CSI to the eNB, wherein the CSI is configured by the UE to indicate a preferred transmission mode based at least in part on the transmission beam index for each of the preferred Tx beams; and receiving a downlink (DL) data transmission from the eNB in accordance with the indicated preferred transmission mode.

[00119] In Example 17, the subject matter of Example 16 optionally includes wherein the processing circuitry comprises baseband processing circuitry, and wherein the CSI for each of the at least two preferred Tx beams further comprises: a rank indicator (RI); a precoding matrix indicator (PMI); and a channel quality indicator (CQI).

[00120] In Example 18, the subject matter of any one or more of Examples 16–17 optionally include or 17, wherein the transmission mode comprises: a single beam transmission mode, when the transmission beam index is the same for the preferred Tx beams; or a dual beam transmission mode, when the transmission beam index is different for the preferred Tx beams.

[00121] In Example 19, the subject matter of any one or more of Examples 16–18 optionally include or 17, wherein the plurality of preferred Tx beams comprises at least a first Tx beam and a second Tx beam.

[00122] In Example 20, the subject matter of Example 19 optionally includes wherein the CSI comprises a first CSI associated with the first Tx beam and a second CSI associated with the second Tx beam.

[00123] In Example 21, the subject matter of Example 20 optionally includes indicating the preferred transmission mode to the eNB by setting a transmission beam index, RI, PMI and CQI in the second CSI to be equal to corresponding transmission beam index, RI, PMI and CQI in the first CSI.

[00124] In Example 22, the subject matter of any one or more of Examples 20–21 optionally include indicating the preferred transmission mode to the eNB by setting RI, PMI and CQI in the second CSI to be equal to zero.

[00125] In Example 23, the subject matter of any one or more of Examples 21–22 optionally include or 22, wherein the indicated preferred transmission mode is a single beam transmission mode.

[00126] In Example 24, the subject matter of any one or more of Examples 20–23 optionally include obtaining RI, PMI and CQI measurements for the first CSI and for the second CSI.

[00127] In Example 25, the subject matter of Example 24 optionally includes indicating a dual beam transmission mode to the eNB when the RI, PMI and CQI measurements for the first CSI are different from the RI, PMI, and CQI measurements for the second CSI.

[00128] In Example 26, the subject matter of any one or more of Examples 16–25 optionally include receiving downlink control information (DCI) from the eNB, the DCI comprising a beam searching algorithm (BSA) value.

[00129] In Example 27, the subject matter of any one or more of Examples 16–26 optionally include receiving downlink control information (DCI) from the eNB, the DCI comprising a beam searching algorithm (BSA) value; and based on the BSA value: reporting the CSI for only one of the preferred Tx beams for a single beam transmission mode; or reporting the CSI for the at least two preferred Tx beams for a dual beam transmission mode.

[00130] In Example 28, the subject matter of any one or more of Examples 26–27 optionally include based on the BSA value: reporting the CSI for only one of the preferred Tx beams for a single beam transmission mode; or reporting the CSI for the at least two preferred Tx beams for a dual beam transmission mode.

[00131] In Example 29, the subject matter of any one or more of Examples 24–28 optionally include or 25, further comprising: receiving an indication from the eNB associated with a CQI derivation method; and applying the indicated CQI derivation method to obtain the CQI measurements for the first CSI and for the second CSI.

[00132] In Example 30, the subject matter of Example 29 optionally includes wherein the CQI derivation method is based on one of: obtain the CQI measurements without accounting for interference between the first Tx beam and the second Tx beam at the UE and during a dual beam transmission from the eNB; or obtain the CQI measurements with accounting for interference between the first Tx beam and the second Tx beam at the UE and during the dual beam transmission from the eNB.

[00133] Example 31 is at least one machine-readable medium that, when executed by a machine, causes the machine to perform any of the methods of Examples 16–30.

[00134] Example 32 is a device comprising means to perform any of the methods of Examples 16–30.

[00135] Example 33 is a user equipment (UE) device, comprising: means for reporting to an Evolved Node-B (eNB), a plurality of transmit (Tx) beams as preferred Tx beams; means for receiving a channel state information reference signal (CSI-RS), the CSI-RS beamformed based on the plurality of preferred Tx beams; means for, in response to the CSI-RS, determining channel state information (CSI) for at least two of the preferred Tx beams, the CSI comprising a transmission beam index for each of the preferred Tx beams; means for reporting the determined CSI to the eNB, wherein the CSI is configured by the UE to indicate a preferred transmission mode base at least in part on the transmission beam index for each of the preferred Tx beams; and means for receiving a downlink (DL) data transmission from the eNB in accordance with the indicated preferred transmission mode.

[00136] In Example 34, the subject matter of Example 33 optionally includes wherein the CSI for each of the at least two preferred Tx beams further comprises: a rank indicator (RI); a precoding matrix indicator (PMI); and a channel quality indicator (CQI).

[00137] In Example 35, the subject matter of any one or more of Examples 33–34 optionally include or 34, wherein the transmission mode comprises: a single beam transmission mode, when the transmission beam index is the same for the preferred Tx beams; or a dual beam transmission mode, when the transmission beam index is different for the preferred Tx beams.

[00138] In Example 36, the subject matter of any one or more of Examples 33–35 optionally include or 34, wherein the plurality of preferred Tx beams comprises at least a first Tx beam and a second Tx beam.

[00139] In Example 37, the subject matter of Example 36 optionally includes wherein the CSI comprises a first CSI associated with the first Tx beam and a second CSI associated with the second Tx beam.

[00140] In Example 38, the subject matter of Example 37 optionally includes means for indicating the preferred transmission mode to the eNB by setting a transmission beam index, RI, PMI and CQI in the second CSI to be equal to corresponding transmission beam index, RI, PMI and CQI in the first CSI.

[00141] In Example 39, the subject matter of any one or more of Examples 37–38 optionally include means for indicating the preferred transmission mode to the eNB by setting RI, PMI and CQI in the second CSI to be equal to zero.

[00142] In Example 40, the subject matter of any one or more of Examples 38–39 optionally include or 39, wherein the indicated preferred transmission mode is a single beam transmission mode.

[00143] In Example 41, the subject matter of any one or more of Examples 37–40 optionally include means for obtaining transmission beam index, RI, PMI and CQI measurements for the first CSI and for the second CSI.

[00144] In Example 42, the subject matter of Example 41 optionally includes means for indicating a dual beam transmission mode to the eNB when the transmission beam index, RI, PMI and CQI measurements for the first CSI are different from the transmission beam index, RI, PMI, and CQI measurements for the second CSI.

[00145] In Example 43, the subject matter of any one or more of Examples 33–42 optionally include means for receiving downlink control information (DCI) from the eNB, the DCI comprising a beam searching algorithm (BSA) value.

[00146] In Example 44, the subject matter of Example 43 optionally includes means for reporting based on the BSA value, the CSI for only one of the preferred Tx beams for a single beam transmission mode; or means for reporting based on the BSA value, the CSI for the at least two preferred Tx beams for a dual beam transmission mode.

[00147] In Example 45, the subject matter of any one or more of Examples 41–44 optionally include or 42, further comprising: means for receiving an indication from the eNB associated with a CQI derivation method; and means for applying the indicated CQI derivation method to obtain the CQI measurements for the first CSI and for the second CSI.

[00148] In Example 46, the subject matter of Example 45 optionally includes wherein the CQI derivation method is based on one of: obtain the CQI measurements without accounting for interference between the first Tx beam and the second Tx beam at the UE and during a dual beam transmission from the eNB; or obtain the CQI measurements with accounting for interference between the first Tx beam and the second Tx beam at the UE and during the dual beam transmission from the eNB.

[00149] Example 47 is an apparatus of an Evolved Node-B (eNB), the apparatus comprising processing circuitry, the processing circuitry configured to: receive from user equipment (UE), a plurality of transmit (Tx) beams as

preferred Tx beams; beamforming a channel state information reference signal (CSI-RS) based on an indication from a user equipment (UE) of a plurality of transmit (Tx) beams as preferred Tx beams; using channel state information (CSI) from the UE for at least two of the preferred Tx beams, determine a transmission mode based on a transmission beam index in the CSI for the at least two of the preferred Tx beams, wherein the transmission mode is a single beam transmission mode or a dual beam transmission mode; and initiate a downlink (DL) data transmission in accordance with the determined transmission mode.

