



(51) International Patent Classification:
H04B 7/04 (2017.01)

(21) International Application Number:
PCT/CN2017/085681

(22) International Filing Date:
24 May 2017 (24.05.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
15/164,373 25 May 2016 (25.05.2016) US

(71) Applicant: **HUAWEI TECHNOLOGIES CO., LTD.**
[CN/CN]; Huawei Administration Building, Bantian, Long-
gang District, Shenzhen, Guangdong 518129 (CN).

(72) Inventors: **NAMMI, Sairamesh**; 2330 Central Express-
way, Santa Clara, CA 95050 (US). **QI, Xiaofeng**; 512 Dud-
ley Court, Westfield, NJ 07090 (US).

(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ,
CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO,
DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,
HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR,
KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG,
MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM,
PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC,

SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR,
TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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

Declarations under Rule 4.17:

— as to the applicant's entitlement to claim the priority of the
earlier application (Rule 4.17(iii))

Published:

— with international search report (Art. 21(3))

(54) Title: CHANNEL-STATE INFORMATION DETERMINATION IN WIRELESS NETWORKS

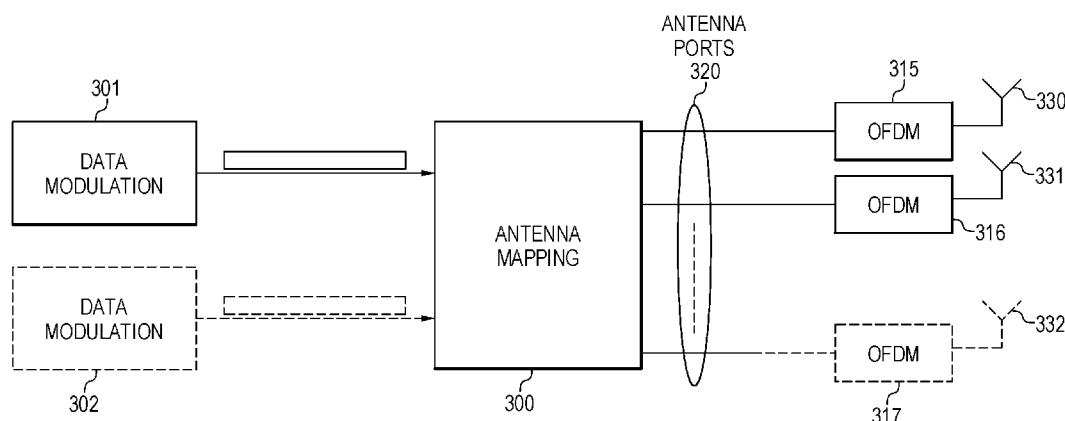


FIG. 3

(57) Abstract: A method for channel-state information determination in a wireless network comprises determining an initial chan-
nel-state information for a wireless channel based on a search of a plurality of sets of precoding codebook elements stored in a multiple
input multiple output user equipment (UE) and determining a subsequent channel-state information based on the initial channel-state
information.

Channel-State Information Determination In Wireless Networks

Cross Reference to Related Application

[0001] This application claims priority to U.S. non-provisional patent application Serial No. 15/164,373, filed on May 25, 2016 and entitled “Channel-State Information Determination In Wireless Networks”, which application is incorporated herein by reference as if reproduced in its entirety.

Technical Field

[0002] The present disclosure is related generally to wireless networks and in particular to determining channel-state information, such as rank information, in a wireless network.

Background

[0003] The Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) radio interface supports both Frequency division duplex (FDD) and Time division duplex (TDD). A multiple input multiple output (MIMO) technique is an advanced antenna technique for a wireless device to improve spectral efficiency and thereby boost overall system capacity of 3GPP LTE systems. MIMO may be used for achieving diversity gain, spatial multiplexing gain and beamforming gain. Massive MIMO systems (i.e., 64+ antennas) are currently under investigation for 5G systems.

[0004] Ideal linear precoding uses full channel-state information (CSI) at the transmitter. This may be possible only for TDD-based systems but not practical for FDD-based systems. Codebook based precoding allows the receiver to explicitly identify a precoding matrix/vector based on a codebook that should be used for transmission. In the 3GPP LTE standard, separate codebooks are defined for various combinations of the number of transmit antennas and the number of transmission layers. The latter is also called rank information (RI).

[0005] For reporting RI and associated precoding matrix index (PMI), the user equipment (UE) uses an exhaustive search over all the precoding codebook elements. The exhaustive search is difficult to implement with the increased

number of transmit antennas in massive MIMO systems. For example, in systems with four transmit antenna ports, the UE needs to search over all the 64 precoding entities for finding rank information and precoding index. Similarly, for 8 transmit antennas, the UE needs to search over all the 122 elements defined in the 3GPP standard. With large scale MIMO, the codebook size becomes larger. Thus, the UE complexity increases with additional transmit antennas deployed at the eNode B. Also, frequent CSI computation drains the UE battery by increasing power consumption, consuming more memory, and using additional processing units at the UE.

Summary

[0006] A method for channel-state information determination in a wireless network comprises determining an initial channel-state information for a wireless channel based on a search of a plurality of sets of precoding codebook elements stored in a multiple input multiple output user equipment (UE) and determining a subsequent channel-state information based on the initial channel-state information.

Brief Description of the Drawings

[0007] FIG. 1 is a diagram of a wireless communication system, in accordance with various embodiments.

[0008] FIG. 2 is a block diagram of a wireless communication device, in accordance with various embodiments.

[0009] FIG. 3 is a block diagram of a MIMO antenna system, in accordance with various embodiments.

[0010] FIG. 4 is a flow diagram showing the message sequence between a base station and a UE, in accordance with various embodiments.

[0011] FIG. 5 is a flowchart showing a method for channel-state information determination in wireless networks, in accordance with various embodiments.

[0012] FIG. 6 is a flowchart showing another method for channel-state information determination in wireless networks, in accordance with various embodiments.

Detailed Description

[0013] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.

[0014] The various embodiments operate in wireless communication systems such as mmWave, Institute of Electrical and Electronics Engineers (IEEE) 802.11 standards-based systems, future 3rd Generation Partnership Project (3GPP) 5G systems based on mmWave as well as other wireless systems. For simplicity, subsequent descriptions refer to communications at the user equipment (UE). However, other embodiments may be applied to communications at the base station as well.

[0015] FIG. 1 is a diagram illustrating a wireless communication system, in accordance with various embodiments. For example, the wireless communication system 100 may be a cellular system that enables a wireless communication device 101 to communicate with one or more base stations 102 (e.g., evolved Node B (eNB), access point, transmission node, RRU, RRH, nodes in distributed antenna systems (DAS), donor node controlling relay, base transceiver state (BTS), multi-standard radio (MSR)) over one or more wireless channels using a wireless communication technique (e.g., mmWave, time division duplex (TDD), frequency division duplex (FDD)).

[0016] The wireless communication device 101 may be a non-stationary device. For example, the wireless communication device 101 may include mobile radiotelephones, tablet computers, lap top computers, and other devices that may communicate over a wireless channel with the base station 102. For consistency and simplicity, the wireless communication device 101 is subsequently referred to as user equipment (UE). The UE includes a transceiver and control circuitry coupled to a plurality of antenna elements through which beamforming may be accomplished.

[0017] The base station 102 may include a plurality of antennas coupled to a transceiver as well as control circuitry to control the base station operation. FIG. 1 and subsequent figures show only a single antenna for purposes of simplicity

and clarity. However, a person of ordinary skill in the art would realize that for beamforming to be accomplished, the base station 102 comprises a plurality of antenna elements.

