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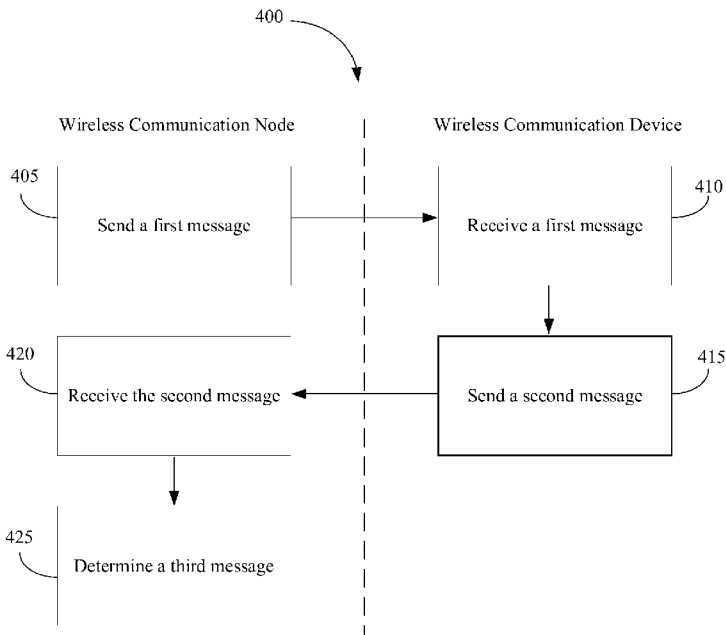


FIG. 4

(57) Abstract: Systems and Methods described herein are related to a wireless communication method. The wireless communication method can include a wireless communication node sending a first message encompassing indications of a first parameter in a first or second discrete set associated with basis selection, to instruct the first wireless communication device to send a second message associated with Channel State Information (CSI) feedback to at least a first one of a plurality of wireless communication devices. The wireless communication method can include the wireless communication node receiving the second message encompassing indications of a second parameter associated with basis selection from each of the plurality of wireless communication devices. The wireless communication method can include the wireless communication node determining a third message for a downlink multi-user transmission.

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SYSTEMS AND METHODS FOR ENHANCED CHANNEL STATE INFORMATION FOR FREQUENCY DIVISION DUPLEX MULTIPLE-INPUT-MULTIPLE-OUTPUT

TECHNICAL FIELD

The disclosure relates generally to wireless communications, including but not limited to systems and methods for Enhanced Channel State Information (CSI) for Frequency Division Duplex (FDD) Multiple-Input-Multiple-Output (MIMO).

BACKGROUND

The standardization organization Third Generation Partnership Project (3GPP) is currently in the process of specifying a new Radio Interface called 5G New Radio (5G NR) as well as a Next Generation Packet Core Network (NG-CN or NGC). The 5G NR will have three main components: a 5G Access Network (5G-AN), a 5G Core Network (5GC), and a User Equipment (UE). In order to facilitate the enablement of different data services and requirements, the elements of the 5GC, also called Network Functions, have been simplified with some of them being software based, and some being hardware based, so that they could be adapted according to need.

SUMMARY

The example embodiments disclosed herein are directed to solving the issues relating to one or more of the problems presented in the prior art, as well as providing additional features that will become readily apparent by reference to the following detailed description when taken in conjunction with the accompanying drawings. In accordance with various embodiments, example systems, methods, devices, and computer program products are disclosed herein. It is understood, however, that these embodiments are presented by way of example and are not limiting, and it will be apparent to those of ordinary skill in the art who read the present disclosure that various modifications to the disclosed embodiments can be made while remaining within the scope of this disclosure.

At least one aspect is directed to a system, method, apparatus, or a computer-readable medium of the following. A wireless communication method can include a wireless communication node sending a first message encompassing indications of a first parameter in a first or second discrete set associated with basis selection, to instruct the first wireless communication device to send a second message associated with Channel State Information (CSI) feedback to at least a first wireless communication device in a plurality of wireless communication devices. The wireless communication method can include the wireless communication node receiving the second message encompassing indications of a second parameter associated with basis selection from each of the plurality of wireless communication devices. The wireless communication method can include the wireless communication node determining a third message for a downlink multi-user transmission.