[00150] In Example 48, the subject matter of Example 47 optionally includes wherein the processing circuitry is further configured to: obtain a rank indicator (RI), a precoding matrix indicator (PMI), and a channel quality indicator (CQI) for each of the preferred Tx beams based on the CSI.

[00151] In Example 49, the subject matter of Example 48 optionally includes wherein the processing circuitry is further configured to: initiate the DL data transmission in accordance with a single beam transmission mode when the RI, the PMI and the CQI for a first one of the preferred Tx beams are equal to the RI, the PMI and the CQI for a second one of the preferred Tx beams.

[00152] In Example 50, the subject matter of any one or more of Examples 48–49 optionally include wherein the processing circuitry is further configured to: initiate the DL data transmission in accordance with a single beam transmission mode when the RI, the PMI and the CQI for at least one of the preferred Tx beams are equal to zero.

[00153] In Example 51, the subject matter of any one or more of Examples 48–50 optionally include wherein the processing circuitry is further configured to: initiate the DL data transmission in accordance with a dual beam transmission mode when the transmission beam index, the RI, the PMI and/or the CQI for a first one of the preferred Tx beams are different from the corresponding transmission beam index, the RI, the PMI and/or the CQI for a second one of the preferred Tx beams.

[00154] In Example 52, the subject matter of any one or more of Examples 47–51 optionally include or 48, wherein the processing circuitry is further configured to: during the dual beam transmission mode of at least two Tx beams, generate an indicator for transmission to the UE, the indicator indicating a CQI derivation mode, wherein the CQI derivation mode specifies whether mutual interference between the at least two Tx beams is taken into account during CQI derivation.

[00155] Example 53 is a method for flexible transmission mode switching, comprising: by an Evolved Node-B (eNB): receiving from user equipment (UE), a plurality of transmit (Tx) beams as preferred Tx beams; transmitting to the UE a channel state information reference signal (CSI-RS), the CSI-RS beamformed based on the plurality of preferred Tx beams; receiving from the UE channel state information (CSI) for at least two of the preferred Tx beams, the CSI comprising a transmission beam index for each of the preferred Tx beams; determining a transmission mode based on the transmission beam index in the CSI for the at least two of the preferred Tx beams, wherein the transmission mode is a single beam transmission mode or a dual beam transmission mode; and initiating a downlink (DL) data transmission in accordance with the determined transmission mode.

[00156] In Example 54, the subject matter of Example 53 optionally includes obtaining a rank indicator (RI), a precoding matrix indicator (PMI), and a channel quality indicator (CQI) for each of the preferred Tx beams based on the CSI.

[00157] In Example 55, the subject matter of Example 54 optionally includes initiating the DL data transmission in accordance with a single beam transmission mode when the transmission beam index, the RI, the PMI and/or the CQI for a first one of the preferred Tx beams are equal to the transmission beam index, the RI, the PMI and/or the CQI for a second one of the preferred Tx beams.

[00158] In Example 56, the subject matter of any one or more of Examples 54–55 optionally include initiating the DL data transmission in accordance with a single beam transmission mode when the RI, the PMI and the CQI for at least one of the preferred Tx beams are equal to zero.

[00159] In Example 57, the subject matter of any one or more of Examples 54–56 optionally include initiating the DL data transmission in accordance with a dual beam transmission mode when the transmission beam index, the RI, the PMI and the CQI for a first one of the preferred Tx beams are different from the transmission beam index, the RI, the PMI and the CQI for a second one of the preferred Tx beams.

[00160] In Example 58, the subject matter of any one or more of Examples 53–57 optionally include or 54, further comprising: during the dual beam transmission mode of at least two Tx beams, transmitting an indicator to the UE on a CQI derivation mode, wherein the CQI derivation mode specifies whether mutual interference between the at least two Tx beams is taken into account during CQI derivation.

[00161] Example 59 is at least one machine-readable medium that, when executed by a machine, causes the machine to perform any of the methods of Examples 53-58.

[00162] Example 60 is a device comprising means to perform any of the methods of Examples 53-58.

[00163] Example 61 is a computer-readable medium comprising instructions that, when executed on processing circuitry of a user equipment (UE), cause the UE to: receive from an Evolved Node-B (eNB) a channel state information reference signal (CSI-RS), the CSI-RS beamformed based on a plurality of preferred Tx beams; receive from the eNB downlink control information (DCI), the DCI comprising an indicator of a transmission mode; in response to the CSI-RS and based on the transmission mode, determine channel state information (CSI) for one or more of the preferred Tx beams; report the determined CSI to the eNB; and receive a downlink (DL) data transmission from the eNB in accordance with the transmission mode, the transmission mode based on the determined CSI.

[00164] In Example 62, the subject matter of Example 61 optionally includes wherein the DCI comprises a beam searching algorithm (BSA) value indicating the transmission mode.

[00165] In Example 63, the subject matter of any one or more of Examples 61–62 optionally include wherein the dual beam transmission mode is associated with at least a first Tx beam and a second Tx beam of the preferred Tx beams, and wherein the instructions further cause the UE to:

derive a first channel quality indicator (CQI) for the first Tx beam and a second CQI for the second Tx beam based on the CQI derivation method.

[00166] In Example 64, the subject matter of Example 63 optionally includes wherein the instructions further cause the UE to: obtain the first and second CQIs without accounting for interference between the first Tx beam and the second Tx beam at the UE; or obtain the first and second CQIs with accounting for interference between the first Tx beam and the second Tx beam at the UE.

[00167] The above detailed description includes references to the accompanying drawings, which form a part of the detailed description. The drawings show, by way of illustration, specific embodiments that may be practiced. These embodiments are also referred to herein as “examples.” Such examples may include elements in addition to those shown or described. However, also contemplated are examples that include the elements shown or described. Moreover, also contemplated are examples using any combination or permutation of those elements shown or described (or one or more aspects thereof), either with respect to a particular example (or one or more aspects thereof), or with respect to other examples (or one or more aspects thereof) shown or described herein.

[00168] Publications, patents, and patent documents referred to in this document are incorporated by reference herein in their entirety, as though individually incorporated by reference. In the event of inconsistent usages between this document and those documents so incorporated by reference, the usage in the incorporated reference(s) are supplementary to that of this document; for irreconcilable inconsistencies, the usage in this document controls.

[00169] 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 the appended claims, 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, device, article, 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 suggest a numerical order for their objects.

[00170] The above description is intended to be illustrative, and not restrictive. For example, the above-described examples (or one or more aspects thereof) may be used in combination with others. Other embodiments may be used, such as by one of ordinary skill in the art upon reviewing the above description. The Abstract is to allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. Also, in the above Detailed Description, various features may be grouped together to streamline the disclosure. However, the claims may not set forth every feature disclosed herein as embodiments may feature a subset of said features. Further, embodiments may include fewer features than those disclosed in a particular example. Thus, the following claims are hereby incorporated into the Detailed Description, with a claim standing on its own as a separate embodiment. The scope of the embodiments disclosed herein is to be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

CLAIMS

What is claimed is:

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

memory; and

processing circuitry coupled to the memory, the processing circuitry configured to:

generate a reporting message for an Evolved Node-B (eNB), the reporting message indicating a plurality of transmit (Tx) beams as preferred Tx beams;

in response to a channel state information reference signal (CSI-RS), determine channel state information (CSI) for at least two of the preferred Tx beams, the CSI-RS beamformed based on the plurality of preferred Tx beams, and the CSI comprising a transmission beam index for each of the preferred Tx beams;

report the determined CSI to the eNB, wherein the CSI is configured by the UE to indicate a preferred transmission mode base at least in part on the transmission beam index for each of the preferred Tx beams; and

process a downlink (DL) data transmission from the eNB, the downlink data transmission associated with the indicated preferred transmission mode.

2. The apparatus of claim 1, wherein the processing circuitry comprises baseband processing circuitry, and wherein the CSI for each of the at least two preferred Tx beams further comprises:

a rank indicator (RI);

a precoding matrix indicator (PMI); and

a channel quality indicator (CQI).

3. The apparatus of claims 1 or 2, wherein the preferred transmission mode comprises:

a single beam transmission mode, when the transmission beam index is the same for the preferred Tx beams; or a dual beam transmission mode, when the transmission beam index is different for the preferred Tx beams.