[0018] The base station 102 has a fixed location and may be part of a stationary base station network including other base stations that are coupled to a larger network. For example, the base station 102 may be part of a wired network that is coupled to the Internet. The UE 101 may then access the larger network by communicating over the wireless communication channels with the base station 102.

[0019] The base station 102 communicates over an area 110 substantially surrounding the base station antenna. This area 110 is typically referred to as a cell 110 and may comprise one or more sectors 120, 121, 122. While three different sectors 120, 121, 122 are shown making up the cell 110 of FIG. 1, other embodiments may comprise different sector quantities.

[0020] While a plurality of UEs 101 may be within the cell 110 generated by the base station 102, not all of the UEs 101 may be in contact with the base station 102. UE 101 that is registered with the base station or is attempting to register with the base station 102 may be defined as “served UEs”. Other UEs may be registered with other, neighboring base stations.

[0021] FIG. 2 is a block diagram of a wireless communication device 200, in accordance with various embodiments. The wireless communication device 200 may be in the example form of the UE (e.g., see FIG. 1), a cellular base station (e.g., eNodeB, eNB), an access point (AP), or some other wireless station. For example, the wireless communication device 200 may be a computer, a personal computer (PC), a tablet PC, a hybrid tablet, a personal digital assistant (PDA), or part of any device configured to execute instructions (sequential or otherwise) that specify actions to be taken by the wireless communication device 200.

[0022] The term “processor-based system” shall be taken to include any set of one or more communication apparatuses that are controlled by or operated by processing circuitry (e.g., a controller) to individually or jointly execute instructions to perform any one or more of the methodologies discussed herein. A set or sequence of instructions may be executed to cause the communication apparatus to perform any one of the methodologies discussed herein, according to an example embodiment.

[0023] The wireless communication device 200 may include at least one controller 202 (e.g., a central processing unit (CPU), a graphics processing unit (GPU) or both, processor cores, compute nodes, etc.), and memory 204 that communicate with each other via a link 208 (e.g., bus). If the wireless communication device 200 is a UE, it may further include a display device 210 (e.g., video, LED, LCD) and an alphanumeric input device 212 (e.g., a keypad, keyboard). In one embodiment, the display device 210 and the input device 212 may be incorporated in one unit as a touch screen display.

[0024] The wireless communication device 200 may additionally include a mass storage device 216 (e.g., a drive unit, hard disk drive, solid state drive, optical drive) and a network interface device 220. The network interface device 220 may include one or more radios (e.g., transmitters and receivers (transceivers)) coupled to a plurality of antenna elements in order to communicate over a wireless network channel 226, as illustrated in FIG. 1. The one or more radios may be configured to operate using one or more communication techniques including the method for channel-state information determination disclosed herein. The network interface device 220 may also include a wired network interface (e.g., X2 backhaul link).

[0025] The storage device 216 includes a computer-readable medium 222 on which is stored one or more sets of data structures and instructions 224 (e.g., software) embodying or utilized by any one or more of the methodologies or functions described herein. The instructions 224 may also reside, completely or at least partially, within the memory 204 and/or within the controller 202 during execution thereof by the communication apparatus 200. A plurality of sets precoding codebook elements including a rank information and a corresponding precoding matrix index may be stored in the memory of the UE

[0026] While the computer-readable medium 222 is illustrated in an example embodiment to be a single medium, the term “computer-readable medium” may include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store the one or more instructions 224.

[0027] The UE may additionally include sensors 230 such as an accelerometer, a global positioning system (GPS) receiver, a gyroscope, and/or a

compass to provide sensory input to the processor 202. These sensors 230 may be used to determine a velocity (i.e., magnitude and direction) of the UE.

[0028] The UE described herein may implement a MIMO antenna configuration. One example of such a configuration is illustrated in FIG. 3.

[0029] FIG. 3 is a block diagram of a MIMO antenna system, in accordance with various embodiments. The MIMO system is an advanced antenna technique to improve spectral efficiency and thereby boosting the overall system capacity. The MIMO technique uses a commonly known notation ($M \times N$) to represent MIMO configuration in terms number of transmit (M) and receive antennas (N). The common MIMO configurations used for various technologies are: (2×1) , (1×2) , (2×2) , (4×2) , (8×2) and (2×4) , (4×4) , (8×4) .

[0030] MIMO antenna systems can increase data carrying capacity of wireless systems. MIMO can also be used for achieving diversity gain, spatial multiplexing gain and beamforming gain. For these reasons, MIMO is an integral part of the 3rd and 4th generation wireless systems.

[0031] FIG. 3 illustrates the general antenna mapping block 300 that maps the outputs of the data modulation blocks 301, 302 to the different antenna ports 320. The input to the antenna mapping block 300 thus comprises modulation symbols (e.g., QPSK, 16QAM, 64QAM, 256QAM) corresponding to the one or two transport blocks. To be more specific, there is one transport block per transmission time interval (TTI) except for spatial multiplexing, in which case there may be two transport blocks per TTI. The output of the antenna mapping block 300 is a set of symbols for each antenna port 320. The symbols of each antenna port 320 are subsequently applied to respective orthogonal frequency division multiplexer (OFDM) modulators 315-317. In other words, the symbols are mapped to the basic OFDM time–frequency grid corresponding to that particular antenna port. The OFDM modulators 315-317 then transmit the symbols from their respective antenna 330-332.

[0032] Massive MIMO is a relatively recent research field in wireless communication where large numbers of antenna elements are deployed at the transmitter. Larger numbers of user terminals can be supported by combining massive MIMO technology with conventional time and frequency division multiplexing via orthogonal frequency division multiplexing. For this purpose, 3GPP may increase the number of antennas at the base station up to 16/32/64.

[0033] FIG. 4 is a flow diagram showing the message sequence between a base station 401 and a UE 400, in accordance with various embodiments. The base station (e.g., eNB) 401 initially transmits cell specific and UE specific reference signals 410 to the UE 400. The reference signals may include signals such as pilot signals.

[0034] The UE 400 uses those reference signals to determine condition of the channel as indicated by the channel-state information (CSI) 420. The CSI may include such elements as, for example, channel quality indicator (CQI), precoding matrix index (PMI), and rank information (RI).

[0035] The CSI information is transmitted back to the eNB 401 over a feedback channel such as physical uplink control channel (PUCCH) for periodic reporting or physical uplink shared channel (PUSCH) for aperiodic reporting. The eNB 401 may then determine the parameters for downlink (DL) transmission (i.e., from the eNB to the UE). These parameters may include transmission power, modulation coding scheme (MCS), and physical resource blocks (PRBs).

[0036] The eNB 401 then transmits these parameters to the UE 400 over the DL control channel 441 (e.g., physical downlink control channel (PDCCH)). However, before sending PDCCH, the eNB sends control format indicator information on PCFICH which is a physical channel providing the UEs with information necessary to decode the set of downlink control channels (PDCCH). After that, the eNB 401 may then transmit data traffic 442 to the UE 400.

[0037] Downlink reference signals are predefined signals occupying specific resource elements within the downlink time-frequency grid. The LTE specification includes several types of downlink reference signals that are transmitted in different ways and used for different purposes by the receiving terminal. For example, downlink reference signals may include cell-specific reference signals (CRS), demodulation-reference signals (DM-RS), and channel-state information-reference signals (CSI-RS).