In some embodiments, the first parameter selected from the first or second discrete set is smaller than or equal to the second parameter. In some embodiments, a maximal element of the second discrete set is

greater than the maximal element of the first discrete set. In some embodiments, the second parameter is a sum of the first parameter and the number of additional bases, determined by one wireless communication device in the plurality of wireless communication devices. In some embodiments, the second message is determined by quantities from one or more rounds of CSI feedback of at least one wireless communication device in the plurality of wireless communication devices. In some embodiments, wherein the second message encompasses feedback quantities of identifying a plurality of bases and/or a plurality of respective combination/weight coefficients. In some embodiments, the wireless communication node is a distributed base station including two or more different nodes.

In some embodiments, each of the two or more different nodes is at least one of: a transmission reception point, an antenna panel, an access point, or one wireless communication device in the plurality of wireless communication devices. In some embodiments, the wireless communication node determines the third message for channel precoding of the downlink multi-user transmission by configuring a filter to refine the selected bases reported in the second message. In some embodiments, the results of the basis selection are a subset of bases and/or corresponding combination coefficients, used for completely or partially representing the wireless channel between the wireless communication node and the wireless communication device.

BRIEF DESCRIPTION OF THE DRAWINGS

Various example embodiments of the present solution are described in detail below with reference to the following figures or drawings. The drawings are provided for purposes of illustration only and merely depict example embodiments of the present solution to facilitate the reader's understanding of the present solution. Therefore, the drawings should not be considered limiting of the breadth, scope, or applicability of the present solution. It should be noted that for clarity and ease of illustration, these drawings are not necessarily drawn to scale.

FIG. 1 illustrates an example cellular communication network in which techniques disclosed herein may be implemented, in accordance with an embodiment of the present disclosure;

FIG. 2 illustrates a block diagram of an example base station and a user equipment device, in accordance with some embodiments of the present disclosure;

FIG. 3 illustrates an example of a uniform planar array, in accordance with an embodiment of the present disclosure; and

FIG. 4 illustrates a flow diagram for enhanced CSI for frequency division duplex for multiple-input-multiple-output in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION

Mobile Communication Technology and Environment

FIG. 1 illustrates an example wireless communication network, and/or system, 100 in which techniques disclosed herein may be implemented, in accordance with an embodiment of the present disclosure. In the following discussion, the wireless communication network 100 may be any wireless network, such as a

cellular network or a narrowband Internet of things (NB-IoT) network and is herein referred to as “network 100.” Such an example network 100 includes a base station 102 (hereinafter “BS 102”; also referred to as wireless communication node) and a user equipment device 104 (hereinafter “UE 104”; also referred to as wireless communication device) that can communicate with each other via a communication link 110 (e.g., a wireless communication channel), and a cluster of cells 126, 130, 132, 134, 136, 138 and 140 overlaying a geographical area 101. In FIG. 1, the BS 102 and UE 104 are contained within a respective geographic boundary of cell 126. Each of the other cells 130, 132, 134, 136, 138 and 140 may include at least one base station operating at its allocated bandwidth to provide adequate radio coverage to its intended users.

For example, the BS 102 may operate at an allocated channel transmission bandwidth to provide adequate coverage to the UE 104. The BS 102 and the UE 104 may communicate via a downlink radio frame 118, and an uplink radio frame 124, respectively. Each radio frame 118/124 may be further divided into sub-frames 120/127 which may include data symbols 122/128. In the present disclosure, the BS 102 and UE 104 are described herein as non-limiting examples of “communication nodes,” generally, which can practice the methods disclosed herein. Such communication nodes may be capable of wireless and/or wired communications, in accordance with various embodiments of the present solution.

