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(54) Title: DEVICE AND METHOD OF SUPPORTING 4 LAYER TRANSMISSION WITH 256 QUADRATURE AMPLITUDE MODULATION

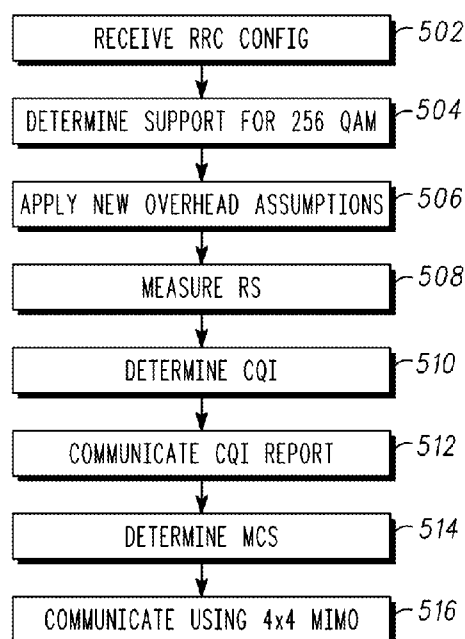


FIG. 5

(57) Abstract: User equipment (UE), an evolved NodeB (eNB) and method of increasing the data rate for 4x4 MIMO at 256QAM is disclosed. The UE may initially determine whether the eNB supports 256QAM from an RRC configuration message. The UE may then receive and measure reference signals from the eNB. The UE may determine a CQI value and use this value to determine a MCS and code rate with which to communicate with the eNB based on table entries using a reduced reference signal overhead compared with a legacy reference signal overhead. The UE may transmit a CQI report to the eNB and subsequently communicate with the eNB using the determined characteristics.



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**DEVICE AND METHOD OF SUPPORTING 4 LAYER
TRANSMISSION WITH 256 QUADRATURE AMPLITUDE
MODULATION**

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PRIORITY CLAIM

[0001] This application claims the benefit of priority to United States Provisional Patent Application Serial No. 62/144,475, filed, April 8, 2015, and entitled “METHOD OF SUPPORTING 4 LAYER TRANSMISSION WITH 256 QUADRATURE AMPLITUDE MODULATION,” which is incorporated herein by reference in its entirety.

15

TECHNICAL FIELD

[0002] Embodiments pertain to radio access networks. Some embodiments relate to support for 4x4 Multiple Input Multiple Output (MIMO), including Third Generation Partnership Project Long Term Evolution (3GPP LTE) networks and LTE advanced (LTE-A) networks as well as 4th generation (4G) networks and 5th generation (5G) networks.

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BACKGROUND

[0003] The use of personal communication devices has increased astronomically over the last two decades. The penetration of mobile devices (user equipment or UEs) in modern society has continued to drive demand for a wide variety of networked devices in a number of disparate environments. The use of networked UEs using 3GPP systems has increased in all areas of home and work life. One result in a greater penetration of such devices into modern life is the

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continuous drive for increased speed of communications between UEs and serving evolved Node-Bs (eNBs). Two categories of UEs with data rates of 750/800 megabits per second (Mbps) and 1 gigabit per second (Gbps) have been agreed upon in 3GPP Release 12. Increasing the communication data rate, however, may involve a number of technological issues with both how the network and how the UEs handle the increase. The interplay between modulation type (e.g., Quadrature Amplitude Modulation (QAM)) and modulation coding scheme (MCS) and coding rate at these data rates as well as the ability of the system to use 4x4 MIMO, for example, becomes complicated. One effect may be that coding rate decisions may use legacy models of overhead assumption and unnecessarily limit the peak data rate at 256QAM.

[0004] It would therefore be desirable to resolve at least some of the technological issues for high data rate transmissions and permit higher data rate communication between the UE and network.

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. The figures illustrate generally, by way of example, but not by way of limitation, various embodiments discussed in the present document.

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

[0007] FIG. 2 illustrates components of a UE in accordance with some embodiments.

[0008] FIG. 3 illustrates a block diagram of a communication device in accordance with some embodiments.

[0009] FIG. 4 illustrates another block diagram of a communication device in accordance with some embodiments.

[0010] FIG. 5 illustrates a flowchart of MIMO communication in accordance with some embodiments.

[0011] FIG. 6 illustrates another flowchart of MIMO communication in accordance with some embodiments.

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DETAILED DESCRIPTION OF THE INVENTION

[0012] 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.

10 [0013] FIG. 1 shows an example of a portion of an end-to-end network architecture of a Long Term Evolution (LTE) network with various components of the network in accordance with some embodiments. As used herein, LTE and LTE-A networks and devices, including 3G, 4G and 5G networks and devices, are referred to merely as LTE networks and devices. The network 100 may comprise 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, only a portion of the core network 120, as well as the RAN 101, is shown in the example. 20 The network 100 may be capable of supporting 4x4 MIMO communication with one or more of the UEs 102 as described in more detail herein.

[0014] The core network 120 may include mobility management entity (MME) 122, serving gateway (serving GW) 124, and packet data network gateway (PDN GW) 126. The RAN includes enhanced node Bs (eNBs) 104 (which may operate as base stations) for communicating with user equipment (UE) 102. The eNBs 104 may include macro eNBs 30

and low power (LP) eNBs. The eNBs 104 and UEs 102 may perform the tracking methods described herein.

[0015] The MME 122 may be similar in function to the control plane of legacy Serving GPRS Support Nodes (SGSN). The MME may manage mobility aspects in access such as gateway selection and tracking area list management. The serving GW 124 may terminate the interface toward the RAN 101, and route 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 may terminate an SGi interface toward the packet data network (PDN). The PDN GW 126 may route data packets between the EPC 120 and the external PDN, and may be a key node for policy enforcement and charging data collection. The PDN GW 126 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.

[0016] The eNBs 104 (macro and micro) may 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, UEs 102 may be configured to communicate Orthogonal Frequency-Division Multiplexing (OFDM) communication signals with an eNB 104 over a multicarrier communication channel in accordance with an OFDMA communication technique. The OFDM signals may comprise a plurality of orthogonal subcarriers. Each of the eNBs 104 may be able to

transmit a reconfiguration message to each UE 102 that is connected to that eNB 104. The reconfiguration message may contain reconfiguration information including one or more parameters that indicate specifics about reconfiguration of the UE 102 upon a mobility scenario (e.g., handover) to reduce the latency involved in the handover. The parameters may include physical layer and layer 2 reconfiguration indicators, and a security key update indicator. The parameters may be used to instruct the UE 102 to avoid or skip one or more of the processes indicated to decrease messaging between the UE 102 and the network.

10 The network may be able to automatically route packet data between the UE 102 and the new eNB 104 and may be able to provide the desired information between the eNBs 104 involved in the mobility. The application, however, is not limited to this, however, and additional embodiments are described in more detail below.

15 **[0017]** The S1 interface 115 is the interface that separates the RAN 101 and the EPC 120. The S1 interface 115 may be split into two parts: the S1-U, which carries traffic data between the eNBs 104 and the serving GW 124, and the S1-MME, which is a signaling interface between the eNBs 104 and the MME 122. The X2 interface is the

20 interface between eNBs 104. The X2 interface may comprise two parts, the X2-C and X2-U. The X2-C may be the control plane interface between the eNBs 104, while the X2-U may be the user plane interface between the eNBs 104.

[0018] With cellular networks, LP cells may be used to extend

25 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 may refer 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

30 microcell. Femtocell eNBs may be typically provided by a mobile network operator to its residential or enterprise customers. A femtocell may be typically the size of a residential gateway or smaller and generally connect to the user's broadband line. Once plugged in, the

femtocell may connect to the mobile operator's mobile network and provide extra coverage in a range of typically 30 to 50 meters for residential femtocells. Thus, an LP eNB might be a femtocell eNB since it is coupled through the PDN GW 126. Similarly, a picocell may
5 be a wireless communication system typically covering a small area, such as in-building (offices, shopping malls, train stations, etc.), or more recently in-aircraft. A picocell eNB 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
10 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.

[0019] Other wireless communication devices may be present in
15 the same geographical region as the RAN 101. As shown in FIG. 1, WLAN devices including one or more access points (APs) 103 and one or more stations (STAs) 105 in communication with the AP 103. The WLAN devices may communicate using one or more IEEE 802.11 protocols, such as IEEE 802.11a/b/n/ac protocols. As the power of the
20 WLAN devices 103, 105 may be fairly limited, compared with the eNBs 104, the WLAN devices 103, 105 may be geographically localized.

[0020] Communication over an LTE network may be split up into 10ms frames, each of which contains ten 1ms subframes. Each subframe, in turn, may contain two slots of 0.5ms. Each slot may
25 contain 6-7 symbols, depending on the system used. A resource block (RB) (also called physical resource block (PRB)) may be the smallest unit of resources that can be allocated to a UE 102. A resource block may be 180 kHz wide in frequency and 1 slot long in time. In frequency, resource blocks may be either 12 x 15 kHz subcarriers or 24
30 x 7.5 kHz subcarriers wide. For most channels and signals, 12 subcarriers may be used per resource block. In Frequency Division Duplexed (FDD) mode, both the uplink and downlink frames may be 10ms and may be frequency (full-duplex) or time (half-duplex)

separated. In a Time Division Duplex (TDD) structure, the uplink and downlink subframes may be transmitted on the same frequency and may be multiplexed in the time domain. A downlink resource grid may be used for downlink transmissions from an eNB to a UE. The grid may be

5 a time-frequency grid, which is the physical resource in the downlink in each slot. Each column and each row of the resource grid may correspond to one OFDM symbol and one OFDM subcarrier, respectively. The duration of the resource grid in the time domain may correspond to one slot. The smallest time-frequency unit in a resource

10 grid may be denoted as a resource element. Each resource grid may comprise a number of the above resource blocks, which describe the mapping of certain physical channels to resource elements. Each resource block may comprise $12 \text{ (subcarriers)} * 14 \text{ (symbols)} = 168$ resource elements.