4. The apparatus of claims 1 or 2, wherein the plurality of preferred Tx beams comprises at least a first Tx beam and a second Tx beam.

5. The apparatus of claim 4, wherein the CSI comprises a first CSI associated with the first Tx beam and a second CSI associated with the second Tx beam.

6. The apparatus of claim 5, wherein the processing circuitry is further configured to:

indicate the preferred transmission mode to the eNB by setting a transmission beam index, an RI, a PMI and a CQI in the second CSI to be equal to a corresponding transmission beam index, RI, PMI and CQI in the first CSI.

7. The apparatus of claim 5, wherein the processing circuitry is further configured to:

indicate the preferred transmission mode to the eNB by setting RI, PMI and CQI in the second CSI to be equal to zero.

8. The apparatus of claims 6 or 7, wherein the indicated preferred transmission mode is a single beam transmission mode.

9. The apparatus of claim 5, wherein the processing circuitry is further configured to:

obtain RI, PMI and CQI measurements for the first CSI and for the second CSI.

10. The apparatus of claim 9, wherein the processing circuitry is further configured to:

indicate a dual beam transmission mode to the eNB when the RI, PMI and CQI measurements for the first CSI are different from the RI, PMI, and CQI measurements for the second CSI.

11. The apparatus of claim 1, further comprising:

a transceiver; and

an antenna assembly coupled to the transceiver, wherein the transceiver is configured to transmit and receive signal using the antenna assembly.

12. The apparatus of claim 11, wherein the transceiver is further configured to:

receive downlink control information (DCI) from the eNB, the DCI comprising a beam searching algorithm (BSA) value.

13. The apparatus of claim 12, wherein the processing circuitry is further configured, based on the BSA value, to:

report the CSI for only one of the preferred Tx beams for a single beam transmission mode; or

report the CSI for the at least two preferred Tx beams for a dual beam transmission mode.

14. The apparatus of claim 9 or 10, wherein the processing circuitry is further configured to:

using an indication from the eNB associated with a CQI derivation method, apply the indicated CQI derivation method to obtain the CQI measurements for the first CSI and for the second CSI.

15. The apparatus of claim 14, wherein the CQI derivation method is based on one of:

obtain the CQI measurements without accounting for interference between the first Tx beam and the second Tx beam at the UE and during a dual beam transmission from the eNB; or obtain the CQI measurements with accounting for interference between the first Tx beam and the second Tx beam at the UE and during the dual beam transmission from the eNB.

16. An apparatus of an Evolved Node-B (eNB), the apparatus comprising processing circuitry, the processing circuitry configured to:

receive from user equipment (UE), a plurality of transmit (Tx) beams as preferred Tx beams;

beamforming a channel state information reference signal (CSI-RS) based on an indication from a user equipment (UE) of a plurality of transmit (Tx) beams as preferred Tx beams;

using channel state information (CSI) from the UE for at least two of the preferred Tx beams, determine a transmission mode based on a transmission beam index in the CSI for the at least two of the preferred Tx beams, wherein the transmission mode is a single beam transmission mode or a dual beam transmission mode; and

initiate a downlink (DL) data transmission in accordance with the determined transmission mode.

17. The apparatus of claim 16, wherein the processing circuitry is further configured to:

obtain a rank indicator (RI), a precoding matrix indicator (PMI), and a channel quality indicator (CQI) for each of the preferred Tx beams based on the CSI.

18. The apparatus of claim 17, wherein the processing circuitry is further configured to:

initiate the DL data transmission in accordance with a single beam transmission mode when the RI, the PMI and the CQI for a first one of the preferred Tx beams are equal to the RI, the PMI and the CQI for a second one of the preferred Tx beams.

19. The apparatus of claim 17, wherein the processing circuitry is further configured to:

initiate the DL data transmission in accordance with a single beam transmission mode when the RI, the PMI and the CQI for at least one of the preferred Tx beams are equal to zero.

20. The apparatus of claim 17, wherein the processing circuitry is further configured to:

initiate the DL data transmission in accordance with a dual beam transmission mode when the transmission beam index, the RI, the PMI and/or the CQI for a first one of the preferred Tx beams are different from the corresponding transmission beam index, the RI, the PMI and/or the CQI for a second one of the preferred Tx beams.

21. The apparatus of claim 16 or 17, wherein the processing circuitry is further configured to:

during the dual beam transmission mode of at least two Tx beams, generate an indicator for transmission to the UE, the indicator indicating a CQI derivation mode, wherein the CQI derivation mode specifies whether mutual interference between the at least two Tx beams is taken into account during CQI derivation.

22. A computer-readable medium comprising instructions that, when executed on processing circuitry of a user equipment (UE), cause the UE to:

receive from an Evolved Node-B (eNB) a channel state information reference signal (CSI-RS), the CSI-RS beamformed based on a plurality of preferred Tx beams;

receive from the eNB downlink control information (DCI), the DCI comprising an indicator of a transmission mode;

in response to the CSI-RS and based on the transmission mode, determine channel state information (CSI) for one or more of the preferred Tx beams;

report the determined CSI to the eNB; and

receive a downlink (DL) data transmission from the eNB in accordance with the transmission mode, the transmission mode based on the determined CSI.

23. The computer-readable medium of claim 22, wherein the DCI comprises a beam searching algorithm (BSA) value indicating the transmission mode.

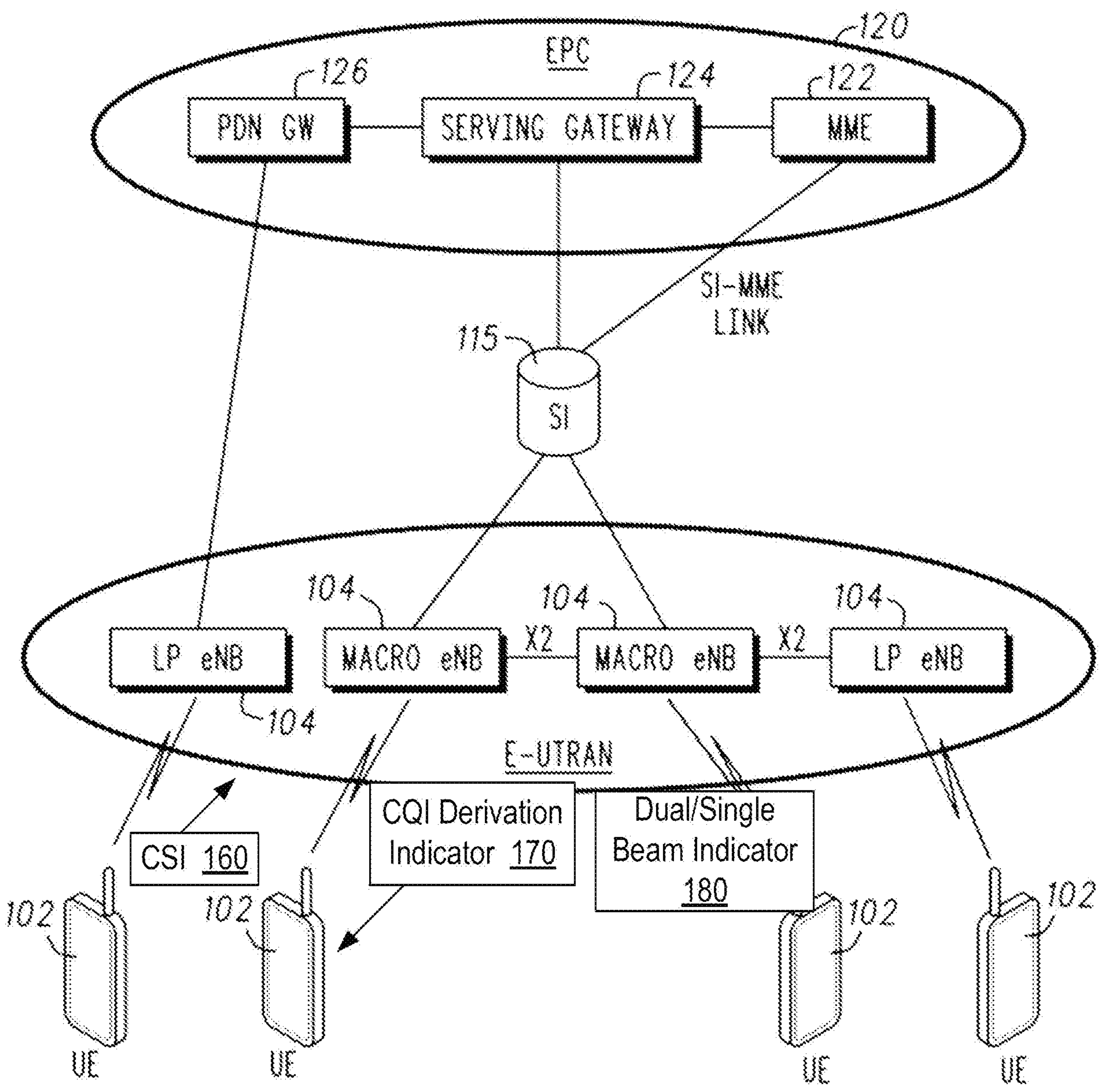
24. The computer-readable medium of claim 22, wherein the dual beam transmission mode is associated with at least a first Tx beam and a second Tx beam of the preferred Tx beams, and wherein the instructions further cause the UE to:

derive a first channel quality indicator (CQI) for the first Tx beam and a second CQI for the second Tx beam based on the CQI derivation method.

25. The computer-readable medium of claim 24, wherein the instructions further cause the UE to:

obtain the first and second CQIs without accounting for interference between the first Tx beam and the second Tx beam at the UE; or

obtain the first and second CQIs with accounting for interference between the first Tx beam and the second Tx beam at the UE.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EPC
126
124
122
PDN GW
SERVING GATEWAY
MME
SI-MME
LINK
115
SI
104
104
104
LP eNB
MACRO eNB
X2
MACRO eNB
X2
LP eNB
104
E-UTRAN
CSI 160
CQI Derivation
Indicator 170
Dual/Single
Beam Indicator
180
102
102
102
102
UE
UE
UE
UE

FIG. 1

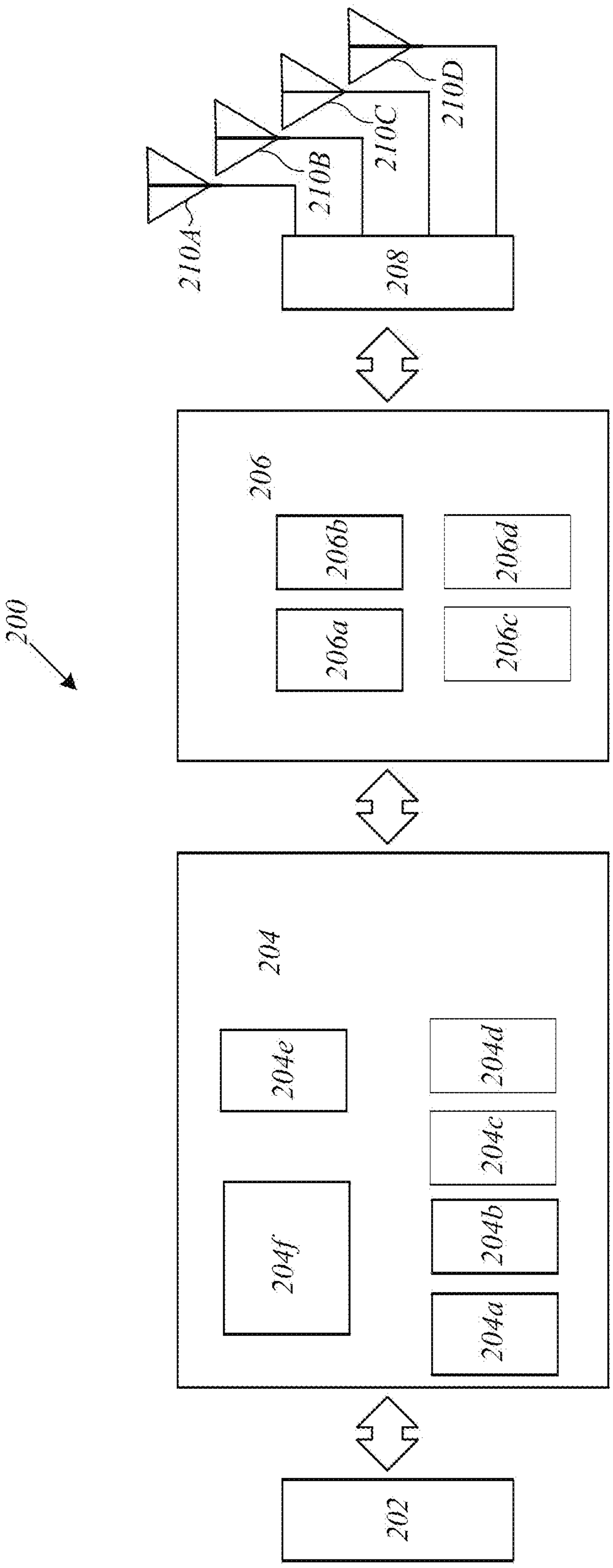
200
210A
210B
210C
210D
208
206
206a
206b
206c
206d
204
204a
204b
204c
204d
204e
204f
202

FIG. 2

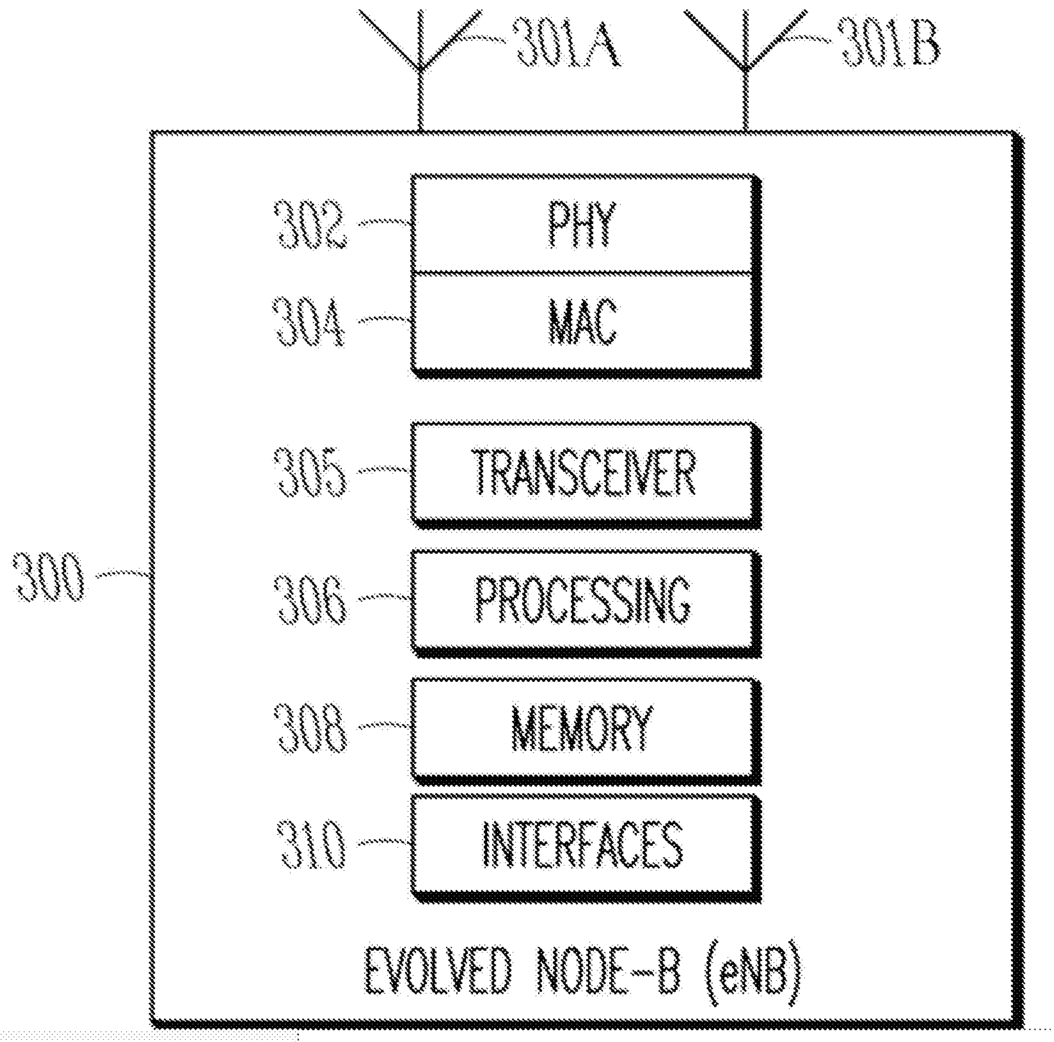
301A
301B
302
PHY
304
MAC
305
TRANSCEIVER
300
306
PROCESSING
308
MEMORY
310
INTERFACES
EVOLVED NODE-B (eNB)