FIG. 2 illustrates a block diagram of an example wireless communication system 200 for transmitting and receiving wireless communication signals (e.g., OFDM/OFDMA signals) in accordance with some embodiments of the present solution. The system 200 may include components and elements configured to support known or conventional operating features that need not be described in detail herein. In one illustrative embodiment, system 200 can be used to communicate (e.g., transmit and receive) data symbols in a wireless communication environment such as the wireless communication environment 100 of FIG. 1, as described above.

System 200 generally includes a base station 202 (hereinafter “BS 202”) and a user equipment device 204 (hereinafter “UE 204”). The BS 202 includes a BS (base station) transceiver module 210, a BS antenna 212, a BS processor module 214, a BS memory module 216, and a network communication module 218, each module being coupled and interconnected with one another as necessary via a data communication bus 220. The UE 204 includes a UE (user equipment) transceiver module 230, a UE antenna 232, a UE memory module 234, and a UE processor module 236, each module being coupled and interconnected with one another as necessary via a data communication bus 240. The BS 202 communicates with the UE 204 via a communication channel 250, which can be any wireless channel or other medium suitable for transmission of data as described herein.

As would be understood by persons of ordinary skill in the art, system 200 may further include any number of modules other than the modules shown in FIG. 2. Those skilled in the art will understand that the various illustrative blocks, modules, circuits, and processing logic described in connection with the embodiments disclosed herein may be implemented in hardware, computer-readable software, firmware, or any practical combination thereof. To clearly illustrate this interchangeability and compatibility of hardware, firmware, and software, various illustrative components, blocks, modules, circuits, and steps are described generally in terms of their functionality. Whether such functionality is implemented as hardware, firmware, or software can depend upon the particular application and design constraints imposed on the overall system. Those familiar with the

concepts described herein may implement such functionality in a suitable manner for each particular application, but such implementation decisions should not be interpreted as limiting the scope of the present disclosure.

In accordance with some embodiments, the UE transceiver 230 may be referred to herein as an "uplink" transceiver 230 that includes a radio frequency (RF) transmitter and a RF receiver each comprising circuitry that is coupled to the antenna 232. A duplex switch (not shown) may alternatively couple the uplink transmitter or receiver to the uplink antenna in time duplex fashion. Similarly, in accordance with some embodiments, the BS transceiver 210 may be referred to herein as a "downlink" transceiver 210 that includes a RF transmitter and a RF receiver each comprising circuitry that is coupled to the antenna 212. A downlink duplex switch may alternatively couple the downlink transmitter or receiver to the downlink antenna 212 in time duplex fashion. The operations of the two transceiver modules 210 and 230 may be coordinated in time such that the uplink receiver circuitry is coupled to the uplink antenna 232 for reception of transmissions over the wireless transmission link 250 at the same time that the downlink transmitter is coupled to the downlink antenna 212. Conversely, the operations of the two transceivers 210 and 230 may be coordinated in time such that the downlink receiver is coupled to the downlink antenna 212 for reception of transmissions over the wireless transmission link 250 at the same time that the uplink transmitter is coupled to the uplink antenna 232. In some embodiments, there is close time synchronization with a minimal guard time between changes in duplex direction.

The UE transceiver 230 and the base station transceiver 210 are configured to communicate via the wireless data communication link 250 and cooperate with a suitably configured RF antenna arrangement 212/232 that can support a particular wireless communication protocol and modulation scheme. In some illustrative embodiments, the UE transceiver 210 and the base station transceiver 210 are configured to support industry standards such as the Long Term Evolution (LTE) and emerging 5G standards, and the like. It is understood, however, that the present disclosure is not necessarily limited in application to a particular standard and associated protocols. Rather, the UE transceiver 230 and the base station transceiver 210 may be configured to support alternate, or additional, wireless data communication protocols, including future standards or variations thereof.