[0038] Cell-specific reference signals are transmitted in every downlink subframe and in every resource block in the frequency domain, thus covering the entire cell bandwidth. The cell-specific reference signals can be used by the UE for channel estimation for coherent demodulation of any downlink physical channel except for PMCH and for PDSCH in the case of transmission modes 7,

8, or 9. The cell-specific reference signals may also be used by the terminal to acquire channel-state information. Terminal measurements on cell-specific reference signals may be used as the basis for cell-selection and handover decisions.

[0039] Demodulation reference signals may also be referred to as UE-specific reference signals and are specifically intended to be used by UEs for channel estimation for PDSCH in the case of transmission modes 7, 8, 9 or 10. The label “UE-specific” relates to the fact that each demodulation reference signal is intended for channel estimation by a single terminal. That specific reference signal is then only transmitted within the resource blocks assigned for PDSCH transmission to that terminal.

[0040] CSI-reference signals are specifically intended to be used by UEs to acquire CSI in the case when demodulation reference signals are used for channel estimation. CSI-reference signals have a significantly lower time/frequency density thus implying less overhead as compared to the cell-specific reference signals.

[0041] In an LTE system, the downlink control channel (PDCCH) carries information about the scheduling grants. Typically this comprises a number of scheduled MIMO layers, transport block sizes, modulation for each code word, parameters related to HARQ, sub-band locations, and also a respective precoding matrix index corresponding to each sub-band.

[0042] Typically, the following information is transmitted by means of the downlink control information (DCI) format: localized/distributed VRB assignment flag, resource block assignment, modulation and coding scheme, HARQ process number, new data indicator, redundancy version, TPC command for PUCCH, downlink Assignment Index, precoding matrix index, and number of layers. Note that all DCI formats may not use all the information as shown above. In general, the contents of PDCCH depends on transmission mode and DCI format.

[0043] Also in an LTE system, the uplink control channel carries information about hybrid automatic repeat request-acknowledge (HARQ-ACK) information corresponding to the downlink data transmission, and channel state information. The CSI typically comprises RI, CQI, and PMI. Either PUCCH or PUSCH can be used to carry this information. Note that the PUCCH reporting is

periodic and the periodicity of the PUCCH is configured by the higher layers, while the PUSCH reporting is aperiodic. Also note that there are various modes for PUCCH and PUSCH and in general it depends on the transmission mode and the formats is configured via higher layer signaling.

[0044] Ideal linear precoding uses full CSI at the transmitter. This may be possible only for TDD based systems but not practical for FDD based systems. Thus, codebook based precoding allows the receiver to explicitly identify a precoding matrix/vector based on a codebook stored in the UE that is used for transmission.

[0045] In the 3GPP LTE standard, separate codebooks are defined for various combinations of the number of transmit antennas and the number of transmission layers. The latter is also referred to as rank information (RI). For example, in 3GPP Release 8, a total of 64 precoding vectors and matrices are defined as shown in Table 1 for 4 transmit antennas. Also for each rank in the codebook for the scenarios of RI=1, 2, 3 and 4, 16 elements per rank are defined. Table 1 is shown only for purposes of illustration and does not limit the present embodiments to any certain information contained therein. The 3GPP standard does not specify the criteria for the UE to use to compute the RI and/or the optimum precoding matrices/vectors.

TABLE 1

Codebook index	u_n	Number of layers ν			
		1	2	3	4
0	$u_0 = [1 \ -1 \ -1 \ -1]^T$	$W_0^{(1)}$	$W_0^{(14)}/\sqrt{2}$	$W_0^{(124)}/\sqrt{3}$	$W_0^{(1234)}/2$
1	$u_1 = [1 \ -j \ 1 \ j]^T$	$W_1^{(1)}$	$W_1^{(12)}/\sqrt{2}$	$W_1^{(123)}/\sqrt{3}$	$W_1^{(1234)}/2$
2	$u_2 = [1 \ 1 \ -1 \ 1]^T$	$W_2^{(1)}$	$W_2^{(12)}/\sqrt{2}$	$W_2^{(123)}/\sqrt{3}$	$W_2^{(3214)}/2$
3	$u_3 = [1 \ j \ 1 \ -j]^T$	$W_3^{(1)}$	$W_3^{(12)}/\sqrt{2}$	$W_3^{(123)}/\sqrt{3}$	$W_3^{(3214)}/2$
4	$u_4 = [1 \ (-1-j)/\sqrt{2} \ -j \ (1-j)/\sqrt{2}]^T$	$W_4^{(1)}$	$W_4^{(14)}/\sqrt{2}$	$W_4^{(124)}/\sqrt{3}$	$W_4^{(1234)}/2$
5	$u_5 = [1 \ (1-j)/\sqrt{2} \ j \ (-1-j)/\sqrt{2}]^T$	$W_5^{(1)}$	$W_5^{(14)}/\sqrt{2}$	$W_5^{(124)}/\sqrt{3}$	$W_5^{(1234)}/2$
6	$u_6 = [1 \ (1+j)/\sqrt{2} \ -j \ (-1+j)/\sqrt{2}]^T$	$W_6^{(1)}$	$W_6^{(13)}/\sqrt{2}$	$W_6^{(134)}/\sqrt{3}$	$W_6^{(1324)}/2$
7	$u_7 = [1 \ (-1+j)/\sqrt{2} \ j \ (1+j)/\sqrt{2}]^T$	$W_7^{(1)}$	$W_7^{(13)}/\sqrt{2}$	$W_7^{(134)}/\sqrt{3}$	$W_7^{(1324)}/2$
8	$u_8 = [1 \ -1 \ 1 \ 1]^T$	$W_8^{(1)}$	$W_8^{(12)}/\sqrt{2}$	$W_8^{(124)}/\sqrt{3}$	$W_8^{(1234)}/2$
9	$u_9 = [1 \ -j \ -1 \ -j]^T$	$W_9^{(1)}$	$W_9^{(14)}/\sqrt{2}$	$W_9^{(134)}/\sqrt{3}$	$W_9^{(1234)}/2$
10	$u_{10} = [1 \ 1 \ 1 \ -1]^T$	$W_{10}^{(1)}$	$W_{10}^{(13)}/\sqrt{2}$	$W_{10}^{(123)}/\sqrt{3}$	$W_{10}^{(1324)}/2$
11	$u_{11} = [1 \ j \ -1 \ j]^T$	$W_{11}^{(1)}$	$W_{11}^{(13)}/\sqrt{2}$	$W_{11}^{(134)}/\sqrt{3}$	$W_{11}^{(1324)}/2$
12	$u_{12} = [1 \ -1 \ -1 \ 1]^T$	$W_{12}^{(1)}$	$W_{12}^{(12)}/\sqrt{2}$	$W_{12}^{(123)}/\sqrt{3}$	$W_{12}^{(1234)}/2$
13	$u_{13} = [1 \ -1 \ 1 \ -1]^T$	$W_{13}^{(1)}$	$W_{13}^{(13)}/\sqrt{2}$	$W_{13}^{(123)}/\sqrt{3}$	$W_{13}^{(1324)}/2$
14	$u_{14} = [1 \ 1 \ -1 \ -1]^T$	$W_{14}^{(1)}$	$W_{14}^{(13)}/\sqrt{2}$	$W_{14}^{(123)}/\sqrt{3}$	$W_{14}^{(3214)}/2$
15	$u_{15} = [1 \ 1 \ 1 \ 1]^T$	$W_{15}^{(1)}$	$W_{15}^{(12)}/\sqrt{2}$	$W_{15}^{(123)}/\sqrt{3}$	$W_{15}^{(1234)}/2$

[0046] In a conventional CSI selection, an exhaustive search is performed of all of the precoding codebook elements. For example, the UE estimates the channel, computes the post-processing signal-to-interference-plus-noise ratio (SINR) for each entity in the precoding codebook, and the link quality metric (LQMs) (e.g., mutual information, capacity) for each entity in the codebook is computed. Then the precoding matrix index and the corresponding RI that maximizes the LQM is chosen.