FIG. 3

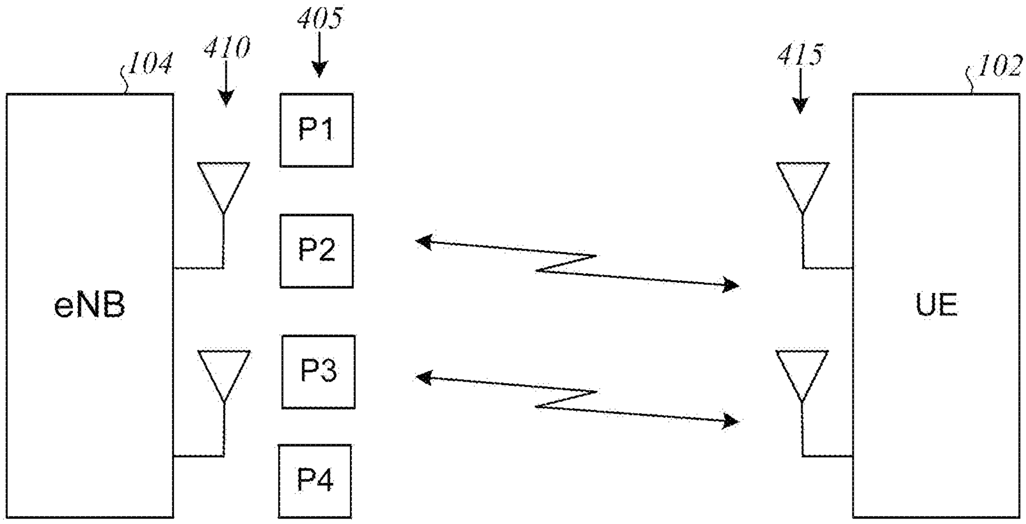

FIG. 4A

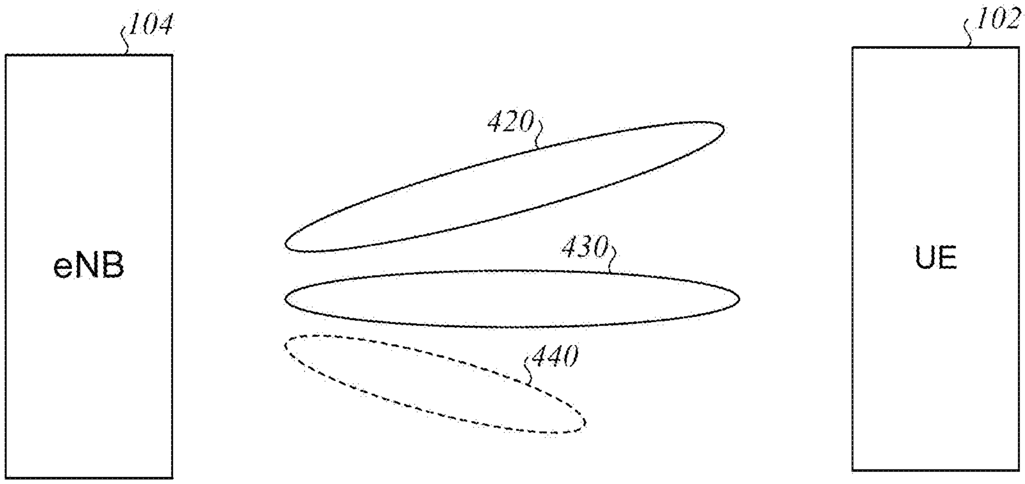

FIG. 4B

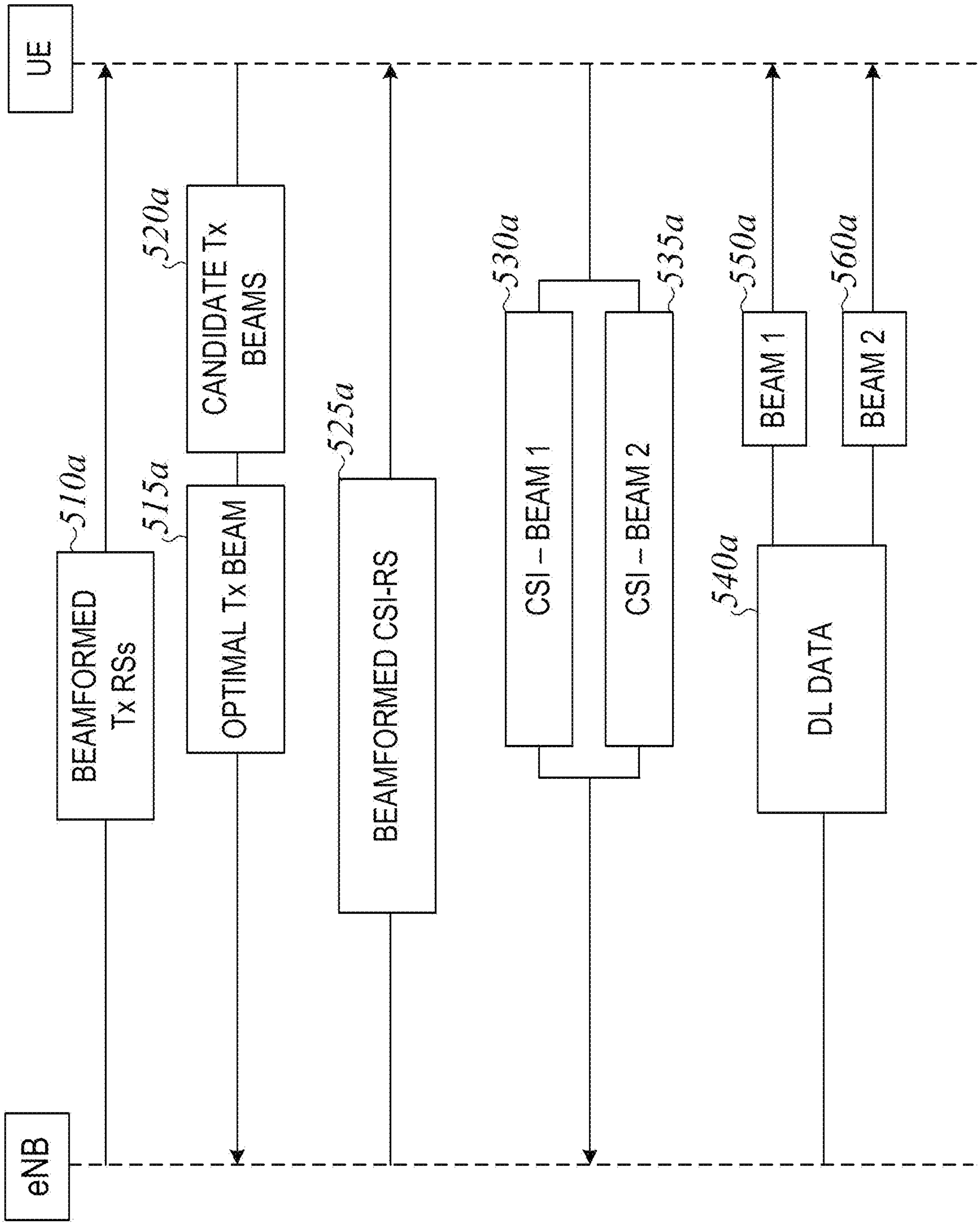
UE
eNB
BEAMFORMED Tx RSs
510a
OPTIMAL Tx BEAM
515a
CANDIDATE Tx BEAMS
520a
BEAMFORMED CSI-RS
525a
CSI – BEAM 1
530a
CSI – BEAM 2
535a
DL DATA
540a
BEAM 1
550a
BEAM 2
560a