In accordance with various embodiments, the BS 202 may be an evolved node B (eNB), a serving eNB, a target eNB, a femto station, or a pico station, for example. In some embodiments, the UE 204 may be embodied in several types of user devices such as a mobile phone, a smart phone, a personal digital assistant (PDA), tablet, laptop computer, wearable computing device, etc. The processor modules 214 and 236 may be implemented, or realized, with a general purpose processor, a content addressable memory, a digital signal processor, an application specific integrated circuit, a field programmable gate array, any suitable programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof, designed to perform the functions described herein. In this manner, a processor may be realized as a microprocessor, a controller, a microcontroller, a state machine, or the like. A processor may also be implemented as a combination of computing devices, e.g., a combination of a digital signal processor and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a digital signal processor core, or any other such configuration.

Furthermore, the steps of a method or algorithm described in connection with the embodiments disclosed herein may be embodied directly in hardware, in firmware, in a software module executed by processor modules 214 and 236, respectively, or in any practical combination thereof. The memory modules 216 and 234 may be realized as RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, a hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. In this regard, memory modules 216 and 234 may be coupled to the processor modules 210 and 230, respectively, such that the processors modules 210 and 230 can read information from, and write information to, memory modules 216 and 234, respectively. The memory modules 216 and 234 may also be integrated into their respective processor modules 210 and 230. In some embodiments, the memory modules 216 and 234 may each include a cache memory for storing temporary variables or other intermediate information during execution of instructions to be executed by processor modules 210 and 230, respectively. Memory modules 216 and 234 may also each include non-volatile memory for storing instructions to be executed by the processor modules 210 and 230, respectively.

The network communication module 218 generally represents the hardware, software, firmware, processing logic, and/or other components of the base station 202 that enable bi-directional communication between base station transceiver 210 and other network components and communication nodes configured to communication with the base station 202. For example, network communication module 218 may be configured to support internet or WiMAX traffic. In a typical deployment, without limitation, network communication module 218 provides an 802.3 Ethernet interface such that base station transceiver 210 can communicate with a conventional Ethernet based computer network. In this manner, the network communication module 218 may include a physical interface for connection to the computer network (e.g., Mobile Switching Center (MSC)). The terms “configured for,” “configured to” and conjugations thereof, as used herein with respect to a specified operation or function, refer to a device, component, circuit, structure, machine, signal, etc., that is physically constructed, programmed, formatted and/or arranged to perform the specified operation or function.

The Open Systems Interconnection (OSI) Model (referred to herein as, “open system interconnection model”) is a conceptual and logical layout that defines network communication used by systems (e.g., wireless communication device, wireless communication node) open to interconnection and communication with other systems. The model is broken into seven subcomponents, or layers, each of which represents a conceptual collection of services provided to the layers above and below it. The OSI Model also defines a logical network and effectively describes computer packet transfer by using different layer protocols. The OSI Model may also be referred to as the seven-layer OSI Model or the seven-layer model. In some embodiments, a first layer may be a physical layer. In some embodiments, a second layer may be a Medium Access Control (MAC) layer. In some embodiments, a third layer may be a Radio Link Control (RLC) layer. In some embodiments, a fourth layer may be a Packet Data Convergence Protocol (PDCP) layer. In some embodiments, a fifth layer may be a Radio Resource Control (RRC) layer. In some embodiments, a sixth layer may be a Non Access Stratum (NAS) layer or an Internet Protocol (IP) layer, and the seventh layer being the other layer.

Various example embodiments of the present solution are described below with reference to the accompanying figures to enable a person of ordinary skill in the art to make and use the present solution. As

would be apparent to those of ordinary skill in the art, after reading the present disclosure, various changes or modifications to the examples described herein can be made without departing from the scope of the present solution. Thus, the present solution is not limited to the example embodiments and applications described and illustrated herein. Additionally, the specific order or hierarchy of steps in the methods disclosed herein are merely example approaches. Based upon design preferences, the specific order or hierarchy of steps of the disclosed methods or processes can be re-arranged while remaining within the scope of the present solution. Thus, those of ordinary skill in the art will understand that the methods and techniques disclosed herein present various steps or acts in a sample order, and the present solution is not limited to the specific order or hierarchy presented unless expressly stated otherwise.