[0047] For example, using mutual information in closed-loop SM, the UE needs to estimate a suitable CSI, (i.e., CQI/PMI/RI), in order to maximize the throughput and simultaneously maintain the block-error-rate (BLER) constraint that can be mathematically described by a joint (integer) optimization problem:

$$\max_{\text{CQI, PMI, RI}} \text{Throughput}(\text{CQI, PMI, RI}) \quad (1)$$

[0048] Unfortunately, this joint (discrete/integer) optimization problem does not have any closed-form solution. Hence, one normally tries to estimate a suitable PMI/RI (independent of CQI). Thereafter, a suitable CQI is estimated accordingly for the chosen PMI and RI. For example, consider a single-cell scenario having perfect time and synchronization, a received system model for (closed-loop) spatial multiplexing (SM) per sub-carrier (post-FFT) can be shown as:

$$\begin{aligned} \mathbf{Y} &= \underbrace{\mathbf{R}_r^{1/2} \mathbf{H}_{\text{IID}} \mathbf{R}_t^{1/2}}_{\mathbf{H}} \mathbf{W}_{\text{PMI}} \mathbf{x} + \mathbf{n} \\ &= \mathbf{H} \mathbf{W}_{\text{PMI}} \mathbf{x} + \mathbf{n} \end{aligned} \quad (1)$$

where, $\mathbf{Y} \in \mathbb{C}^{N_r \times 1}$ corresponds to a received signal vector, and $\mathbf{H} \in \mathbb{C}^{N_r \times N_t}$ describes an overall channel matrix incorporating the receiver and transmitter spatial correlation $\mathbf{R}_r \in \mathbb{C}^{N_r \times N_r}$ and $\mathbf{R}_t \in \mathbb{C}^{N_t \times N_t}$, respectively. A complex zero-mean Gaussian noise vector $\mathbf{n} \in \mathbb{C}^{N_r \times 1}$ is having covariance $\mathbf{R}_n$. An unknown complex data/symbol vector is denoted by $\mathbf{x} \in \mathbb{C}^{N_L \times 1}$ (having normalized power $\mathbf{E}\{\mathbf{x}\mathbf{x}^H\} = \mathbf{R}_x = \mathbf{I}$) corresponding to M-QAM (e.g., 64-QAM) constellation. A (complex) precoder $\mathbf{W}_{\text{PMI}} \in \mathbb{C}^{N_t \times N_L}$ is selected from a given/known codebook $\mathcal{I}$ having N_I number of precoders (where, $\text{PMI} = \{0, 1, \dots, N_I - 1\}$) for a given $\text{rank} \leq \min\{N_r, N_t\}$.

[0049] The post-processing SINR per i^{th} spatial layer for a given PMI, assuming linear-MMSE detector employed at the receiver, reads

$$SINR_i = \frac{1}{\left[\left(\mathbf{W}_{PMI}^H \mathbf{H}^H \mathbf{R}_n^{-1} \mathbf{H} \mathbf{W}_{PMI} + \mathbf{I}_{N_L} \right)^{-1} \right]_{i,i}} - 1, \quad (2)$$

where $[\mathbf{A}]_{i,i}$ corresponds to an i^{th} diagonal element of a matrix $\mathbf{A}$.

[0050] In order to estimate a suitable PMI/RI, a link-quality metric (LQM) is computed. The LQM (e.g., mean mutual information) may be denoted as mMI (per sub-band/wide-band) and is computed as given below:

$$\text{mMI}(\text{PMI}, \text{RI}) = \left(\frac{1}{K \cdot \text{rank}} \right) \sum_{k=1}^K \sum_{i=1}^{\text{RI} = \text{rank}} \mathcal{I}(SINR_i[k]), \quad (3)$$

[0051] Where, $\mathcal{I}(SINR_i[k])$ is a mutual information that is a function of post-processing $SINR_i[k]$ as given in Table 2 for i^{th} spatial layer and k^{th} resource-element. The number of resource-elements employed for the computation of the aforementioned LQM is given by a parameter K (depending on the wide-band/sub-band PMI estimate).

TABLE 2

Modulation Alphabet $\mathcal{A}$	Mutual Information per symbol
4-QAM	$\mathcal{I}(SINR_i) = J(\sqrt{4 SINR_i})$
16-QAM	$\mathcal{I}(SINR_i) \approx \left(\frac{1}{2}\right)J(0.8818\sqrt{SINR_i}) + \left(\frac{1}{4}\right)J(1.6764\sqrt{SINR_i}) + \left(\frac{1}{4}\right)J(0.9316\sqrt{SINR_i})$
64-QAM	$\mathcal{I}(SINR_i) \approx \left(\frac{1}{3}\right)J(1.1233\sqrt{SINR_i}) + \left(\frac{1}{3}\right)J(0.4381\sqrt{SINR_i}) + \left(\frac{1}{3}\right)J(0.4765\sqrt{SINR_i})$
$J(a) \approx \begin{cases} -0.04210610 a^3 + 0.209252 a^2 - 0.00640081 a, & 0 < a < 1.6363 \\ 1 - \exp(0.00181491 a^3 - 0.142675 a^2 - 0.08220540 a + 0.0549608), & 1.6363 < a < \infty. \end{cases}$	

[0052] After having the estimate of mMI (per sub-band/wide-band), the PMI and RI may be estimated jointly employing unconstrained optimization which can be given as:

$$\max_{PMI, RI} \text{mMI}(\text{PMI}, \text{RI}) \quad (5)$$

[0053] In a capacity approach, instead of using the LQM, the capacity information is used to maximize the capacity for every combination of RI, PMI as follows:

$$\text{capacity(PMI, RI)} = \left(\frac{1}{K \cdot \text{rank}} \right) \sum_{k=1}^K \sum_{i=1}^{\text{RI} = \text{rank}} \log_2(1 + \text{SINR}_i[k]) . \quad (6)$$

[0054] Note that the received SINR at the output of the MIMO detector (MMSE, MLD etc.) is a function of channel matrix H, precoding matrix, the noise power spectral density, and the co-channel interference power.

[0055] The present embodiments reduce the complexity in finding CSI (e.g., rank information, precoding matrix index, channel quality indicator) using an iterative search method (incremental/decremental search) for finding the rank information and associated precoding matrix index, thereby avoiding the conventional exhaustive search for finding this information. The present embodiments are based upon the premise that the RI changes very little during normal cellular communications. In fact, the RI mostly changes in steps of ± 1 for most Doppler frequency ranges unless the UE is moving at a velocity greater than a predetermined threshold relative to the eNB (e.g., highway velocities). Thus, in the present embodiments, the prior RI of past reports is used to compute the RI for future use.

[0056] FIG. 5 is a flowchart showing a method for channel-state information determination in wireless networks, in accordance with various embodiments. In block 501, an initial channel-state information is determined for a wireless channel based on a search of a plurality of sets of precoding codebook elements stored in a multiple input multiple output UE. Each set of the plurality of sets of precoding codebook elements may include a rank information and a corresponding precoding matrix index such that determining the initial channel-state information comprises determining the rank information and the corresponding precoding matrix index for the wireless channel.