FIG. 5A

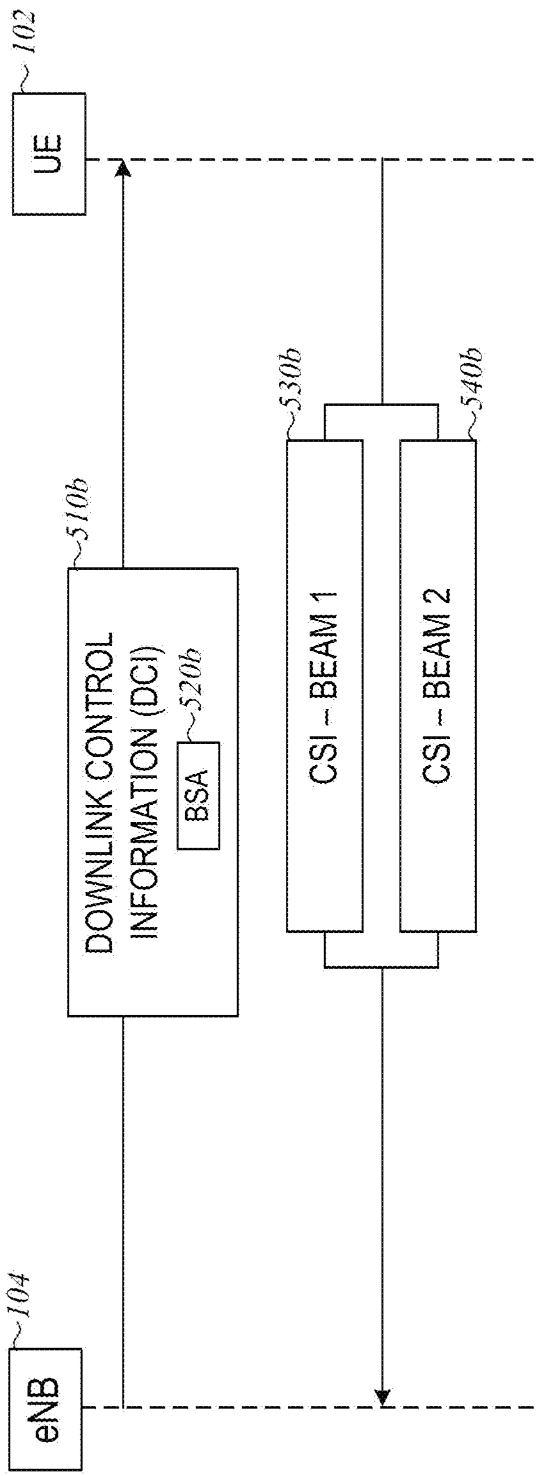
UE
102
eNB
104
DOWNLINK CONTROL INFORMATION (DCI)
510b
BSA
520b
CSI – BEAM 1
530b
CSI – BEAM 2
540b

FIG. 5B

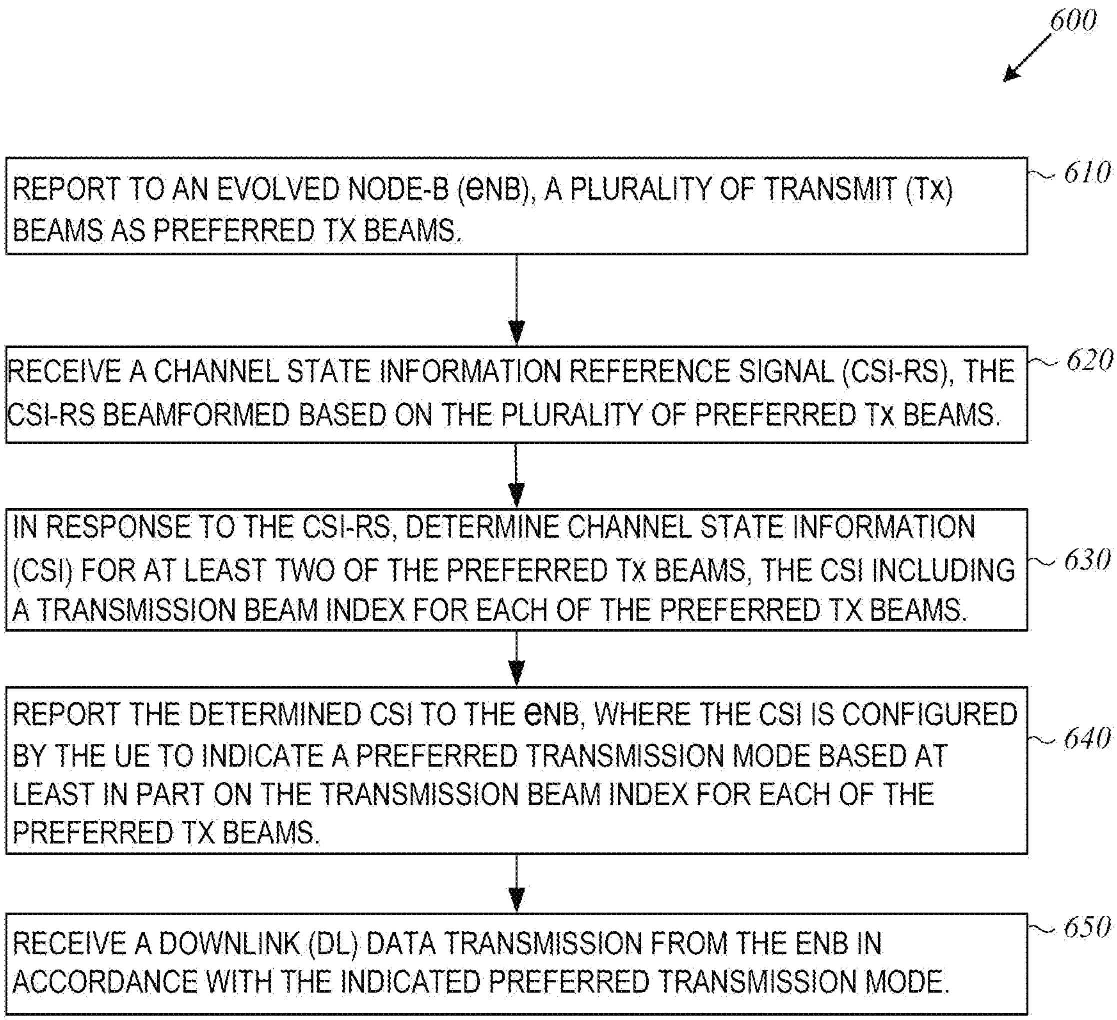
600
REPORT TO AN EVOLVED NODE-B (eNB), A PLURALITY OF TRANSMIT (Tx) BEAMS AS PREFERRED TX BEAMS.
610
RECEIVE A CHANNEL STATE INFORMATION REFERENCE SIGNAL (CSI-RS), THE CSI-RS BEAMFORMED BASED ON THE PLURALITY OF PREFERRED Tx BEAMS.
620
IN RESPONSE TO THE CSI-RS, DETERMINE CHANNEL STATE INFORMATION (CSI) FOR AT LEAST TWO OF THE PREFERRED Tx BEAMS, THE CSI INCLUDING A TRANSMISSION BEAM INDEX FOR EACH OF THE PREFERRED TX BEAMS.
630
REPORT THE DETERMINED CSI TO THE eNB, WHERE THE CSI IS CONFIGURED BY THE UE TO INDICATE A PREFERRED TRANSMISSION MODE BASED AT LEAST IN PART ON THE TRANSMISSION BEAM INDEX FOR EACH OF THE PREFERRED TX BEAMS.
640
RECEIVE A DOWNLINK (DL) DATA TRANSMISSION FROM THE ENB IN ACCORDANCE WITH THE INDICATED PREFERRED TRANSMISSION MODE.
650