Systems and Methods for Enhanced Channel State Information for Frequency Division Duplex Multiple-Input-Multiple-Output

Channel state information (CSI) feedback for the UE 104 may be built on mathematical representation channel response matrix, $\mathbf{H}$, throughout a plurality of subcarriers (referred to as sub-bands herein) of a bandwidth part (BWP). In some arrangements, the mathematical channel response matrix may be written as,

$$\mathbf{H} = \mathbf{W}_1 \times \mathbf{W}_2 \quad (1.1).$$

where $\mathbf{W}_1$ that includes a plurality of bases which span a specific space and $\mathbf{W}_2$ is a coefficient matrix. Instead of $\mathbf{H}$, a variant may directly be applied a CSI feedback procedure. In some arrangements, a related variant may be a unitary matrix $\mathbf{V}$ derived through single value decomposition (SVD),

$$\mathbf{H} = \mathbf{U} \mathbf{\Sigma} \mathbf{V}.$$

In some arrangements, channel response information in spatial and/or frequency domain may be domain may be included into $\mathbf{H}$. In some arrangements, $\mathbf{W}_1$ may consist of discrete Fourier transform (DFT) bases associated with samplings of array aperture and spatial parameters. In some arrangements, a spatial parameter may be the distance between reference antennas of BS and UE, angle of departure (AOD), or angle of arrival (AOA) in a wireless transmission. In some arrangements, array aperture may be determined by the number of antennas and inter-antenna spacing. For example, a DFT basis for a $N_1 \times N_2$ planar array may be depicted by

$$\begin{aligned} \mathbf{v} &= \begin{bmatrix} e^{j\Phi'_1} & e^{j\Phi'_2} & \dots & e^{j\Phi'_{N_1}} \end{bmatrix}^T \otimes \mathbf{u} \\ &= \begin{bmatrix} e^{j\Phi'_1} \mathbf{u} & e^{j\Phi'_2} \mathbf{u} & \dots & e^{j\Phi'_{N_1}} \mathbf{u} \end{bmatrix}^T. \end{aligned}$$

where T is transpose, $\otimes$ is the Kronecker product operator and $\mathbf{u} = \begin{bmatrix} e^{j\Phi_1} & e^{j\Phi_2} & \dots & e^{j\Phi_{N_2}} \end{bmatrix}^T$ is a column vector.

FIG. 3 illustrates an example of a uniform planar array (UPA) 300. The UPA may be placed on an x-z plane at the BS 102. A method for modeling phase offset from a (b_1, b_2) th antenna ($1 \leq b_1 \leq N_1$, $1 \leq b_2 \leq N_2$) to reference antenna ($b_1=1, b_2=1$) may be calculated by

$$\Phi_{b_1, b_2} = \frac{2\pi}{\lambda} \left(\sqrt{r^2 + (b_1 - 1)^2 d_x^2 + (b_2 - 1)^2 d_z^2} - 2r(b_1 - 1)d_x \cos \theta \sin \phi - 2r(b_2 - 1)d_z \cos \phi - r \right) \quad (1.2).$$

where d_x, d_z, θ and ϕ are inter-antenna spacing along x axis and z axis direction, azimuth angle, an elevation angle, respectively. In some arrangements, equation (1.2) may be adjusted into

$$\Phi_{b_1, b_2} = 2\pi \left(\sqrt{\left(\frac{r}{\lambda}\right)^2 + (b_1 - 1)^2 \left(\frac{d_x}{\lambda}\right)^2 + (b_2 - 1)^2 \left(\frac{d_z}{\lambda}\right)^2} - 2(b_1 - 1) \frac{rd_x}{\lambda^2} \cos\theta \sin\phi - 2(b_2 - 1) \frac{rd_z}{\lambda^2} \cos\phi - \frac{r}{\lambda} \right).$$