15 **[0021]** There may be several different physical downlink channels that are conveyed using such resource blocks. Two of these physical downlink channels may be the physical down link control channel (PDCCH) and the physical downlink shared channel (PDSCH). Each subframe may be partitioned into the PDCCH and the PDSCH.

20 The PDCCH may normally occupy the first two symbols of each subframe and carry, among other things, information about the transport format and resource allocations related to the PDSCH channel, as well as H-ARQ information related to the uplink shared channel. The PDSCH may carry user data and higher-layer signaling to a UE 102 and

25 occupy the remainder of the subframe. Typically, downlink scheduling (assigning control and shared channel resource blocks to UEs 102 within a cell) may be performed at the eNB 104 based on channel quality information provided from the UEs 102 to the eNB, and then the downlink resource assignment information may be sent to each UE 102

30 on the PDCCH used for (assigned to) the UE 102. A TTI Transmission Time Interval (TTI) may be the smallest unit of time in which an eNB 104 is capable of scheduling a UE 102 for uplink or downlink transmission. The PDCCH may contain downlink control information

(DCI) in one of a number of formats that tell the UE 102 how to find and decode data, transmitted on PDSCH in the same subframe, from the resource grid. The DCI format may provide details such as number of resource blocks, resource allocation type, modulation scheme, transport
5 block, redundancy version, coding rate etc. Each DCI format may have a cyclic redundancy code (CRC) and may be scrambled with a Radio Network Temporary Identifier (RNTI) that identifies the target UE 102 for which the PDSCH is intended. Use of the UE 102-specific RNTI may limit decoding of the DCI format (and hence the corresponding
10 PDSCH) to only the intended UE 102.

[0022] Similarly, the uplink subframe may contain a Physical Uplink Control Channel (PUCCH) with a Physical Random Access Channel (PRACH) and a physical uplink shared channel (PUSCH). The PUCCH may provide a various control signals including HARQ
15 acknowledgment/non-acknowledgement, one or more Channel Quality Indicators (CQI), MIMO feedback (Rank Indicator, RI; Precoding Matrix Indicator, PMI) and scheduling requests for uplink transmission. The PUCCH may transmit in a frequency region at the edge of the system bandwidth and may comprise one RB per transmission at one
20 end of the system bandwidth followed by a RB in the following slot at the opposite end of the channel spectrum, thus making use of frequency diversity. A PUCCH Control Region may comprise every two RBs. BPSK or QPSK may be used for modulation of PUCCH information. The PRACH may be used for random access functions and
25 made up from two sequences: a cyclic prefix and a guard period. The preamble sequence may be repeated to enable the eNB to decode the preamble when link conditions are poor. The PMI is used for precoding, in which beams of layers are formed to increase reception quality of the layers taking into account characteristics of transmission
30 channels. The eNB 104 may measure the channel and inform the UE 102 of a precoder employing an appropriate precoding scheme, allowing the UE 102 to perform precoding based on this information. The precoder may be represented in a matrix (i.e., precoding matrix), in

which the number of rows is equal to the number of antennas and the number of columns is equal to the number of layers.

[0023] The eNB 104 may also periodically transmit reference signals to the UEs 102. The reference signals may be common
5 reference signals broadcast to all UEs 102 served by the eNB 104 or UE-specific reference signals. The reference signals may include, for example, cell-specific reference signals (CRS) that may be used for scheduling transmissions to the UEs 102 and for channel estimation used in coherent demodulation at each UE 102, channel state
10 information reference signals (CSI-RS) used for measurement purposes, and Discovery Reference Signals (DRS) specific to an individual UE. The UE 102 may measure the signal-to-noise ratio (SNR) and signal-to-interference plus noise ratio (SINR) of the reference signals (or other characteristics such as the received signal strength (RSS) or the bit-
15 error-rate (BER) before or after the channel decoder) and respond to the eNB 104 with a Channel Quality Indication (CQI) report carried by the PUCCH. The eNB 104 may be able to obtain a more granular CQI report (wideband to one or more specific subbands) through aperiodic CSI feedback on the PUSCH. If closed loop MIMO is used, a
20 Precoding Matrix Indicator (PMI) and Rank Indication (RI) may also be reported by the UE 102 to the eNB 104 in the PUCCH. The PMI may indicate the codebook that the eNB 104 is to use for data transmission over multiple antennas. The RI may indicate the number of transmission layers that the UE 102 can distinguish (i.e., the number of
25 different data streams communicated simultaneously using the same time and frequency resources but different antennas). The maximum number of transmission layers, 2^n , is less than or equal to the number of transmit antennas of the eNB, where n is the number of bits transmitted in the RI report. For example, when 2 antennas are used, when RI=1 the
30 UE 102 has measured an acceptable characteristic (e.g., SINR) only for a single MIMO layer, indicating to the eNB to provide a single antenna port or transmit diversity transmission mode (TM), and when RI=2 the UE 102 has measured an acceptable characteristic for both MIMO

layers, and thus the eNB can schedule MIMO transmissions. Spatial multiplexing can be supported only when $RI > 1$, and CQI may be reported on a per-codeword basis, for which a maximum of 2 codewords may be used.

5 **[0024]** There are 10 TMs presently in LTE, each corresponding to a specific multiple antenna technique. For each TM, a set of CQI reports is defined, based on the type of CQI report. For example, the CQI reports may depend on whether the reference signals (and thus CQI report) is periodic or aperiodic, whether the CQI report is wideband or a
10 selected subband (either UE-selected or configured by higher layer signaling), and how many PMIs are in the CQI report. The CQI value in the CQI report may be mapped to a particular code rate, dependent on the QAM scheme and number of CRS ports. As discussed in more detail below, however, presently support for 4x4 MIMO is limited to
15 only TM 9 and 10. TM 9 may be used for eight layer spatial multiplexing. DCI format 2C may be used for TM 9 data scheduling and CSI-RS (used by the UE 102 to calculate and report the CSI feedback) and demodulation reference signals (DM-RS) (which provide support for additional layers) are defined in TM9. DCI format 2C
20 specifies the number of layers (1-8) that the eNB 104 intends to use for data transmission and may or may not specify the precoding matrix. The eNB 104 then transmits the PDSCH on antenna ports 7 to $7 + n$, where n is the number of layers that the UE 102 is using. The maximum number of codewords is two. The UE may provide the PMI, which
25 indicates the precoding at the eNB 104 that the UE 102 would ideally like to use by the eNB for PDSCH transmission. Instead of indicating the precoders, in some embodiments the UE 102 may provide indices of the precoders that are each able to vary from 0 to 15 to provide more finely-grained feedback and can be used by the eNB 104 to reconstruct
30 the requested precoding matrix. TM10 permits the UE 102 to evaluate and report multiple sets of CSI-RS. DCI format 2D allows configuration of antenna port-specific scrambling codes used for the DM-RS. The eNB 104 may also indicate to the UE 102 if the DM-RS

antenna is quasi co-located with the cell from which the UE 102 receives the downlink allocation. The eNB 104 may specify a set of RSs associated with the PDSCH, different from RSs associated with the PDCCH and offers HARQ ACK/NACK for the downlink transmission.

5 **[0025]** Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. FIG. 2 illustrates components of a UE in accordance with some embodiments. The UE 200 may be one of the UEs 102 shown in FIG. 1 and may be a stationary, non-mobile device or may be a mobile device. In some
10 embodiments, the UE 200 may include application circuitry 202, baseband circuitry 204, Radio Frequency (RF) circuitry 206, front-end module (FEM) circuitry 208 and one or more antennas 210, coupled together at least as shown. At least some of the baseband circuitry 204, RF circuitry 206, and FEM circuitry 208 may form a transceiver. In
15 some embodiments, other network elements, such as the eNB may contain some or all of the components shown in FIG. 2.

[0026] The application or processing 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
20 more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with and/or may include memory/storage and may be configured to execute instructions stored in the
25 memory/storage to enable various applications and/or operating systems to run on the system.

[0027] 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
30 and/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 circuitry 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, and/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, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 204 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

[0028] 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), and/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 and/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
5 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 a chip (SOC).

[0029] In some embodiments, the baseband circuitry 204 may

10 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) and/or other wireless metropolitan area networks (WMAN), a wireless local area network
15 (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. In some embodiments, the device can be configured to operate in accordance with communication
20 standards or other protocols or standards, including Institute of Electrical and Electronic Engineers (IEEE) 802.16 wireless technology (WiMax), IEEE 802.11 wireless technology (WiFi) including IEEE 802 ad, which operates in the 60 GHz millimeter wave spectrum, various other wireless technologies such as global system for mobile
25 communications (GSM), enhanced data rates for GSM evolution (EDGE), GSM EDGE radio access network (GERAN), universal mobile telecommunications system (UMTS), UMTS terrestrial radio access network (UTRAN), or other 2G, 3G, 4G, 5G, etc. technologies either already developed or to be developed.

30 **[0030]** 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.

[0031] 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.

[0032] 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.

[0033] 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 and/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 and/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.

[0034] 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.

[0035] 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.

[0036] 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.

[0037] 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.

[0038] 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.

[0039] 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 N_d equal packets of phase, where N_d is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

[0040] 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 (f_{LO}). In some embodiments, the RF circuitry 206 may include an IQ/polar
5 converter.

[0041] FEM circuitry 208 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 210, amplify the received signals and provide the amplified versions of the received signals to the RF
10 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 210.

[0042] In some embodiments, the FEM circuitry 208 may
15 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.,
20 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).