FIG. 6

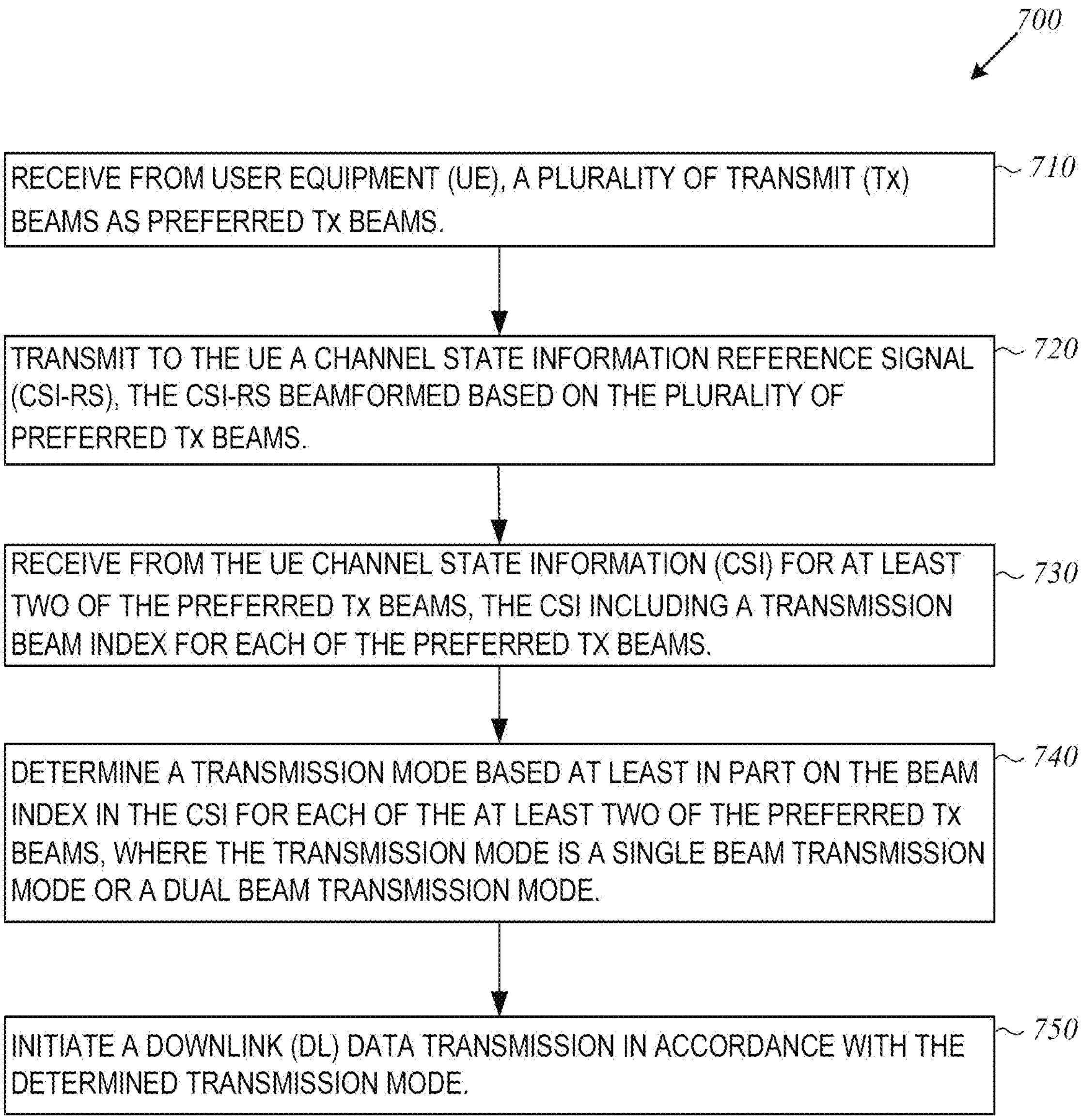
700
RECEIVE FROM USER EQUIPMENT (UE), A PLURALITY OF TRANSMIT (Tx) BEAMS AS PREFERRED Tx BEAMS.
710
TRANSMIT TO THE UE A CHANNEL STATE INFORMATION REFERENCE SIGNAL (CSI-RS), THE CSI-RS BEAMFORMED BASED ON THE PLURALITY OF PREFERRED Tx BEAMS.
720
RECEIVE FROM THE UE CHANNEL STATE INFORMATION (CSI) FOR AT LEAST TWO OF THE PREFERRED Tx BEAMS, THE CSI INCLUDING A TRANSMISSION BEAM INDEX FOR EACH OF THE PREFERRED TX BEAMS.
730
DETERMINE A TRANSMISSION MODE BASED AT LEAST IN PART ON THE BEAM INDEX IN THE CSI FOR EACH OF THE AT LEAST TWO OF THE PREFERRED Tx BEAMS, WHERE THE TRANSMISSION MODE IS A SINGLE BEAM TRANSMISSION MODE OR A DUAL BEAM TRANSMISSION MODE.
740
INITIATE A DOWNLINK (DL) DATA TRANSMISSION IN ACCORDANCE WITH THE DETERMINED TRANSMISSION MODE.
750

FIG. 7

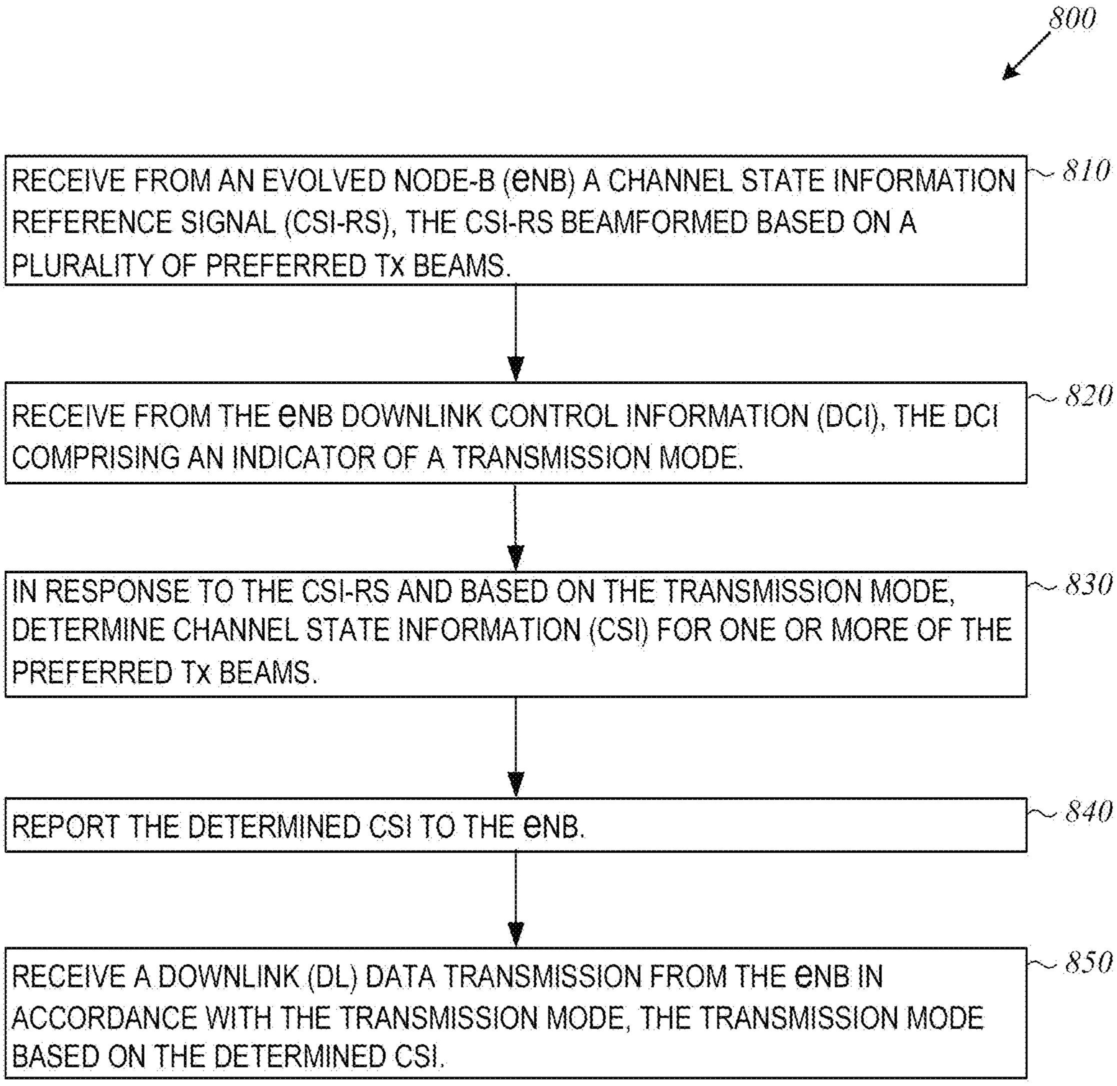
800
RECEIVE FROM AN EVOLVED NODE-B (eNB) A CHANNEL STATE INFORMATION REFERENCE SIGNAL (CSI-RS), THE CSI-RS BEAMFORMED BASED ON A PLURALITY OF PREFERRED Tx BEAMS.
810
RECEIVE FROM THE eNB DOWNLINK CONTROL INFORMATION (DCI), THE DCI COMPRISING AN INDICATOR OF A TRANSMISSION MODE.
820
IN RESPONSE TO THE CSI-RS AND BASED ON THE TRANSMISSION MODE, DETERMINE CHANNEL STATE INFORMATION (CSI) FOR ONE OR MORE OF THE PREFERRED Tx BEAMS.
830
REPORT THE DETERMINED CSI TO THE eNB.
840
RECEIVE A DOWNLINK (DL) DATA TRANSMISSION FROM THE eNB IN ACCORDANCE WITH THE TRANSMISSION MODE, THE TRANSMISSION MODE BASED ON THE DETERMINED CSI.
850