where $r_r = \frac{r}{\lambda}$, $r_{d_x} = \frac{d_x}{\lambda}$, and $r_{d_z} = \frac{d_z}{\lambda}$. By expansion operation, an approximated version may be shown by,

$$\Phi_{b_1, b_2} \approx \frac{2\pi}{\lambda} \left(-(b_1 - 1)d_x \cos\theta \sin\phi + \frac{(b_1 - 1)^2 d_x^2 (1 - \cos^2\theta \sin^2\phi)}{2r} - (b_2 - 1)d_z \cos\phi + \frac{(b_2 - 1)^2 d_z^2 \sin^2\phi}{2r} \right).$$

In some arrangements, the method for modeling the phase offset above may be extended to other arrangements using a different reference antenna. For example, when antenna (N_1, N_2) may be considered as the reference point, the phase offset may be expressed by,

$$\Phi_{b_1, b_2} \approx \frac{2\pi}{\lambda} \left((b_1 - 1)d_x \cos\theta \sin\phi - \frac{(b_1 - 1)^2 d_x^2 (1 - \cos^2\theta \sin^2\phi)}{2r} + (b_2 - 1)d_z \cos\phi - \frac{(b_2 - 1)^2 d_z^2 \sin^2\phi}{2r} \right) \quad (1.3).$$

Based on equation (1.3), an array or “steering” vector $\mathbf{v}$ and $\mathbf{u}$ may be given by

$$\mathbf{u} = \begin{bmatrix} 1 & e^{j2\pi \left(\frac{d_x \cos\phi - d_z^2 \sin^2\phi}{\lambda} \right)} & \dots & e^{j2\pi \left(\frac{(N_2 - 1)d_x \cos\phi - (N_2 - 1)^2 d_z^2 \sin^2\phi}{\lambda} \right)} \end{bmatrix}^T \quad (1.4),$$

$$\mathbf{v} = \begin{bmatrix} e^{j2\pi \left(\frac{d_x \cos\theta \sin\phi - d_x^2 (1 - \cos^2\theta \sin^2\phi)}{2r\lambda} \right)} & \dots & e^{j2\pi \left(\frac{(N_1 - 1)d_x \cos\theta \sin\phi - (N_1 - 1)^2 d_x^2 (1 - \cos^2\theta \sin^2\phi)}{2r\lambda} \right)} \end{bmatrix}^T \quad (1.5).$$

In some arrangements, substituting $d_z \cos\phi / \lambda = m / O_2 N_2$ into equation (1.4), then equation (1.4) can be rewritten as,

$$\mathbf{u} = \mathbf{u}_m = \begin{bmatrix} 1 & e^{j2\pi \left(\frac{m}{O_2 N_2} - \beta O_2' \left(\frac{m}{O_2 N_2} \right)^2 \right)} & \dots & e^{j2\pi \left(\frac{(N_2 - 1)m}{O_2 N_2} - \beta O_2' (N_2 - 1)^2 \left(\frac{m}{O_2 N_2} \right)^2 \right)} \end{bmatrix}^T \quad (1.6),$$

or

$$\mathbf{u} = \mathbf{u}_m = \begin{bmatrix} 1 & e^{j2\pi \left(\frac{m}{O_2 N_2} - \beta O_2' \left[1 - \left(\frac{m}{O_2 N_2} \right)^2 \right] \right)} & \dots & e^{j2\pi \left(\frac{(N_2 - 1)m}{O_2 N_2} - \beta O_2' (N_2 - 1)^2 \left[1 - \left(\frac{m}{O_2 N_2} \right)^2 \right] \right)} \end{bmatrix}^T.$$