[0057] In block 503, a subsequent channel-state information is determined based on the initial channel-state information. The plurality of sets of precoding codebook elements may be stored in a predetermined order in the UE and determining the subsequent channel-state information may include selecting the set of precoding codebook elements, including the subsequent rank information, that is immediately previous to the set of precoding codebook elements including the initial channel-state information. In another embodiment, determining the subsequent channel-state information may include selecting the set of precoding

codebook elements, including the subsequent rank information, that is immediately subsequent to the set of precoding codebook elements including the initial channel-state information.

[0058] In yet another embodiment, a velocity of the UE relative to the serving base station may be determined (e.g., using a GPS receiver) and the subsequent channel-state information may be determined based on the search of the plurality of sets of precoding codebook elements or the initial channel-state information when the velocity is less than a threshold (e.g., less than highway speed). The subsequent channel-state information may also be determined (e.g., see FIG. 6) based on the initial channel-state information when the velocity is greater than the threshold. In block 505, the subsequent channel-state information may be reported to the serving base station over the wireless channel.

[0059] FIG. 6 is a flowchart showing a method for channel-state information determination in wireless networks, in accordance with various embodiments. This method illustrates one method for determining the initial channel-state information.

[0060] In block 601, the channel conditions are estimated based on reference signals transmitted over the channel. This estimating may be accomplished based on pilot signals and data signals. In block 603, a signal-interference plus noise ratio (SINR) is determined for each set of precoding codebook elements of the plurality of sets of precoding codebook elements. In block 605, a link quality metric (LQM) is determined for each set of precoding codebook elements of the plurality of sets of precoding codebook elements. In block 607, the rank information and the corresponding precoding matrix index are determined that provide a largest LQM from a plurality of LQMs as discussed previously.

[0061] The methods for CSI determination may provide advantages over the convention exhaustive search method for determining CSI. For example, the percentage degradation with respect to full search is zero, while the complexity can be reduced significantly. Battery life on the UE side is improved since the power used to compute RI/PMI is less compared to the conventional exhaustive search method. The UE hardware resources (e.g., memory and processing units) can be partly relieved to allow the UE to efficiently execute additional procedures (e.g. inter-RAT measurements) in parallel with the CSI estimation.

[0062] In one embodiment, a user equipment includes radio transceiver means coupled to a plurality of antenna elements, wherein the radio transceiver means is a multiple input multiple output (MIMO) radio; and

[0063] control means, coupled to the radio transceiver means and antenna elements, the control means configured to determine a first rank information for a wireless channel based on a search of a plurality of precoding codebook elements stored in a multiple input multiple output UE and determine a second rank information based on the first rank information. In one embodiment, the control means is further configured to report the first and second rank information and respective corresponding precoding matrix indices to a base station over the wireless channel. In one embodiment, the control means is further configured to report a third rank information, subsequent to the second rank information, to the base station based on the search of the plurality of precoding codebook elements. The control means may further be configured to estimate a channel condition of the wireless channel based on reference symbols and/or data received over the wireless channel, to determine a signal-to-interference plus noise ratio (SINR), for a first precoding matrix index corresponding to the first rank information, based on the channel condition, to determine a mutual information or capacity of the wireless channel based on the SINR and to select the second rank information and corresponding second precoding matrix index based on the mutual information or the capacity. An embodiment of the transceiver may also include a reporting means configured to report the second precoding matrix index, the second rank information, and a channel quality indicator, associated with the second precoding matrix index, to a base station communicating with the UE over the wireless channel.

[0064] In an embodiment, the control means may further be configured to estimate a channel condition of the wireless channel from reference symbols and/or data received over the wireless channel and to determine a signal-to-interference plus noise ratio (SINR), for each precoding matrix index corresponding to each respective precoding codebook element of the plurality of precoding codebook elements, based on the channel condition. The control

means may further be configured to determine a mutual information or capacity of the wireless channel based on the SINR, to select a precoding matrix index based on the mutual information or the capacity and to report rank information and channel quality indicator, associated with the selected precoding matrix index, to a base station communicating with the UE over the wireless channel.

[0065] 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 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. In some embodiments, a system may include one or more processors and may be configured with instructions stored on a computer-readable storage device.

[0066] 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 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. In some embodiments, a system may include one or more processors and may be configured with instructions stored on a computer-readable storage device.

[0067] The Abstract is provided with the understanding that it will not be used to limit or interpret the scope or meaning of the claims. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate embodiment.

CLAIMS

What is claimed is:

1. A method comprising:
determining in a multiple input multiple output user equipment (UE) an initial channel-state information for a wireless channel based on a search of a plurality of sets of precoding codebook elements stored in the UE; and
determining a subsequent channel-state information based on the initial channel-state information.
2. The method of claim 1, wherein each set of the plurality of sets of precoding codebook elements comprises a rank information and a corresponding precoding matrix index and determining the initial channel-state information comprises determining the rank information and the corresponding precoding matrix index for the wireless channel.
3. The method of anyone of claims 1-2, wherein the respective rank information of each of the plurality of sets of precoding codebook elements are stored in a predetermined order and determining the subsequent channel-state information comprises selecting the rank information that is immediately previous to the rank information in the set of precoding codebook elements including the initial channel-state information.
4. The method of anyone of claims 1-3, wherein the respective rank information of each of the plurality of sets of precoding codebook elements are stored in a predetermined order and determining the subsequent channel-state information comprises selecting the rank information that is immediately subsequent to the rank information in the set of precoding codebook elements including the initial channel-state information.
5. The method of anyone of claims 1-4, wherein determining the initial channel-state information further comprises:
estimating channel conditions based on reference signals transmitted over the channel;

determining a signal-interference plus noise ratio (SINR) for each set of precoding codebook elements of the plurality of sets of precoding codebook elements;

determining a link quality metric (LQM) for each set of precoding codebook elements of the plurality of sets of precoding codebook elements; and

determining the rank information and the corresponding precoding matrix index that provides a largest LQM from a plurality of LQMs.

6. The method of anyone of claims 1-5, wherein estimating the channel based on reference signals comprises estimating the channel based on pilot signals and data signals.

7. The method of anyone of claims 1-6, further comprising reporting the subsequent channel-state information to a base station over the wireless channel.

8. The method of anyone of claims 1-7, further comprising forming a subset of the plurality of sets of precoding codebook elements comprising a quantity of precoding codebook elements that is less than the plurality of sets of precoding codebook elements.

9. The method of anyone of claims 1-8, wherein the subsequent channel-state information is part of a set of precoding codebook elements that is selected from the subset of sets of the precoding codebook elements.

10. The method of anyone of claims 1-9, further comprising:
determining a velocity of the UE relative to a base station communicating with the UE over the wireless channel; and
determining the subsequent channel-state information based on one of the search of the plurality of sets of precoding codebook elements stored in the UE or the initial channel-state information when the velocity is less than a threshold.

11. The method of anyone of claims 1-10, wherein
determining a velocity of the UE relative to a base station communicating with the UE over the wireless channel; and

determining the subsequent channel-state information based on the initial channel-state information when the velocity is greater than a threshold.

12. A user equipment (UE) comprising:

a radio coupled to a plurality of antenna elements, wherein the radio is a multiple input multiple output (MIMO) radio; and

a controller, coupled to the radio and antenna elements, configured to determine a first rank information for a wireless channel based on a search of a plurality of precoding codebook elements stored in a multiple input multiple output UE and determine a second rank information based on the first rank information.