[0043] In some embodiments, the UE 200 may include
25 additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface as described in more detail below. In some embodiments, the UE 200 described herein may be part of a portable wireless communication device, such as a personal
30 digital assistant (PDA), a laptop or portable computer with wireless communication capability, a web tablet, a wireless telephone, a smartphone, a wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, a medical device (e.g., a

heart rate monitor, a blood pressure monitor, etc.), or other device that may receive and/or transmit information wirelessly. In some embodiments, the UE 200 may include one or more user interfaces designed to enable user interaction with the system and/or peripheral component interfaces designed to enable peripheral component interaction with the system. For example, the UE 200 may include one or more of a keyboard, a keypad, a touchpad, a display, a sensor, a non-volatile memory port, a universal serial bus (USB) port, an audio jack, a power supply interface, one or more antennas, a graphics processor, an application processor, a speaker, a microphone, and other I/O components. The display may be an LCD or LED screen including a touch screen. The sensor may include a gyro sensor, an accelerometer, a proximity sensor, an ambient light sensor, and a positioning unit. The positioning unit may communicate with components of a positioning network, e.g., a global positioning system (GPS) satellite.

[0044] The antennas 210 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 210 may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result.

[0045] Although the UE 200 is illustrated as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For example, some elements may comprise one or more microprocessors, DSPs, field-programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), radio-frequency integrated circuits (RFICs) and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the

functional elements may refer to one or more processes operating on one or more processing elements.

[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] FIG. 3 is a block diagram of a communication device in accordance with some embodiments. The device may be a UE or eNB, for example, such as the UE 102 or eNB 104 shown in FIG. 1 that may be configured to track the UE as described herein. The communication device 300 may include physical layer circuitry 302 for transmitting and receiving signals using one or more antennas 301. The communication device 300 may also include medium access control layer (MAC) circuitry 304 for controlling access to the wireless medium. The communication device 300 may also include processing circuitry 306, such as one or more single-core or multi-core processors, and memory 308 arranged to perform the operations described herein. The physical layer circuitry 302, MAC circuitry 304 and processing circuitry 306 may handle various radio control functions that enable communication with one or more radio networks compatible with one or more radio technologies. The radio control functions may include signal modulation, encoding, decoding, radio frequency shifting, etc. For example, similar to the device shown in FIG. 2, in some embodiments, communication may be enabled with one or more of a WMAN, a

WLAN, and a WPAN. In some embodiments, the communication device 300 can be configured to operate in accordance with 3GPP standards or other protocols or standards, including WiMax, WiFi, GSM, EDGE, GERAN, UMTS, UTRAN, or other 3G, 3G, 4G, 5G, etc.

5 technologies either already developed or to be developed.

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

[0049] Although the communication device 300 is illustrated as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including DSPs, and/or other hardware elements. For example, some elements may comprise one or more microprocessors, DSPs, FPGAs, ASICs, RFICs and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements may refer to one or more processes operating on one or more processing elements. Embodiments may be implemented in one or a combination of hardware, firmware and software. Embodiments may also be implemented as instructions stored on a computer-readable storage device, which may be read and executed by at least one processor to perform the operations described herein.

[0050] FIG. 4 illustrates another block diagram of a communication device in accordance with some embodiments. In alternative embodiments, the communication device 400 may operate as a standalone device or may be connected (e.g., networked) to other communication devices. In a networked deployment, the communication device 400 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 400 may act as a peer communication device in peer-to-peer (P2P) (or other distributed) network environment. The communication device 400 may be a UE, eNB, AP, STA, 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.

[0051] 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.

[0052] 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.

[0053] Communication device (e.g., computer system) 400 may include a hardware processor 402 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 404 and a static memory 406, some or all of which may communicate with each other via an interlink (e.g., bus) 408. The communication device 400 may further include a display unit 410, an alphanumeric input device 412 (e.g., a keyboard), and a user interface (UI) navigation device 414 (e.g., a mouse). In an example, the display unit 410, input device 412 and UI navigation device 414 may be a touch screen display. The communication device 400 may additionally include a storage device (e.g., drive unit) 416, a signal generation device 418 (e.g., a speaker), a network interface device 420, and one or more sensors 421, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The communication device 400 may include an output controller 428, 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.).

[0054] The storage device 416 may include a communication device readable medium 422 on which is stored one or more sets of data structures or instructions 424 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The

instructions 424 may also reside, completely or at least partially, within the main memory 404, within static memory 406, or within the hardware processor 402 during execution thereof by the communication device 400. In an example, one or any combination of the hardware processor 402, the main memory 404, the static memory 406, or the storage device 416 may constitute communication device readable media.

[0055] While the communication device readable medium 422 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 424.

[0056] 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 400 and that cause the communication device 400 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.

[0057] The instructions 424 may further be transmitted or received over a communications network 426 using a transmission medium via the network interface device 420 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 420 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 426. In an example, the network interface device 420 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 420 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 400, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

[0058] As above, in a desire to increase the communication data rate to the desired rate of 750/800 Mbps and 1Gbps, the most recent releases of the 3GPP LTE standard have employed 4x4 MIMO techniques. 4x4 MIMO techniques may communicate using up to 4 four transmitting and receiving antennas and thus 4 independent channels and associated data streams. The MIMO techniques may employ carrier aggregation (CA) using component carriers (CC) in the LTE spectrum and perhaps the unlicensed spectrum, and 256QAM modulation. The

combination of 4x4 MIMO and 256QAM may be able to achieve, for example, a 1 Gbps data rate using a combination of a 1CC 4x4 MIMO 256QAM transmission and a 3CC 2x2 MIMO 256QAM transmission or a combination of a 2CC 4x4 MIMO 256QAM transmission and a 1CC 2x2 MIMO 256QAM transmission.

[0059] Currently, support of 4x4 MIMO for all UE categories other than UE category 5 is currently limited to TM 9 and 10. 4x4 MIMO, at present, may be unable to be used for other TMs, e.g., cell-specific reference signal (CRS)-based TMs. One of the reasons to define this restriction in Release 10 was to avoid ambiguity in the rate matching and RI reporting between Release 8 and Release 10 UE categories without explicit eNB signaling on the supported release. This approach, however, limited support of 4x4 MIMO for other transmission modes. However, enabling 4x4 MIMO transmissions for other TMs (e.g., TM 3, 4 and 8) may be desirable due to a decreased reference signal overhead and channel estimation performance compared to DM-RS based transmission modes (TM9 and TM10). Reference signals generally introduce overhead due to the increasing unavailability of resource elements to carry data having, for example, overhead values of about 4.8% for 1 antenna port, 9.5% for 2 antenna ports, 14.3 % for 4 antenna ports. More specifically, the overhead assumptions taken in the legacy (Release 12) design of the 256QAM TBS tables is significantly lower than the overhead assumption defined in Release 10 for CQI calculation in 4x4 MIMO with DM-RS based TMs in which 256QAM was not an option. As a result, several CQI entries in the CQI-to-MCS table are mapped to the same MCS index.

[0060] In particular, in accordance with 3GPP Technical Specification 36.213, the CQI is defined as the best combination of modulation and transport block size that can be used for downlink transmission to provide a transport block error rate of less than or equal to 0.1 (10%) by using the same modulation order as defined for the CQI index and by using the transport block size in accordance with the MCS. TS 36.213 also defines the overhead assumptions to be considered for

the CQI calculation. More specifically, for a UE configured to use TM 9 and 10, the overhead from the UE-specific reference signals are counted in accordance with the RI report (when PMI/RI reporting is configured), and CRS overhead are in accordance with the CRS configuration at the eNB and control channel overhead is fixed at 3 OFDM symbols. For example, in TM9 and 10 for CQI reports with RI = 3, 4, the number of PDSCH resource elements available for data transmission in the resource block is equal to 96 REs and 92 REs for 2 and 4 CRS antenna ports, respectively. As fewer data REs are available for communications using 2 CRS antenna ports than 4 CRS antenna ports, this leads to a higher code rate being used for communications using 4 CRS antenna ports than 2 CRS antenna ports to achieve the same amount of data transfer.

[0061] The overhead assumption used in the design of new TBS entries corresponding to 256QAM is specified to be, except for the last row in the TBS table, which corresponds to the maximum TBS, 120 resource elements per resource block. The overhead assumption for the last TBS row is 136 resource elements per resource block to get a higher peak data rate with 256QAM. The coding rates corresponding to different MCS with the overhead assumption specified for CQI (again assuming RI = 3, 4 reporting) are provided in Table 1 below.

MCS	Modulation	Code rates	
		2 CRS ports	4 CRS ports
0	2 (QPSK)	0.1454	0.1517
1	2	0.2387	0.2491
2	2	0.3762	0.3926
3	2	0.5363	0.5596
4	2	0.7350	0.7670
5	4 (16QAM)	0.4575	0.4774
6	4	0.5169	0.5393
7	4	0.5969	0.6228
8	4	0.6629	0.6917
9	4	0.7379	0.7700
10	4	0.7963	0.8309
11	6 (64QAM)	0.5704	0.5952
12	6	0.6371	0.6648
13	6	0.6811	0.7107
14	6	0.7607	0.7938
15	6	0.8140	0.8494

16	6	0.8858	0.9243
17	6	0.9558	0.9974
18	6	0.9954	1.0387
19	6	1.0706	1.1171
20	8 (256QAM)	0.8304	0.8665
21	8	0.8671	0.9048
22	8	0.9259	0.9662
23	8	0.9598	1.0015
24	8	1.0248	1.0693
25	8	1.0570	1.1029
26	8	1.1036	1.1516
27	8	1.2747	1.3301

Table 1: Coding rates for MCS with 256QAM in TM9 and 10 and overhead defined for CQI

- [0062]** As can be seen, most of the MCS/TBS indexes (22-27) corresponding to 256QAM become unusable due to the coding rates, which are above the highest CQI coding rate (=0.9258). In addition, the grid of the coding rates for MCS becomes more compressed for 256QAM. Table 2 shows the CQI-to-MCS mapping for the 256QAM CQI table, assuming RI = 3, 4 reporting. It can be seen that there is large fraction of the CQI that are mapped to the same MCS index, making almost half of the CQI entries useless.