FIG. 8

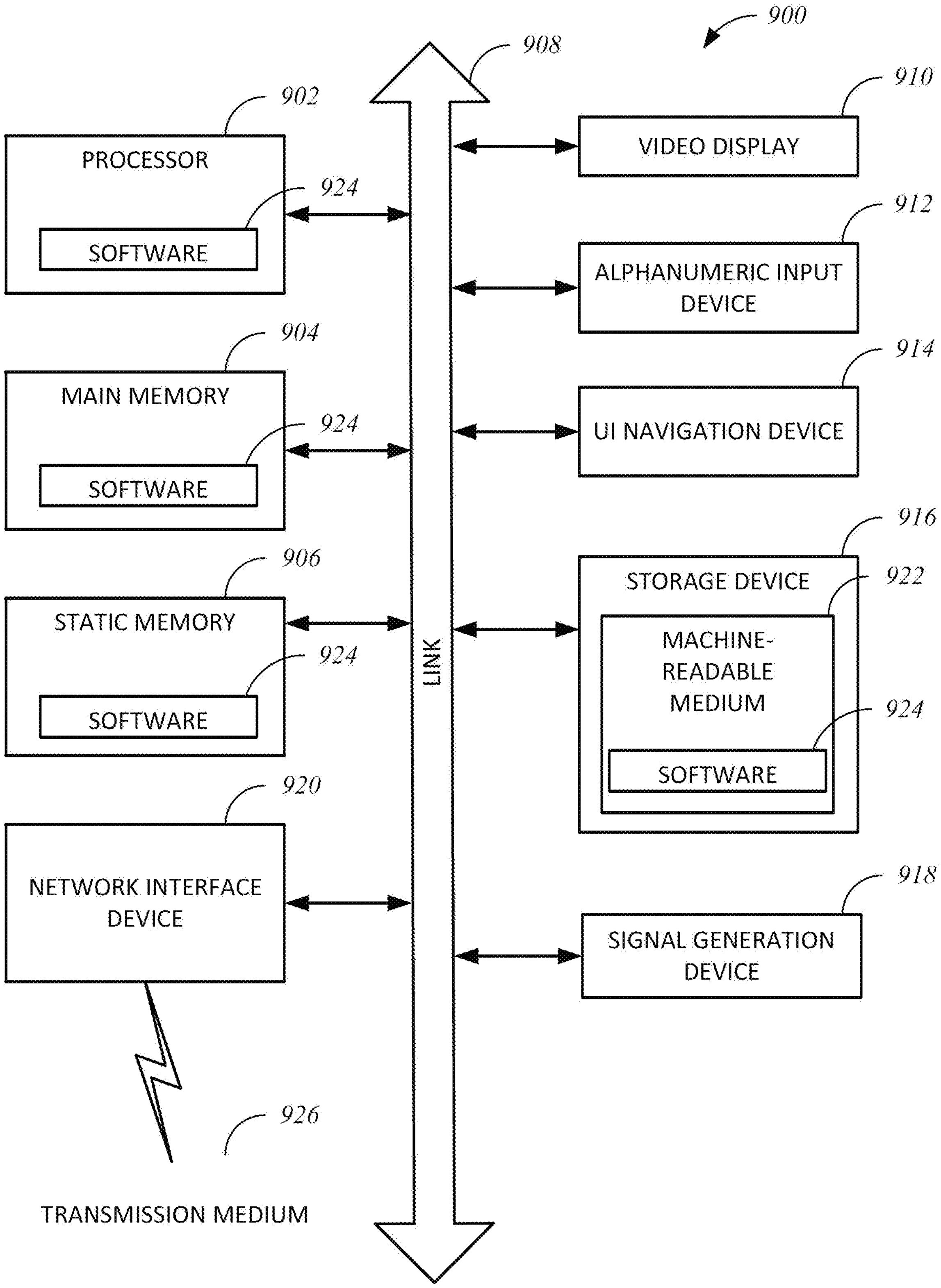
900
908
902
PROCESSOR
924
SOFTWARE
904
MAIN MEMORY
924
SOFTWARE
906
STATIC MEMORY
924
SOFTWARE
920
NETWORK INTERFACE DEVICE
926
TRANSMISSION MEDIUM
LINK
910
VIDEO DISPLAY
912
ALPHANUMERIC INPUT DEVICE
914
UI NAVIGATION DEVICE
916
STORAGE DEVICE
922
MACHINE-READABLE MEDIUM
924
SOFTWARE
918
SIGNAL GENERATION DEVICE

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2016/084279

A. CLASSIFICATION OF SUBJECT MATTER

H04W 24/10(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)

H04Q,H04W,H04L,H04B,H04J,H04M

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI;EPODOC;CNPAT;CNKI;3GPP;GOOGLE: CSI, CQI, beam index, beam, index, indices, prefer, transmission mode, single beam, single stream, dual beam, dual stream, mode, single, dual, two, double, stream, CSI-RS, feedback

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	CN 104541540 A (SAMSUNG ELECTRONICS CO.， LTD.) 22 April 2015 (2015-04-22) description paragraphs [0050]-[0103]	1-25
Y	TENXC WIRELESS INC. "Pre-coded MIMO DL for E-UTRA exploiting X-pol antennas" *3GPP TSG RAN WG1 R1-051326,* 11 November 2005 (2005-11-11), sections 1-4	1-25
A	CN 101971516 A (FRANCE TELECOM) 09 February 2011 (2011-02-09) the whole document	1-25
A	CN 104040908 A (SAMSUNG ELECTRONICS CO.， LTD.) 10 September 2014 (2014-09-10) the whole document	1-25
A	US 2007099578 A1 (ADENEY， KATHRYN ET AL.) 03 May 2007 (2007-05-03) the whole document	1-25
A	US 2013235742 A1 (SAMSUNG ELECTRONICS CO.， LTD.) 12 September 2013 (2013-09-12) the whole document	1-25

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 January 2017	**09 February 2017**

Name and mailing address of the ISA/CN	Authorized officer
STATE INTELLECTUAL PROPERTY OFFICE OF THE P.R.CHINA **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088** **China**	**ZHANG,Fan**
Facsimile No. **(86-10)62019451**	Telephone No. **(86-10)62413355**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2016/084279

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		WO 2014027824 A1	20 February 2014
		US 2014044044 A1	13 February 2014
		KR 20150043310 A	22 April 2015
CN 101971516 A	09 February 2011	WO 2009083680 A1	09 July 2009
		EP 2243227 A1	27 October 2010
		US 2010284294 A1	11 November 2010
CN 104040908 A	10 September 2014	KR 20130070560 A	27 June 2013
		JP 2015509305 A	26 March 2015
		US 2013156120 A1	20 June 2013
		EP 2795808 A1	29 October 2014
		WO 2013094980 A1	27 June 2013
		IN 1301KOLNP2014 A	16 October 2015
US 2007099578 A1	03 May 2007	None	
US 2013235742 A1	12 September 2013	EP 2823579 A1	14 January 2015
		WO 2013133672 A1	12 September 2013
		KR 20130103449 A	23 September 2013