13. The user equipment of claim 12, wherein the controller is further configured to report the first and second rank information and respective corresponding precoding matrix indices to a base station over the wireless channel.

14. The user equipment of anyone of claims 12-13, wherein the controller is further configured to report a third rank information, subsequent to the second rank information, to the base station based on the search of the plurality of precoding codebook elements.

15. The user equipment of anyone of claims 12-14, wherein the controller is further configured to:

estimate a channel condition of the wireless channel based on reference symbols and/or data received over the wireless channel;

determine a signal-to-interference plus noise ratio (SINR), for a first precoding matrix index corresponding to the first rank information, based on the channel condition;

determine a mutual information or capacity of the wireless channel based on the SINR;

select the second rank information and corresponding second precoding matrix index based on the mutual information or the capacity; and

report the second precoding matrix index, the second rank information, and a channel quality indicator, associated with the second precoding matrix index, to a base station communicating with the UE over the wireless channel.

16. The user equipment of anyone of claims 12-15, wherein the controller is further configured to:

estimate a channel condition of the wireless channel from reference symbols and/or data received over the wireless channel;

determine a signal-to-interference plus noise ratio (SINR), for each precoding matrix index corresponding to each respective precoding codebook element of the plurality of precoding codebook elements, based on the channel condition;

determine a mutual information or capacity of the wireless channel based on the SINR;

select a precoding matrix index based on the mutual information or the capacity; and

report rank information and channel quality indicator, associated with the selected precoding matrix index, to a base station communicating with the UE over the wireless channel.

17. A non-transitory computer-readable storage medium that stores instructions for execution by processing circuitry of a multiple input multiple output user equipment (UE) to perform operations that:

determine an initial channel-state information for a wireless channel based on a search of a plurality of sets of precoding codebook elements stored in the UE; and

determine a subsequent channel-state information based on the initial channel-state information.

18. The non-transitory computer-readable storage medium of claim 17, wherein each set of the plurality of precoding codebook elements is associated with a respective precoding matrix index and associated rank information, the plurality of sets of precoding codebook elements stored in a predetermined order,

the operations further report the precoding matrix index associated with the subsequent channel-state information.

19. The non-transitory computer-readable storage medium of anyone of claims 17-18, wherein the subsequent channel-state information is associated with a first set of a plurality of precoding codebook elements that precedes a second set of a plurality of precoding codebook elements comprising the initial channel-state information or succeeds the second set of the plurality of precoding codebook elements, in the predetermined order.

20. The non-transitory computer-readable storage medium of anyone of claims 17-19, wherein the operations further determine a velocity of the UE, relative to a base station communicating with the UE over the wireless channel, and select a rank information based on the velocity of the UE.