CQI	Modulation	code rate	2 CRS ports	4 CRS ports
1	2	0.0762	0	0
2	2	0.1885	0	0
3	2	0.4385	2	2
4	4	0.3691	5	5
5	4	0.4785	5	5
6	4	0.6016	7	7
7	6	0.4551	11	11
8	6	0.5537	11	11
9	6	0.6504	12	12
10	6	0.7539	14	14
11	6	0.8525	16	15
12	8	0.6943	20	20
13	8	0.7783	20	20
14	8	0.8643	21	20
15	8	0.9258	22	21

Table 2: CQI-to-MCS mapping for 256QAM and TM9, 10

- [0063]** To combat this inefficiency, 4x4 MIMO may be used for TM 9 and 10 using different assumptions. FIG. 5 illustrates a flowchart of MIMO communication in accordance with some embodiments. The operations in FIG. 5 may be applied by the UE 102 and eNB 104 shown in FIGS 1 and 2. In the method of FIG. 5 the overhead assumption used

in the CQI calculation in TM9 and TM10 may be aligned with the assumption used in the MCS/TBS design by reducing the overhead from the control channel (from the current 3 to 2 or 1) or the overhead from the reference signals. For CQI calculations, the overhead is virtual and
5 specified in the LTE specification to align the eNB and the UE about the assumptions used to derive the CQI.

[0064] In some embodiments, when 4x4 MIMO and/or 256QAM for TM 9 and 10 is used for communications between the UE 102 and the eNB 104, the control overhead used for CQI calculation and
10 reporting may be reduced in the CQI definition. With reduced overhead in CQI definition, CQI reporting for 4x4 MIMO may become more efficient.

[0065] Whichever TM is indicated in the RRC Configuration message for the UE 102 to use, it may also be desirable for the UE 102
15 to determine whether 256QAM is available as some legacy eNBs may be unable to support this modulation (e.g., supporting up to 64QAM). Thus, in operation 504, the UE 102 may thus determine that the eNB 104 supports 256QAM from the RRC Configuration message. In some embodiments, the UE 102 may determine this dependent on whether the
20 RRC Configuration message indicates use of the altCQI-Table-r12 by the eNB 104.

[0066] In some embodiments, the reduced overhead can be achieved for CQI calculation in TM9 and TM10 by reducing control signaling overhead from 3 OFDM symbols to 2 OFDM symbols or 1
25 OFDM symbol, to better match CQI and MCS/TBS tables and achieve mostly or all one-to-one mapping between CQI and MCS entries. The reduced overhead may also be achieved by reducing the reference signal overhead (number of reference signals transmitted). Thus, at operation 506, in response to the UE 102 determining that the altCQI-Table-r12 is
30 present in the RRC Configuration message, the UE 102 may follow use different signaling overhead assumptions of control signals (PDCCH) occupying the first 1 or 2 OFDM symbols in a subframe extending over

the entire system bandwidth. The RRC configuration message may also indicate the configured number of CRS ports being used.

[0067] In some embodiments, a fixed UE-specific RS overhead may be assumed corresponding to 1 or 2 layers. The reduced overhead
5 assumption may be used when PMI/RI reporting and 256QAM is configured for TM 9 and 10. In some embodiments, the reduced overhead may be used when CSI reporting is performed for 4 or 8 CSI-RS antenna ports and with configured PMI/RI reporting. In some
10 embodiments, the reduced overhead may be achieved by not counting overhead from CRS of the serving eNB 104 is 256QAM is configured. In some embodiments, the overhead may be in accordance to the multicast-broadcast single-frequency network (MBSFN) subframe without CRS in the PDSCH region.

[0068] After the UE 102 determines at operation 506 that a
15 reduced overhead assumption is to apply, the eNB 104 may transmit reference signals to the UE 102 such as CRS, CSI-RS, or channel state information interference measurement resource (CSI-MR). The UE 102 may measure these reference signals at operation 508 for CSI calculation. The UE 102 may determine one or more of various
20 characteristics of the reference signal, and thus channel quality. The UE 102 may measure, for example, the SNR or SINR. As above, the number of reference signals may be reduced or the control signaling may be reduced.

[0069] The UE 102, after measuring the reference signal
25 characteristics, may determine at operation 510 a CQI value of between 1 and 15 based on the measured characteristics. Note that the 3GPP specification does not define how the measured value(s) are used or whether any other factors are involved in determining the CQI value. Instead, for example, testing may be performed to correlate the
30 measured SNR/SINR and a measured Block Error Rate (BLER), a ratio of the number of erroneous blocks to the total number of blocks received, and create an internal table or equation for the correlation. The UE may, for the determined link conditions and overhead described

for CQI, estimate the best MCS that has BLER not higher than 10%.

The UE may then convert the MCS to the CQI that has the same modulation order and the closest coding rate.

[0070] Once the CQI value is determined at operation 510, the

5 UE 102 may also transmit a CQI report to the eNB 104 in the PUCCH. The CQI report may include the CQI value, PMI and RI and perhaps the MCS, although the eNB 104 may independently determine the corresponding MCS. The CQI report and information carried therein may depend on whether the CQI report is periodic or aperiodic, whether
10 the CQI report is wideband or a selected subband (either UE-selected or configured by higher layer signaling), and how many PMIs are in the CQI report.

[0071] Once the eNB 104 has the CQI information, at operation

15 514 the eNB may derive the MCS that defines the modulation and the code rate to be used for PDSCH transmission using a CQI-to-MCS mapping table. The CQI to MCS mapping table for the eNB 104 is shown in Table 3 and 4 below. If 256QAM is not supported, Tables 1 and 2 above may be used by the UE 102. If 256QAM is not supported, Tables 3 and 4 below may be used by the UE 102 to map the CQI to the
20 MCS. Tables 3 and 4 respectively show one embodiment of a CQI-to-MCS mapping for 256QAM CQI table assuming RI = 3, 4 reporting and reduced control signaling overhead from 3 to 2 OFDM symbols and 1 OFDM symbol. It can be seen that one-to-one mapping between CQI and MCS entries can be achieved for almost the entire CQI table when 2
25 symbols are assumed and for the entire CQI table when 1 symbol are assumed. The MCS and code rate, as shown, may be dependent on the CQI and number of CRS ports.

CQI	Modulation	code rate	2 CRS ports	4 CRS ports
1	2	0.0762	0	0
2	2	0.1885	1	1
3	2	0.4385	3	3
4	4	0.3691	5	5
5	4	0.4785	6	6
6	4	0.6016	8	8
7	6	0.4551	11	11

8	6	0.5537	12	11
9	6	0.6504	14	13
10	6	0.7539	15	15
11	6	0.8525	17	17
12	8	0.6943	20	20
13	8	0.7783	21	20
14	8	0.8643	23	22
15	8	0.9258	25	24

Table 3: CQI-to-MCS mapping for 256QAM and TM9, 10, reduced to 2 symbols

CQI	Modulation	code rate	2 CRS ports	4 CRS ports
1	2	0.0762	0	0
2	2	0.1885	1	1
3	2	0.4385	3	3
4	4	0.3691	5	5
5	4	0.4785	7	7
6	4	0.6016	9	8
7	6	0.4551	11	11
8	6	0.5537	13	12
9	6	0.6504	15	14
10	6	0.7539	17	16
11	6	0.8525	19	18
12	8	0.6943	21	20
13	8	0.7783	23	22
14	8	0.8643	26	24
15	8	0.9258	26	26

Table 4: CQI-to-MCS mapping for 256QAM and TM9, 10, reduced to 1 symbol

5 **[0072]** In addition, as shown in Tables 3 and 4, the usable MCS values may increase by about 20%. As can be seen, for a CQI of 15, corresponding to 256QAM and code rate of 0.9258, rather than being limited to MCS of 21 (for 4 CRS ports) or 22 (for 2 CRS ports), the MCS may extend to 25 or 26 with usable code rates.

10 **[0073]** Once the eNB 104 has the CQI information, the eNB may convert CQI value to the MCS that defines the modulation and the code rate, the eNB 104 may communicate using the determined communication characteristics. These characteristics may include using up to 4 MIMO layers and up to 256QAM (if supported by the eNB 104)

15 at the indicated MCS for downlink communications.

[0074] FIG. 6 illustrates another flowchart of MIMO communication in accordance with some embodiments. The operations in FIG. 6 may be applied by the UE 102 and eNB 104 shown in FIGS 1 and 2. FIG. 6 illustrates an embodiment in which the UE 102 may be

20 configured with 256QAM and use 4x4 MIMO when in TM 3, 4 or 8

instead of TM 9 and 10 as in the flowchart of FIG. 5. In this case, the UE 102 may support more layers in supportedMIMO-CapabilityDL than is given by the “maximum number of supported layers for spatial multiplexing in DL.” As above, the UE 102 may be provided with the
5 RRCConnectionConfiguration information from the eNB 104 at operation 602.

[0075] The UE 102 may determine at operation 604 that the altCQI-Table-r12 is being used for downlink communications provided by the eNB 104. In response, the UE 102 may determine that an
10 adjustment in the RI feedback may be desirable.

[0076] In some embodiments, 4x4 MIMO may be used for PDSCH transmission to the UE 102 in TM3 and TM4. Configuration of 256QAM (i.e., altCQI-Table-r12) on the downlink communications may be used to resolve the ambiguities in the rate matching and RI reporting
15 between Release 8 and Release 12 UE categories without explicit eNB signaling on the supported release. The indication of rate matching of the coded bits and bit width for RI reporting according to 4x4 MIMO may be a configuration of 256QAM CQI table for downlink communications only supported by the Rel-12 eNB.