Where constant β may be set to 0, 1/2, or 1/4. In some arrangements, the range of quantity m may be $\{0, 1, 2, \dots, O_2 N_2 - 1\}$ and O_2 may be an (integer) oversampling factor. For example, quantity O_2' used for scaling a quadratic term may be specified by,

$$O_2' = \begin{cases} 0 \\ \frac{1}{C^{m'}} \end{cases}.$$

where the base of an exponential function, C , may be set to 2, 10 or natural base e . Furthermore, the quantity m' may be $m' \in \{0, 1, \dots, O_2 N_2 - 1\}$ in some arrangements. Referring to equation (1.5), after substituting

$$\frac{d_x \cos \theta \sin \phi}{\lambda} = \frac{l}{O_1 N_1}, l \in \{0, \dots, O_1 N_1 - 1\}, \text{ into equation (1.5), it may be changed to,}$$

$$\mathbf{v} = \mathbf{v}_{l,m} = \begin{bmatrix} \mathbf{u}_m & e^{j2\pi \left(\frac{l}{O_1 N_1} - \beta O'_1 \left(\frac{l}{O_1 N_1} \right)^2 \right)} \mathbf{u}_m & \dots & e^{j2\pi \left(\frac{(N_1-1)l}{O_1 N_1} - \beta O'_1 (N_1-1)^2 \left(\frac{l}{O_1 N_1} \right)^2 \right)} \mathbf{u}_m \end{bmatrix}^T \quad (1.7),$$

or,

$$\mathbf{v} = \mathbf{v}_{l,m} = \begin{bmatrix} \mathbf{u}_m & e^{j2\pi \left(\frac{l}{O_1 N_1} - \beta O'_1 \left[1 - \left(\frac{l}{O_1 N_1} \right)^2 \right] \right)} \mathbf{u}_m & \dots & e^{j2\pi \left(\frac{(N_1-1)l}{O_1 N_1} - \beta O'_1 (N_1-1)^2 \left[1 - \left(\frac{l}{O_1 N_1} \right)^2 \right] \right)} \mathbf{u}_m \end{bmatrix}^T.$$

where O_1 may be an (integer) oversampling factor and O'_1 may be another scale factor used for another quadratic term. Specifically, O'_1 may be provided by,

$$O'_1 = \begin{cases} 0 \\ \frac{1}{C^{l'}} \end{cases}.$$

In at least one arrangement, quantity O'_2 may be equal to O'_1 therefore,

$$O'_1 = O'_2 = \begin{cases} 0 \\ \frac{1}{C^{m''}} \end{cases}.$$

where $m'' \in \{0, 1, \dots, O_1 N_1 - 1\}$, $m'' \in \{0, 1, \dots, O_2 N_2 - 1\}$, or $m'' \in \{0, 1, \dots, O_1 N_1 O_2 N_2 - 1\}$. In some arrangements, L bases are selected to report CSI at UE, and a corresponding array vector $\mathbf{u}_m$ for the i th basis may be represented as

$$\mathbf{u}_{m^i} = \begin{bmatrix} 1 & e^{j2\pi \left(\frac{O_2 n_2^i + q_2}{O_2 N_2} - \beta O'_2 \left(\frac{O_2 n_2^i + q_2}{O_2 N_2} \right)^2 \right)} & \dots & e^{j2\pi \left(\frac{(N_2-1)(O_2 n_2^i + q_2)}{O_2 N_2} - \beta O'_2 (N_2-1)^2 \left(\frac{O_2 n_2^i + q_2}{O_2 N_2} \right)^2 \right)} \end{bmatrix}^T \quad (1.8),$$

or,

$$\mathbf{u}_{m^i} = \begin{bmatrix} 1 & e^{j2\pi \left(\frac{O_2 n_2^i + q_2}{O_2 N_2} - \beta O'_2 \left[1 - \left(\frac{O_2 n_2^i + q_2}{O_2 N_2} \right)^2 \right] \right)} & \dots & e^{j2\pi \left(\frac{(N_2-1)(O_2 n_2^i + q_2)}{O_2 N_2} - \beta O'_2 (N_2-1)^2 \left[1 - \left(\frac{O_2 n_2^i + q_2}{O_2 N_2} \right)^2 \right] \right)} \end{bmatrix}^T.$$