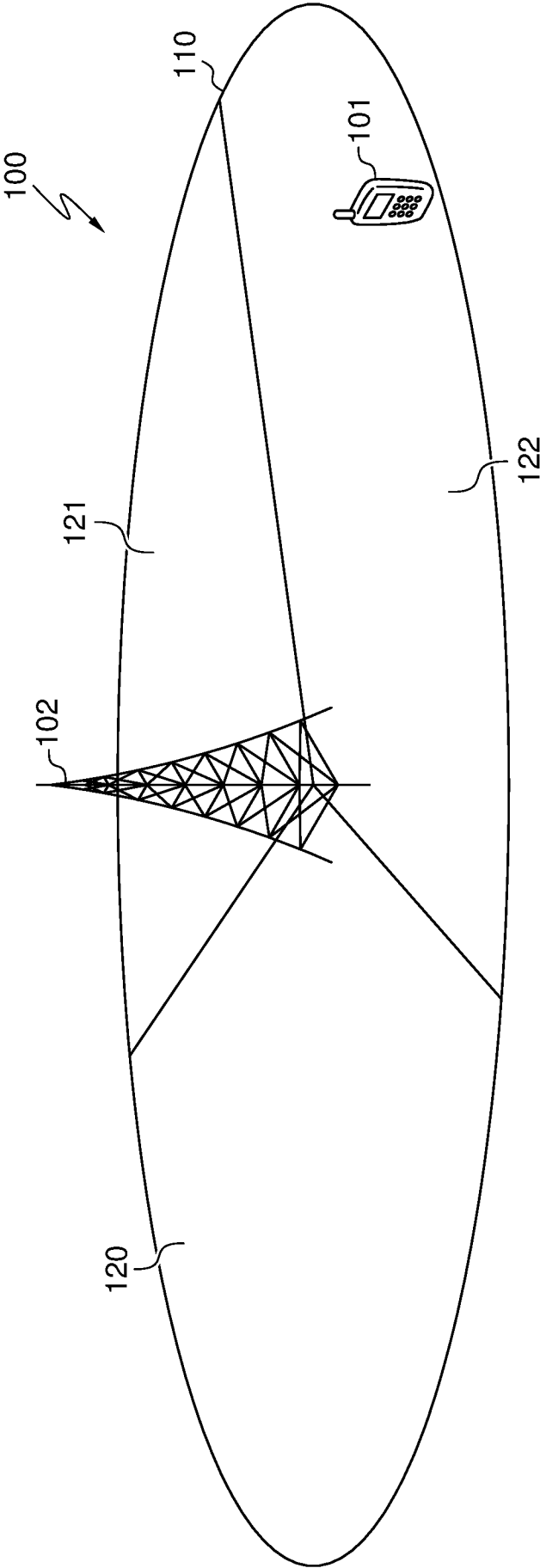


FIG. 1

2 / 5

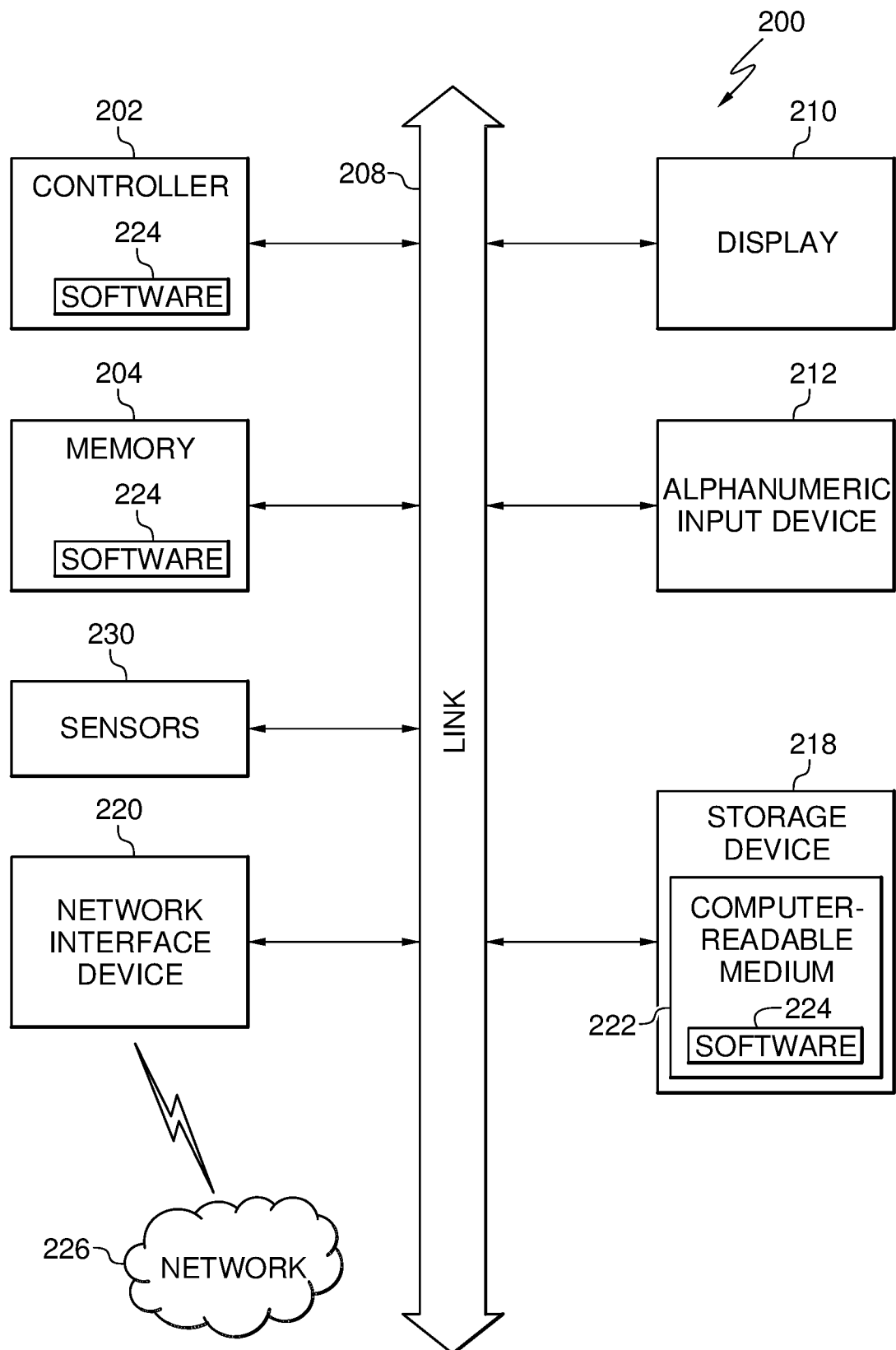


FIG. 2

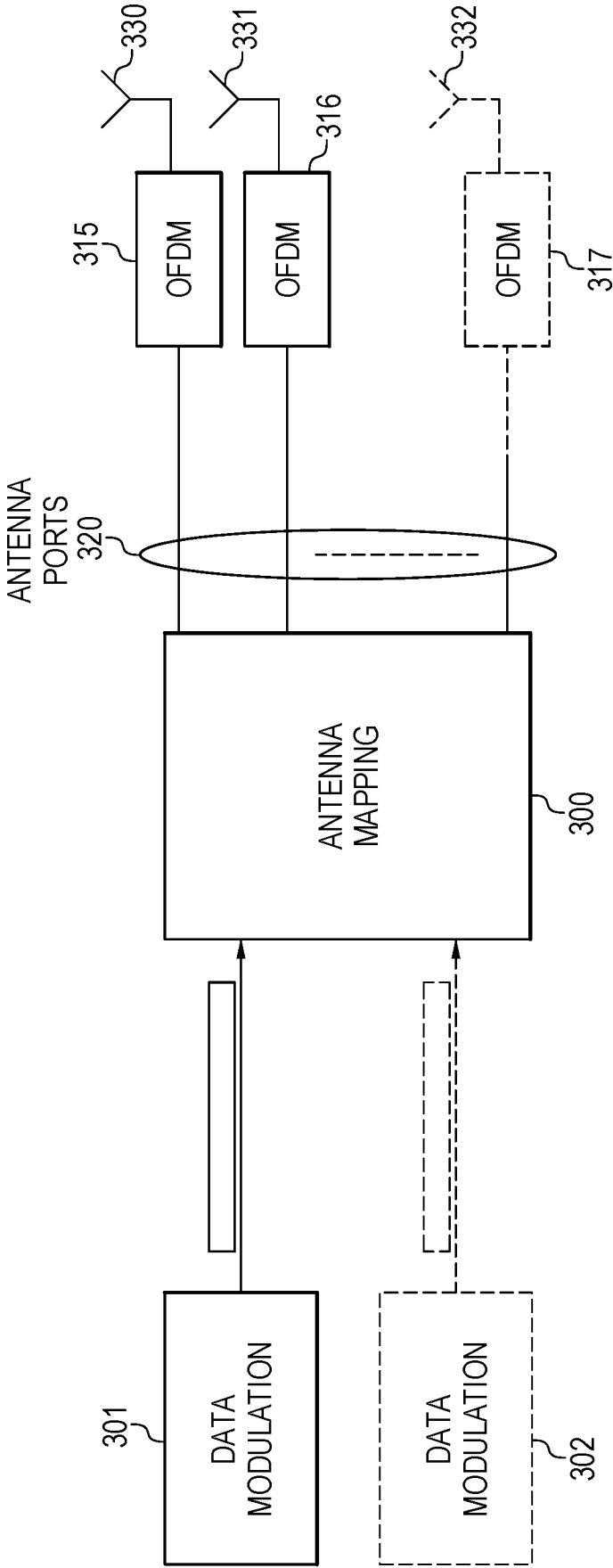


FIG. 3

4 / 5

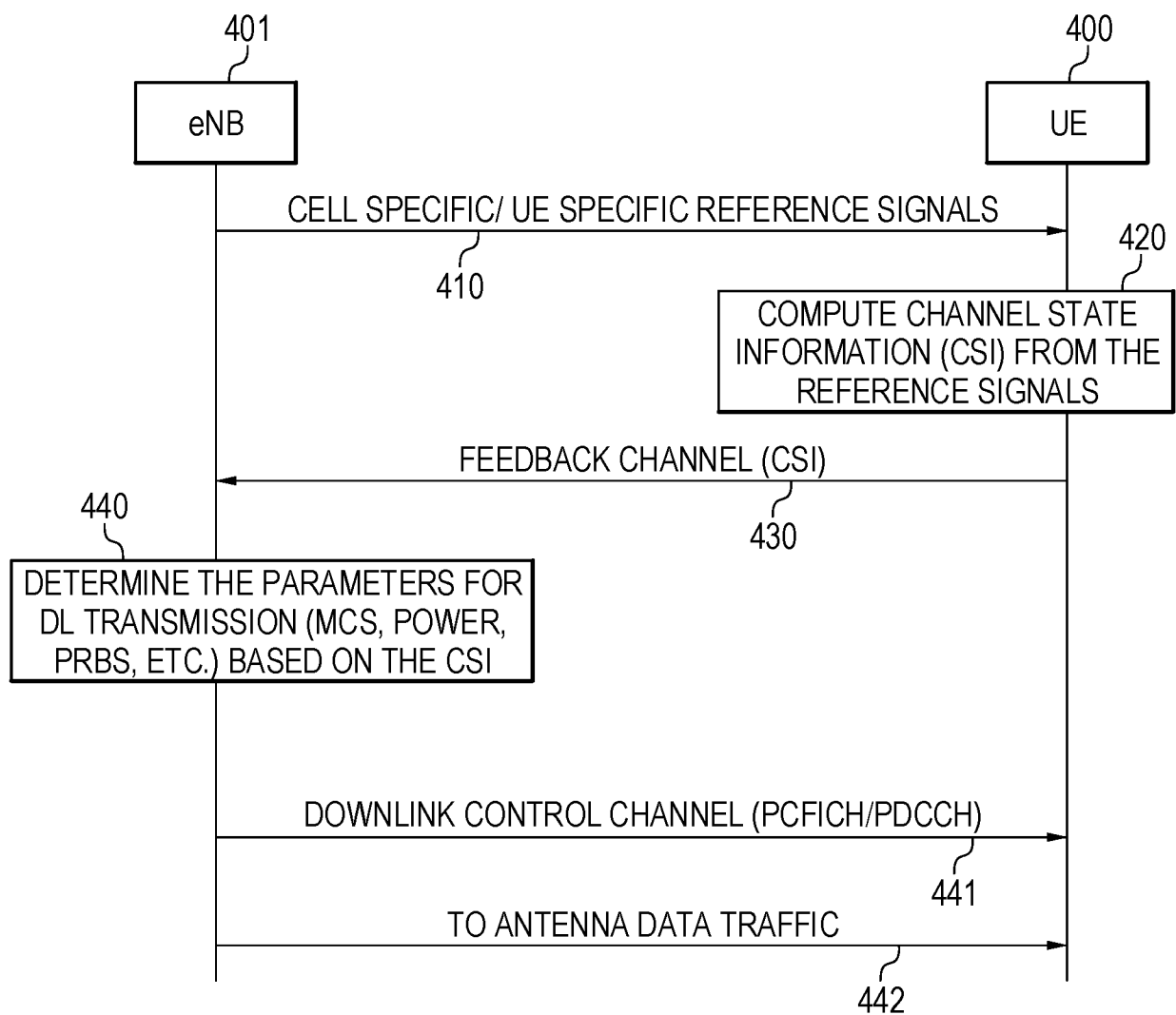


FIG. 4

5 / 5

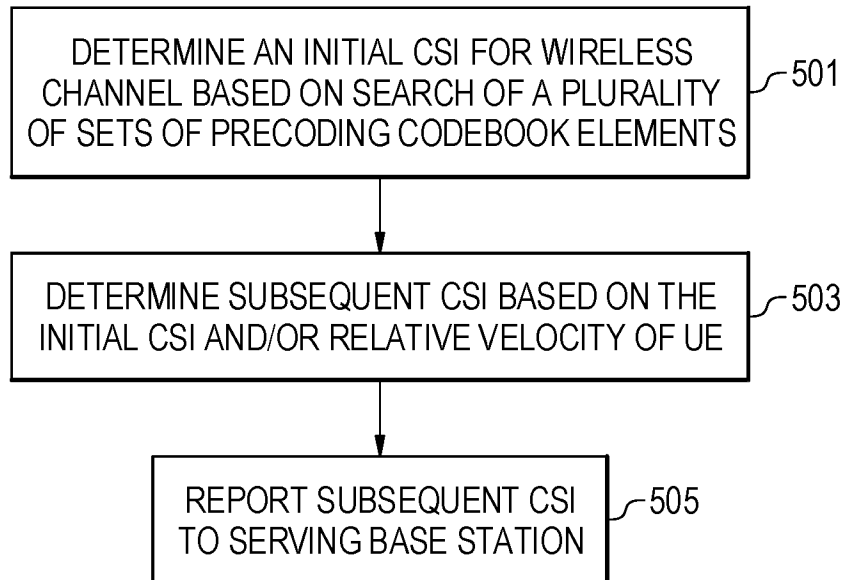


FIG. 5

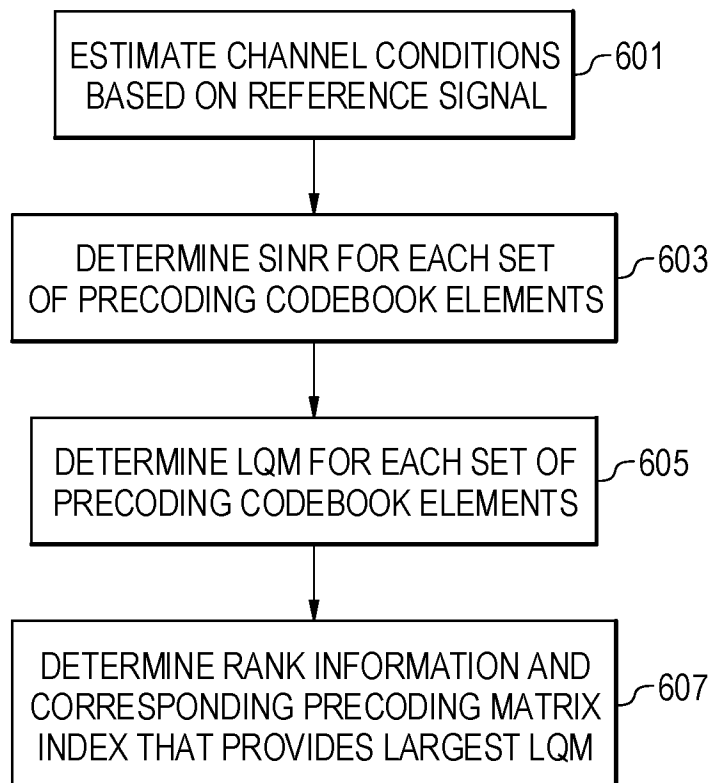


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2017/085681

A. CLASSIFICATION OF SUBJECT MATTER

H04B 7/04(2017.01)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)

H04B

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

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

CNPAT,WPI,EPODOC,GOOGLE,CNKI:multiple w input w multiple w output, MIMO, channel w state w information, CSI, channel w quality w indication, CQI, precoding w matrix w indication, PMI, rank w indicator, RI, rank w information, codebook, reference w signal, RS, link, channel, network

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 102122977 A (CHINA ACADEMY OF TELECOMMUNICATIONS TECHNOLOGY) 13 July 2011 (2011-07-13) description paragraphs [0002], [0036]-[0085]	1-11, 17-20
X	WO 2010127183 A1 (INTEL CORPORATION) 04 November 2010 (2010-11-04) description page 1 line 6 - line 16, page 2 line 25 - page 13 line 10	12-16
A	CN 102082639 A (DATANG MOBILE COMMUNICATIONS EQUIPMENT CO., LTD.) 01 June 2011 (2011-06-01) the whole document	1-20