[0077] The UE 102 may determine the bit widths for RI
20 feedback assuming a revised maximum number of layers. Specifically, at operation 606 if the UE 102 is configured with the altCQI-Table-r12 and the supportedMIMO-CapabilityDL-r10 field is included in the UE-EUTRA-Capability in the RRC Configuration message, the maximum
25 number of layers for RI report and coded bits rate matching for PDSCH reception in TM 3, 4 or 8 may be determined according to the minimum of the configured number of CRS ports and the maximum of the reported UE downlink MIMO capabilities for the same band in the corresponding band combination. If the UE 102 is not configured with
30 the altCQI-Table-r12, i.e. 256QAM is not being used, the UE 102 may follow legacy procedures and may follow an original RI reporting and rate matching assumption of a maximum of 2 MIMO layers in TM3 and TM4. This is to say that the UE 102 may use at most two MIMO layers

in TM 3, 4 or 8 for RI reporting and coded bits rate matching. If the UE 102 is configured with the altCQI-Table-r12, Nsoft for rate matching in TS 36.212 may be derived assuming Nsoft of the UE category (UE-Category-r12). Nsoft is the total number of soft channel bits in the UE soft buffer of the Hybrid Automatic Repeat Request (HARQ) scheme to enable the HARQ scheme to combine an incorrectly received coded data block and a retransmitted block.

5 [0078] After the UE 102 determines at operation 606 if the UE 102 is configured with the altCQI-Table-r12, the UE 102 may measure the reference signals transmitted by the eNB 104 at operation 608 for CSI calculation. The UE 102 may determine one or more of various characteristics of the reference signal, and thus channel quality. The UE 102 may measure, for example, the SNR or SINR.

[0079] The UE 102, after measuring the reference signal characteristics, may determine at operation 610 a CQI value of between 15 1 and 15 based on the measured characteristics. Note that the 3GPP specification does not define how the measured value(s) are used or whether any other factors are involved in determining the CQI value. Instead, for example, testing may be performed to correlate the measured SNR/SINR and a measured Block Error Rate (BLER), a ratio of the number of erroneous blocks to the total number of blocks received, and create an internal table or equation for the correlation. The UE may, for the determined link conditions and overhead described for CQI, estimate the best MCS that has BLER not higher than 10%. 25 The UE may then convert the MCS to the CQI that has the same modulation order and the closest coding rate.

[0080] Once the CQI value is determined at operation 610, the UE 102 may also transmit a CQI report to the eNB 104 in the PUCCH. The CQI report may include the CQI value, PMI and RI and perhaps the MCS, although the eNB 104 may independently determine the 30 corresponding MCS. The CQI report and information carried therein may depend on whether the CQI report is periodic or aperiodic, whether the CQI report is wideband or a selected subband (either UE-selected or

configured by higher layer signaling), and how many PMIs are in the CQI report.

[0081] Once the eNB 104 has the CQI information, at operation 614 the eNB may derive the MCS that defines the modulation and the code rate to be used for PDSCH transmission. The eNB may use a CQI-to-MCS mapping table stored in memory.

[0082] Once the eNB 104 has the CQI information, the eNB may convert CQI value to the MCS that defines the modulation and the code rate, the eNB 104 may communicate using the determined communication characteristics. These characteristics may include using up to 4 MIMO layers and up to 256QAM (if supported by the eNB 104) at the indicated MCS for downlink communications.

[0083] In Example 1, an apparatus of a user equipment (UE) comprises: a transceiver arranged to communicate with an evolved NodeB (eNB); and processing circuitry arranged to: receive higher layer signaling indicating a Channel Quality Indication (CQI) table that supports 256 Quadrature Amplitude Modulation (QAM); determine whether 256 Quadrature Amplitude Modulation (QAM) is configured for downlink communication dependent on the CQI table indicated by the higher layer signaling; based on 256QAM being indicated, one of: measure, based on reference signals received from the eNB, a channel quality of a channel used to communicate with the eNB, wherein a CQI calculation is based on one of a reduced control and reference signal overhead compared with a respective legacy control and reference signal overhead of CQI used when a CQI table supporting at most 64QAM is configured at the UE, and determine a maximum number of layers for Rank Indicator (RI) reporting and coded bit rate matching for physical downlink shared channel (PDSCH) reception using a minimum of: a configured number of cell-specific reference signal (CRS) ports and a maximum of reported UE downlink MIMO capabilities for a band in a corresponding band combination; and configure the transceiver to communicate with the eNB using up to 4 Multiple Input Multiple Output (MIMO) layers.

[0084] In Example 2, the subject matter of Example 1 optionally includes that the processing circuitry is further arranged to: configure the transceiver to receive configuration information from the eNB in a Radio Resource Control (RRC) Connection Configuration message, and
5 determine from the configuration information whether the eNB supports CQI reports with 256 QAM.

[0085] In Example 3, the subject matter of any one or more of Examples 1–2 optionally include that the processing circuitry is further arranged to: measure the channel quality using at least one of a signal-
10 to-noise ratio (SNR) and signal-to-interference plus noise ratio (SINR) of the reference signals, and configure the transceiver to transmit a CQI report comprising a CQI value based on the channel quality to the eNB.

[0086] In Example 4, the subject matter of Example 3 optionally includes that: the reference signals comprise at least one of a cell-
15 specific reference signal (CRS), a Channel State Information Reference Signal (CSI-RS) and a Channel State Information Interference Measurements (CSI-IM).

[0087] In Example 5, the subject matter of any one or more of Examples 1–4 optionally include that: communication with the eNB
20 uses one of transmission mode 9 and 10, based on 256QAM being indicated, the processing circuitry is arranged to measure the channel quality and determine the CQI calculation based on the one of a reduced control and reference signal overhead, and the reduced control signal overhead comprises at most 2 Orthogonal Frequency-Division
25 Multiplexing (OFDM) symbols.

[0088] In Example 6, the subject matter of Example 5 optionally includes that: the reduced reference signal overhead is selected such that a one-to-one mapping between Channel Quality Indication (CQI) and the MCS is present in each entry in a CQI-to-MCS mapping table stored
30 in a memory of the UE for 2 cell-specific reference signal (CRS) ports.

[0089] In Example 7, the subject matter of any one or more of Examples 5–6 optionally include that: the reduced reference signal overhead is selected such that a one-to-one mapping between Channel

Quality Indication (CQI) and MCS is present in each entry in a CQI-to-MCS mapping table stored in a memory of the UE for 4 cell-specific reference signal (CRS) antenna ports.

[0090] In Example 8, the subject matter of any one or more of Examples 1–7 optionally include that: wherein the reduced control signal overhead is used when the CQI is calculated based on 4 or 8 Channel State Information reference signal (CSI-RS) antenna ports.

[0091] In Example 9, the subject matter of Example 8 optionally includes that the processing circuitry is further arranged to: eliminate consideration of cell-specific reference signals (CRS) of the eNB to reduce the reference signal overhead.

[0092] In Example 10, the subject matter of any one or more of Examples 1–9 optionally include that: communication with the eNB uses one of transmission mode 3, 4 and 8, and the processing circuitry is arranged to determine the maximum number of layers for RI reporting and coded bit rate matching for PDSCH reception.

[0093] In Example 11, the subject matter of Example 10 optionally includes that the processing circuitry is further arranged to: configure the transceiver to use at most 2 MIMO layers in response to determining that at most 64 QAM is configured.

[0094] In Example 12, the subject matter of any one or more of Examples 1–11 optionally include at least 4 antennas configured to transmit and receive 4x4 MIMO communications between the transceiver and the eNB.

[0095] Example 13 is an apparatus of an evolved NodeB (eNB) comprising: a transceiver arranged to communicate with a user equipment (UE); and processing circuitry arranged to: configure the transceiver to transmit a Radio Resource Control (RRC) Connection Configuration to the UE that indicates that the eNB supports 256 Quadrature Amplitude Modulation (QAM) with the UE; configure the transceiver to transmit reference signals; receive, from the UE, a channel quality measurement based on the reference signals; based on the channel quality, determine a modulation coding scheme (MCS)

comprising a code rate with which to communicate with the UE using 4x4 Multiple Input Multiple Output (MIMO) and one of a reduced control and reference signal overhead compared with a legacy control and reference signal overhead, respectively; and communicate with the
5 UE using 4x4 MIMO and the determined MCS.

[0096] In Example 14, the subject matter of Example 13 optionally includes that: the reference signals comprise at least one of a cell-specific reference signal (CRS), a Channel State Information Reference Signal (CSI-RS) and a Channel State Information
10 Interference Measurements (CSI-IM), the channel quality measurement comprises at least one of a signal-to-noise ratio (SNR) and signal-to-interference plus noise ratio (SINR) of the CRS, the processing circuitry is arranged to determine a Channel Quality Indication (CQI) based on the at least one of the SNR and SINR of the CRS, and the MCS is
15 determined using a CQI-to-MCS mapping.

[0097] In Example 15, the subject matter of any one or more of Examples 13–14 optionally include that: communication with the UE uses one of transmission mode 9 and 10, the reduced reference signal overhead comprises at most 2 Orthogonal Frequency-Division
20 Multiplexing (OFDM) symbols, and the reduced reference signal overhead is selected such that a one-to-one mapping between Channel Quality Indication (CQI) and MCS is present in each entry in a CQI-to-MCS mapping table stored in a memory of the eNB for at least one of 2 and 4 cell-specific reference signal (CRS) ports.

[0098] In Example 16, the subject matter of any one or more of Examples 13–15 optionally include that: wherein the reduced reference signal overhead is used when Precoding Matrix Indicator (PMI) and Rank Indicator (RI) reporting is configured for 4 or 8 Channel State Information (CSI) reference signals (CSI-RS) antenna ports.

[0099] In Example 17, the subject matter of Example 16 optionally includes that the processing circuitry is further arranged to: eliminate consideration of cell-specific reference signals (CRS) of the

eNB to reduce a reference signal overhead to the reduced reference signal overhead.

[00100] In Example 18 a non-transitory computer-readable storage medium that stores instructions for execution by one or more processors of a user equipment (UE) to configure the UE to communicate with an evolved NodeB (eNB), the one or more processors to configure the UE to: determine from Radio Resource Control (RRC) Connection Configuration information that the eNB supports 256 Quadrature Amplitude Modulation (QAM); based on 256QAM being indicated, one of: measure, based on reference signals received from the eNB, a channel quality of a channel used to communicate with the eNB, using one of a reduced control and reference signal overhead compared with a legacy control and reference signal overhead, respectively, and determine modulation coding scheme (MCS) comprising a code rate with which to communicate with the eNB using 4x4 Multiple Input Multiple Output (MIMO), and determine a maximum number of layers for Rank Indicator (RI) reporting and coded bit rate matching for physical downlink shared channel (PDSCH) reception using a minimum of: a configured number of cell-specific reference signal (CRS) ports and a maximum of reported UE downlink MIMO capabilities for a band in a corresponding band combination; and communicate with the eNB using at least 4x4 MIMO and the determined MCS.

[00101] In Example 19, the subject matter of Example 18 optionally includes that: the reference signals comprise at least one of a cell-specific reference signal (CRS), a Channel State Information Reference Signal (CSI-RS) and a Channel State Information Interference Measurements (CSI-IM), the channel quality measurement comprises a Channel Quality Indication (CQI) determined from at least one of a signal-to-noise ratio (SNR) and signal-to-interference plus noise ratio (SINR) of the CRS, and the MCS is determined using a CQI-to-MCS mapping.

[00102] In Example 20, the subject matter of any one or more of Example 18-19 optionally includes that: communication with the eNB

uses one of transmission mode 9 and 10, the reduced reference signal overhead comprises at most 2 Orthogonal Frequency-Division Multiplexing (OFDM) symbols, and the reduced reference signal overhead is selected such that a one-to-one mapping between Channel Quality Indication (CQI) and MCS is present in each entry in a CQI-to-MCS mapping table for one of 2 and 4 cell-specific reference signal (CRS) ports.

[00103] In Example 21, the subject matter of any one or more of Example 18-20 optionally includes that the instructions further
10 configure the UE to: eliminate consideration of cell-specific reference signals (CRS) of the eNB to reduce a reference signal overhead to the reduced reference signal overhead.

[00104] In Example 22 the subject matter of any one or more of Example 18-21 optionally includes that: communication with the eNB
15 uses one of transmission mode 3, 4 and 8, and the maximum number of layers for RI reporting and coded bit rate matching for PDSCH reception is determined, and at most 2 MIMO layers is used in response to determining that at most 64 QAM is configured.

[00105] The term "machine readable medium" may include a
20 single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) configured to store one or more instructions. The term "machine readable medium" may include any medium that is capable of storing, encoding, or carrying instructions for execution by the 3GPP device 200 and that cause it to
25 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. The term "transmission medium" shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution, and includes
30 digital or analog communications signals or other intangible medium to facilitate communication of such software. In some embodiments, some of the elements described in FIG. 2 may be omitted or additional

elements may be provided. The device shown and described herein is thus not limited to the embodiment shown in FIG. 2.

[00106] Although an embodiment has been described with reference to specific example embodiments, it will be evident that various modifications and changes may be made to these embodiments without departing from the broader spirit and scope of the present disclosure. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense. The accompanying drawings that form a part hereof show, by way of illustration, and not of limitation, specific embodiments in which the subject matter may be practiced. The embodiments illustrated are described in sufficient detail to enable those skilled in the art to practice the teachings disclosed herein. Other embodiments may be utilized and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope of this disclosure. This Detailed Description, therefore, is not to be taken in a limiting sense, and the scope of various embodiments is defined only by the appended claims, along with the full range of equivalents to which such claims are entitled.

[00107] Such embodiments of the inventive subject matter may be referred to herein, individually and/or collectively, by the term “invention” merely for convenience and without intending to voluntarily limit the scope of this application to any single invention or inventive concept if more than one is in fact disclosed. Thus, although specific embodiments have been illustrated and described herein, it should be appreciated that any arrangement calculated to achieve the same purpose may be substituted for the specific embodiments shown. This disclosure is intended to cover any and all adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, will be apparent to those of skill in the art upon reviewing the above description.

[00108] In this document, the terms “a” or “an” are used, as is common in patent documents, to include one or more than one,

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

[00109] The Abstract of the Disclosure is provided to comply with 37 C.F.R. §1.72(b), requiring an abstract that will 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. In addition, in the foregoing Detailed Description, it can be seen that various features are grouped together in a single embodiment for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed embodiment. Thus the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separate embodiment.

CLAIMS

What is claimed is:

1. An apparatus of a user equipment (UE) comprising:
 - a transceiver arranged to communicate with an evolved NodeB (eNB); and
 - processing circuitry arranged to:
 - receive higher layer signaling indicating a Channel Quality Indication (CQI) table that supports 256 Quadrature Amplitude Modulation (QAM);
 - determine whether 256 Quadrature Amplitude Modulation (QAM) is configured for downlink communication dependent on the CQI table indicated by the higher layer signaling;
 - based on 256QAM being indicated, one of:
 - measure, based on reference signals received from the eNB, a channel quality of a channel used to communicate with the eNB, wherein a CQI calculation is based on one of a reduced control and reference signal overhead compared with a respective legacy control and reference signal overhead of CQI used when a CQI table supporting at most 64QAM is configured at the UE, and
 - determine a maximum number of layers for Rank Indicator (RI) reporting and coded bit rate matching for physical downlink shared channel (PDSCH) reception using a minimum of: a configured number of cell-specific reference signal (CRS) ports and a maximum of reported UE downlink Multiple Input Multiple Output (MIMO) capabilities for a band in a corresponding band combination; and
 - configure the transceiver to communicate with the eNB using up to 4 MIMO layers.

2. The apparatus of claim 1, wherein the processing circuitry is further arranged to:
 - configure the transceiver to receive configuration information from the eNB in a Radio Resource Control (RRC) Connection Configuration message, and
 - determine from the configuration information whether the eNB supports CQI reports with 256 QAM.
3. The apparatus of claim 1 or 2, wherein the processing circuitry is further arranged to:
 - measure the channel quality using at least one of a signal-to-noise ratio (SNR) and signal-to-interference plus noise ratio (SINR) of the reference signals, and
 - configure the transceiver to transmit a CQI report comprising a CQI value based on the channel quality to the eNB.
4. The apparatus of claim 3, wherein:
 - the reference signals comprise at least one of a cell-specific reference signal (CRS), a Channel State Information Reference Signal (CSI-RS) and a Channel State Information Interference Measurements (CSI-IM).
5. The apparatus of claim 1 or 2, wherein:
 - communication with the eNB uses one of transmission mode 9 and 10,
 - based on 256QAM being indicated, the processing circuitry is arranged to measure the channel quality and determine the CQI calculation based on the one of a reduced control and reference signal overhead, and
 - the reduced control signal overhead comprises at most 2 Orthogonal Frequency-Division Multiplexing (OFDM) symbols.
6. The apparatus of claim 5, wherein:

the reduced reference signal overhead is selected such that a one-to-one mapping between Channel Quality Indication (CQI) and the MCS is present in each entry in a CQI-to-MCS mapping table stored in a memory of the UE for 2 cell-specific reference signal (CRS) ports.

7. The apparatus of claim 5, wherein:

the reduced reference signal overhead is selected such that a one-to-one mapping between Channel Quality Indication (CQI) and MCS is present in each entry in a CQI-to-MCS mapping table stored in a memory of the UE for 4 cell-specific reference signal (CRS) antenna ports.

8. The apparatus of claim 1 or 2, wherein:

wherein the reduced control signal overhead is used when the CQI is calculated based on 4 or 8 Channel State Information reference signal (CSI-RS) antenna ports.

9. The apparatus of claim 8, wherein the processing circuitry is further arranged to:

eliminate consideration of cell-specific reference signals (CRS) of the eNB to reduce the reference signal overhead.

10. The apparatus of claim 1 or 2, wherein:

communication with the eNB uses one of transmission mode 3, 4 and 8, and

the processing circuitry is arranged to determine the maximum number of layers for RI reporting and coded bit rate matching for PDSCH reception.

11. The apparatus of claim 10, wherein the processing circuitry is further arranged to:

configure the transceiver to use at most 2 MIMO layers in response to determining that at most 64 QAM is configured.

12. The apparatus of claim 1 or 2, further comprising at least 4 antennas configured to transmit and receive 4x4 MIMO communications between the transceiver and the eNB.
13. An apparatus of an evolved NodeB (eNB) comprising:
a transceiver arranged to communicate with a user equipment (UE); and
processing circuitry arranged to:
 configure the transceiver to transmit a Radio Resource Control (RRC) Connection Configuration to the UE that indicates that the eNB supports 256 Quadrature Amplitude Modulation (QAM) with the UE;
 configure the transceiver to transmit reference signals;
 receive, from the UE, a channel quality measurement based on the reference signals;
 based on the channel quality, determine a modulation coding scheme (MCS) comprising a code rate with which to communicate with the UE using 4x4 Multiple Input Multiple Output (MIMO) and one of a reduced control and reference signal overhead compared with a legacy control and reference signal overhead, respectively; and
 communicate with the UE using 4x4 MIMO and the determined MCS.
14. The apparatus of claim 13, wherein:
the reference signals comprise at least one of a cell-specific reference signal (CRS), a Channel State Information Reference Signal (CSI-RS) and a Channel State Information Interference Measurements (CSI-IM),
the channel quality measurement comprises at least one of a signal-to-noise ratio (SNR) and signal-to-interference plus noise ratio (SINR) of the CRS,

the processing circuitry is arranged to determine a Channel Quality Indication (CQI) based on the at least one of the SNR and SINR of the CRS, and

the MCS is determined using a CQI-to-MCS mapping.