A	WO 2014131031 A1 (TEXAS INSTRUMENTS INCORPORATED) 28 August 2014 (2014-08-28) the whole document	1-20

☐ 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

27 July 2017

Date of mailing of the international search report

23 August 2017

Name and mailing address of the ISA/CN

STATE INTELLECTUAL PROPERTY OFFICE OF THE
P.R.CHINA
6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing
100088
China

Authorized officer

WANG,Xinyue

Facsimile No. (86-10)62019451

Telephone No. (86-10)82245268

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2017/085681

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
CN	102122977	A	13 July 2011	None			
WO	2010127183	A1	04 November 2010	CN	102460996	A	16 May 2012
				JP	2012525796	A	22 October 2012
				EP	2425544	A1	07 March 2012
				US	2011064158	A1	17 March 2011
				KR	20120010271	A	02 February 2012
CN	102082639	A	01 June 2011	WO	2012062199	A1	18 May 2012
				JP	2014502085	A	23 January 2014
				KR	20130109167	A	07 October 2013
				US	2014050276	A1	20 February 2014
				EP	2651066	A1	16 October 2013
WO	2014131031	A1	28 August 2014	JP	2016517192	A	09 June 2016
				CN	104995929	A	21 October 2015
				US	2014328422	A1	06 November 2014
				US	2017019158	A1	19 January 2017
				US	2016352399	A1	01 December 2016
				EP	3033892	A1	22 June 2016
				US	2016028460	A1	28 January 2016