15. The apparatus of claim 13 or 14, wherein:

communication with the UE uses one of transmission mode 9 and 10,

the reduced reference signal overhead comprises at most 2 Orthogonal Frequency-Division Multiplexing (OFDM) symbols, and

the reduced reference signal overhead is selected such that a one-to-one mapping between Channel Quality Indication (CQI) and MCS is present in each entry in a CQI-to-MCS mapping table stored in a memory of the eNB for at least one of 2 and 4 cell-specific reference signal (CRS) ports.

16. The apparatus of claim 13 or 14, wherein:

wherein the reduced reference signal overhead is used when Precoding Matrix Indicator (PMI) and Rank Indicator (RI) reporting is configured for 4 or 8 Channel State Information (CSI) reference signals (CSI-RS) antenna ports.

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

eliminate consideration of cell-specific reference signals (CRS) of the eNB to reduce a reference signal overhead to the reduced reference signal overhead.

18. A computer-readable storage medium that stores instructions for execution by one or more processors of a user equipment (UE) to configure the UE to communicate with an evolved NodeB (eNB), the one or more processors to configure the UE to:

determine from Radio Resource Control (RRC) Connection Configuration information that the eNB supports 256 Quadrature Amplitude Modulation (QAM);

based on 256QAM being indicated, one of:

measure, based on reference signals received from the eNB, a channel quality of a channel used to communicate with the eNB, using one of a reduced control and reference signal overhead compared with a legacy control and reference signal overhead, respectively, and determine modulation coding scheme (MCS) comprising a code rate with which to communicate with the eNB using 4x4 Multiple Input Multiple Output (MIMO), and

determine a maximum number of layers for Rank Indicator (RI) reporting and coded bit rate matching for physical downlink shared channel (PDSCH) reception using a minimum of: a configured number of cell-specific reference signal (CRS) ports and a maximum of reported UE downlink MIMO capabilities for a band in a corresponding band combination; and communicate with the eNB using at least 4x4 MIMO and the determined MCS.

19. The medium of claim 18, wherein:

the reference signals comprise at least one of a cell-specific reference signal (CRS), a Channel State Information Reference Signal (CSI-RS) and a Channel State Information Interference Measurements (CSI-IM),

the channel quality measurement comprises a Channel Quality Indication (CQI) determined from at least one of a signal-to-noise ratio (SNR) and signal-to-interference plus noise ratio (SINR) of the CRS, and

the MCS is determined using a CQI-to-MCS mapping.

20. The medium of claim 18 or 19, wherein:

communication with the eNB uses one of transmission mode 9 and 10,

the reduced reference signal overhead comprises at most 2 Orthogonal Frequency-Division Multiplexing (OFDM) symbols, and

the reduced reference signal overhead is selected such that a one-to-one mapping between Channel Quality Indication (CQI) and MCS is present in each entry in a CQI-to-MCS mapping table for one of 2 and 4 cell-specific reference signal (CRS) ports.

21. The medium of claim 18 or 19, wherein the instructions further configure the UE to:

eliminate consideration of cell-specific reference signals (CRS) of the eNB to reduce a reference signal overhead to the reduced reference signal overhead.

22. The medium of claim 18, wherein:

communication with the eNB uses one of transmission mode 3, 4 and 8, and

the maximum number of layers for RI reporting and coded bit rate matching for PDSCH reception is determined, and

at most 2 MIMO layers is used in response to determining that at most 64 QAM is configured.

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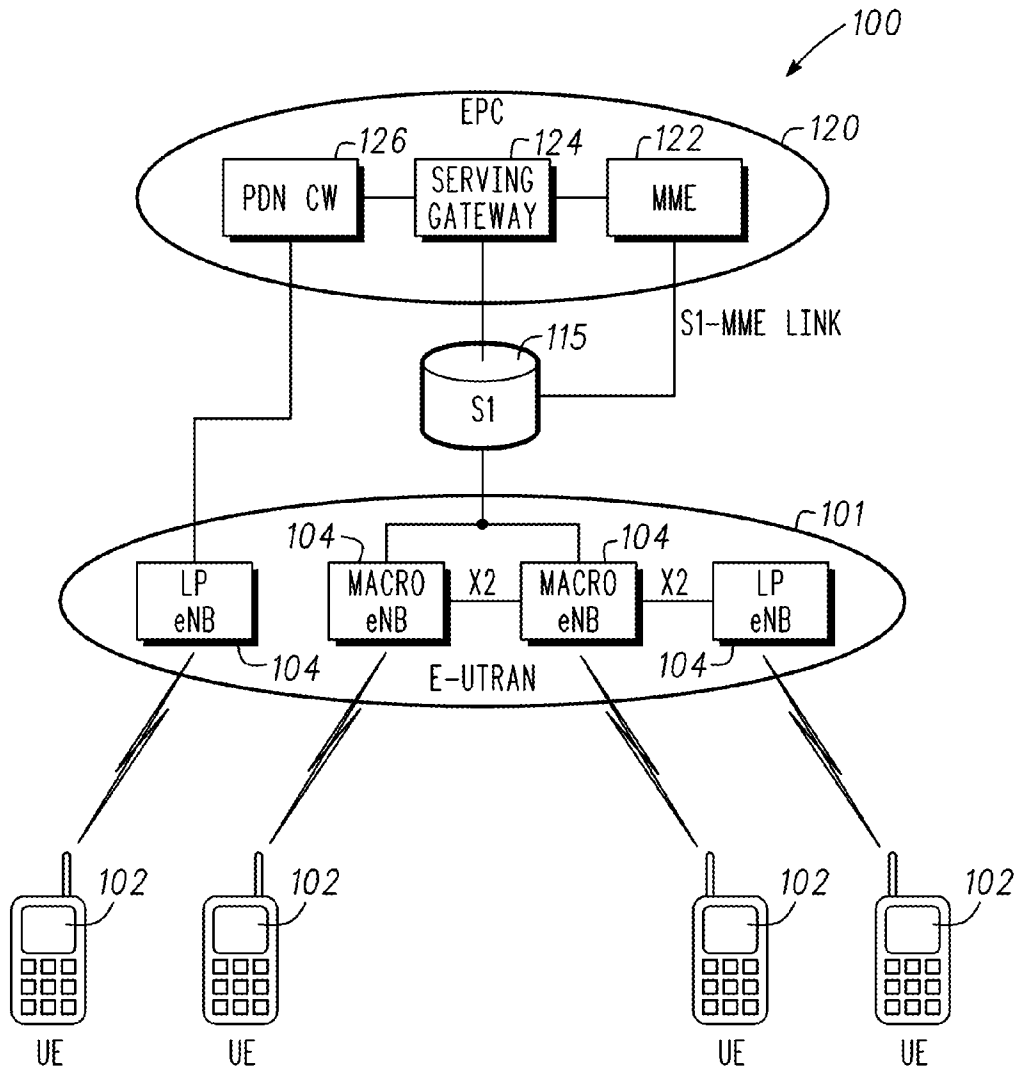


FIG. 1

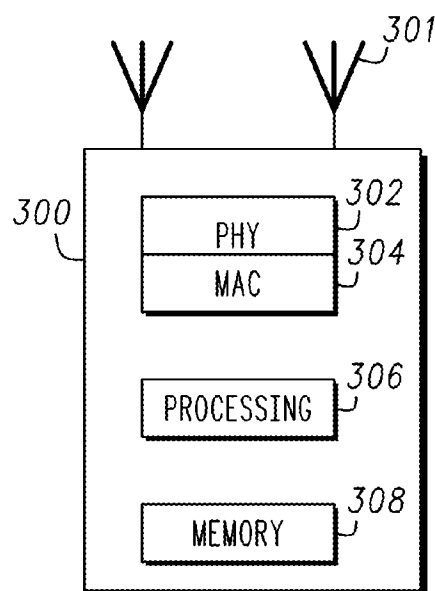


FIG. 2

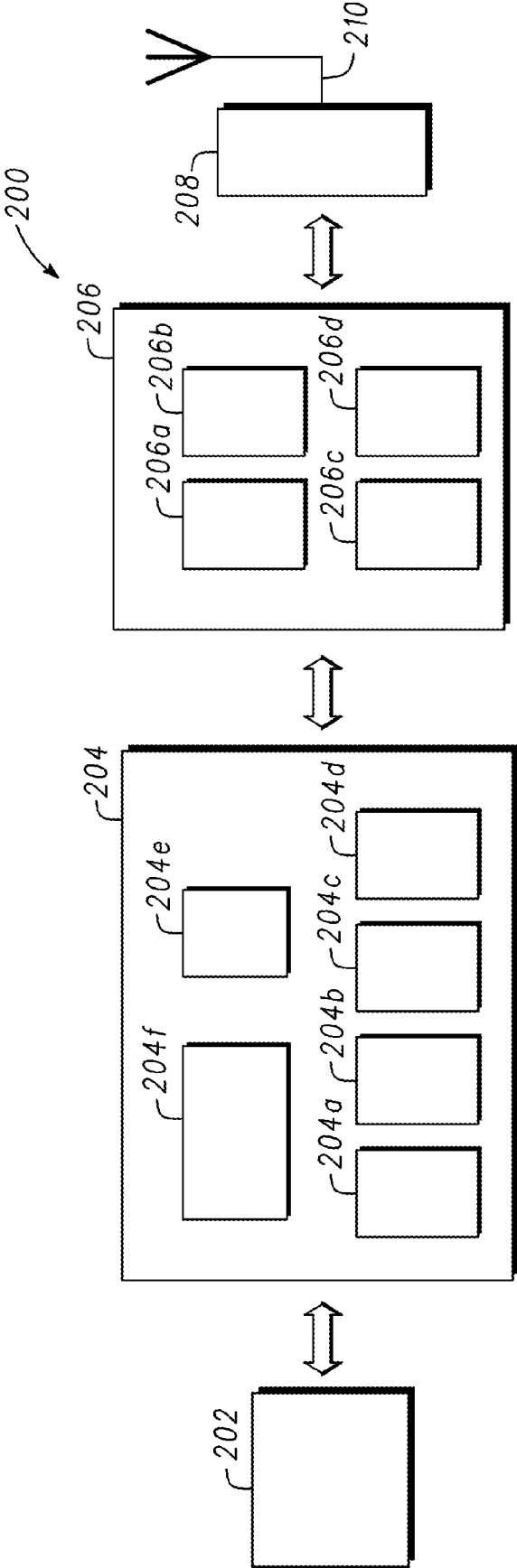


FIG. 2

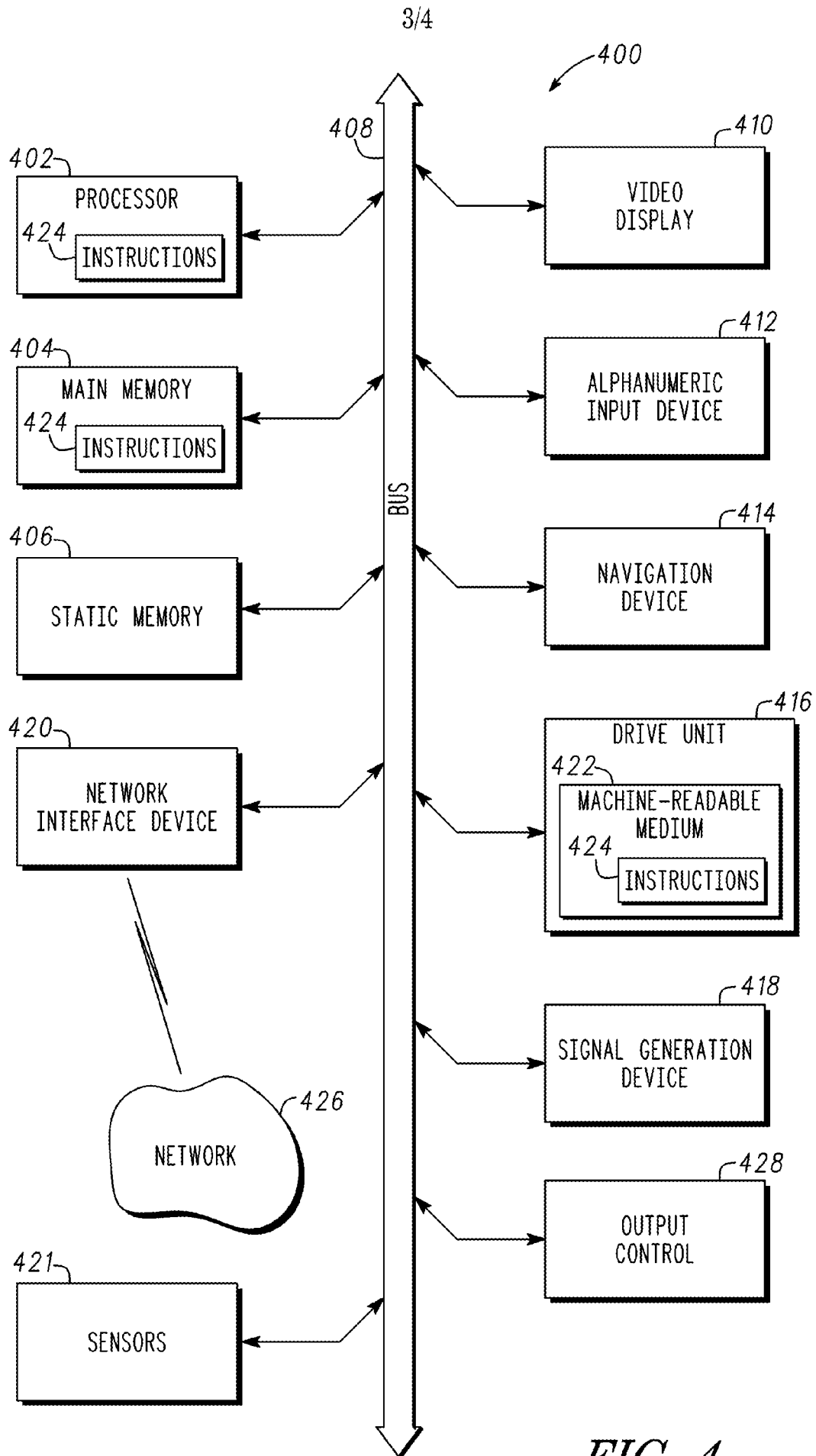
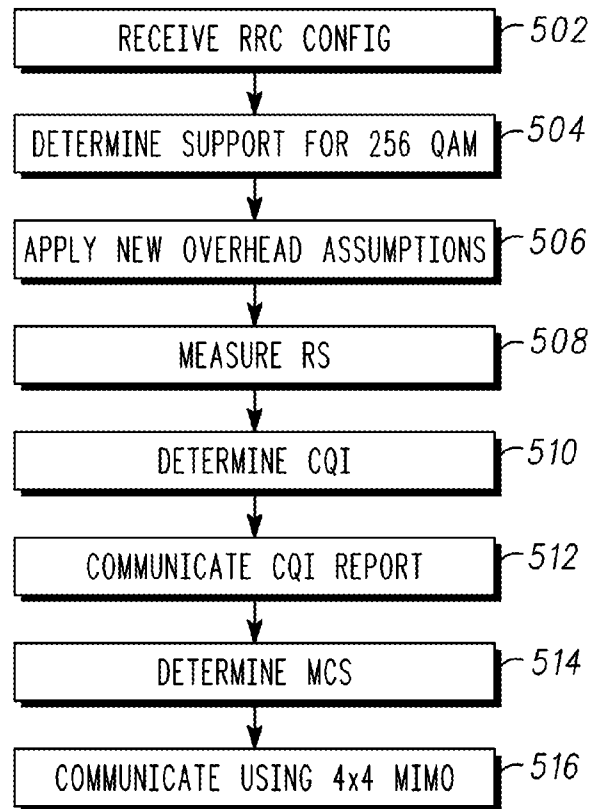
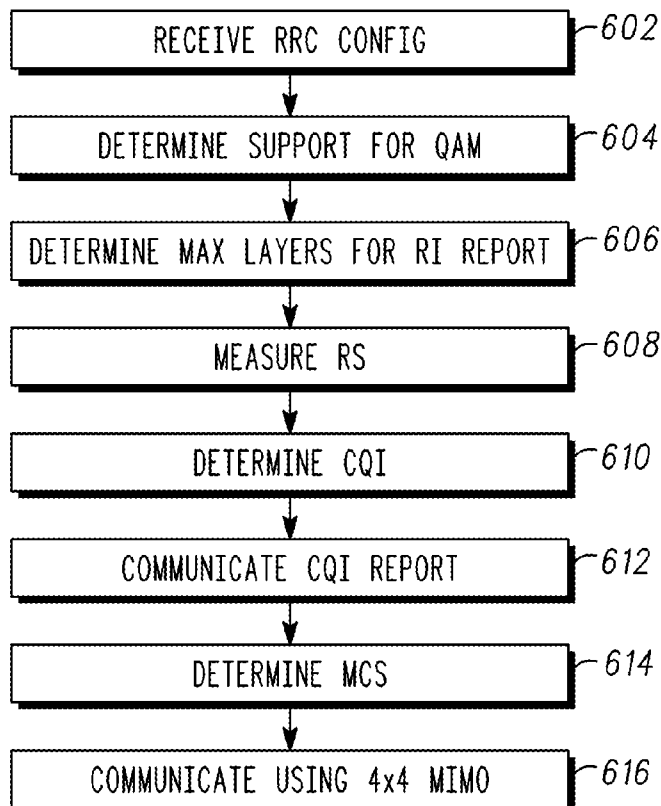


FIG. 4

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*FIG. 5**FIG. 6*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/063106**A. CLASSIFICATION OF SUBJECT MATTER****H04L 1/00(2006.01)i, H04L 1/06(2006.01)i, H04L 27/34(2006.01)i, H04L 27/26(2006.01)i**

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04L 1/00; H04L 1/06; H04L 27/34; H04L 27/26

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & keywords: 256 QAM, 4x4 MIMO, CQI table, reduced control signal, reduced reference signal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2014-163430 A1 (SAMSUNG ELECTRONICS CO., LTD.) 09 October 2014 See paragraphs [0056]-[0100], [0123]-[0167], [0228]; and figures 9-23.	1-4, 10-12, 18, 19, 22
A		5-9, 13-17, 20, 21
Y	HUAWEI, HISILICON, 'Discussion on application scenarios and standard impacts for UE categories 11 and 12', R1-143698, 3GPP TSG RAN WG1 Meeting #78bis, Ljubljana, Slovenia, 27 September 2014 See pages 1-5.	1-4, 10-12, 18, 19, 22
A	WO 2014-176034 A1 (MOTOROLA MOBILITY LLC) 30 October 2014 See paragraphs [0056]-[0104]; and figures 5, 6.	1-22
A	WO 2013-123961 A1 (NOKIA SIEMENS NETWORKS OY) 29 August 2013 See paragraphs [0123]-[0156]; and figures 9-16.	1-22
A	WO 2014-109915 A1 (QUALCOMM INCORPORATED) 17 July 2014 See paragraphs [0123]-[0156]; and figures 9-16.	1-22



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

08 April 2016 (08.04.2016)

Date of mailing of the international search report

08 April 2016 (08.04.2016)

Name and mailing address of the ISA/KR

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