In a similar manner, $\mathbf{v}_{l,m}$ for the i th basis may be replaced by,

$$\mathbf{v}_{l^i, m^i} = \begin{bmatrix} \mathbf{u}_{m^i} & e^{j2\pi \left(\frac{O_1 n_1^i + q_1}{O_1 N_1} - \beta O'_1 \left(\frac{O_1 n_1^i + q_1}{O_1 N_1} \right)^2 \right)} \mathbf{u}_{m^i} & \dots & e^{j2\pi \left(\frac{(N_1-1)(O_1 n_1^i + q_1)}{O_1 N_1} - \beta O'_1 (N_1-1)^2 \left(\frac{O_1 n_1^i + q_1}{O_1 N_1} \right)^2 \right)} \mathbf{u}_{m^i} \end{bmatrix}^T \quad (1.9),$$

or,

$$\mathbf{v}_{l^i, m^i} = \begin{bmatrix} \mathbf{u}_{m^i} & e^{j2\pi\left(\frac{O_1 n_1^i + q_1}{O_1 N_1} - \beta O_1^2 \left[1 - \left(\frac{O_1 n_1^i + q_1}{O_1 N_1}\right)^2\right]\right)} \mathbf{u}_{m^i} & \dots & e^{j2\pi\left(\frac{(N_1-1)O_1 n_1^i + q_1}{O_1 N_1} - \beta O_1^2 (N_1-1)^2 \left[1 - \left(\frac{O_1 n_1^i + q_1}{O_1 N_1}\right)^2\right]\right)} \mathbf{u}_{m^i} \end{bmatrix}^T.$$

where $m^i = O_2 n_2^i + q_2$,

$$l^i = O_1 n_1^i + q_1,$$

$$n_1^i \in \{0, 1, \dots, N_1 - 1\},$$

$$n_2^i \in \{0, 1, \dots, N_2 - 1\},$$

$$q_1 \in \{0, 1, \dots, O_1 - 1\},$$

$$q_2 \in \{0, 1, \dots, O_2 - 1\},$$

$$i \in \{0, 1, \dots, L - 1\}.$$

In some arrangements, distance r approaches infinity (e.g., far field) creating a simple form for equation (1.3). The simple form of equation (1.3) may be,

$$\Phi_{b_1, b_2} \approx \frac{2\pi}{\lambda} ((b_1 - 1)d_x \cos \theta \sin \phi + (b_2 - 1)d_z \cos \phi).$$

Therefore equations (1.4), (1.5), (1.6), (1.7), (1.8) and (1.9) may be simplified to,

$$\mathbf{u} = \begin{bmatrix} 1 & e^{j2\pi\left(\frac{d_z \cos \phi}{\lambda}\right)} & \dots & e^{j2\pi\left(\frac{(N_2-1)d_z \cos \phi}{\lambda}\right)} \end{bmatrix}^T,$$

$$\mathbf{v} = \begin{bmatrix} \mathbf{u} & e^{j2\pi\left(\frac{d_x \cos \theta \sin \phi}{\lambda}\right)} \mathbf{u} & \dots & e^{j2\pi\left(\frac{(N_1-1)d_x \cos \theta \sin \phi}{\lambda}\right)} \mathbf{u} \end{bmatrix}^T,$$

$$\mathbf{u} = \mathbf{u}_m = \begin{bmatrix} 1 & e^{j2\pi\left(\frac{m}{O_2 N_2}\right)} & \dots & e^{j2\pi\left(\frac{(N_2-1)m}{O_2 N_2}\right)} \end{bmatrix}^T,$$

$$\mathbf{v} = \mathbf{v}_{l, m} = \begin{bmatrix} \mathbf{u}_m & e^{j2\pi\left(\frac{l^2}{O_1 N_1}\right)} \mathbf{u}_m & \dots & e^{j2\pi\left(\frac{(N_1-1)l^2}{O_1 N_1}\right)} \mathbf{u}_m \end{bmatrix}^T,$$

$$\mathbf{u}_{m^i} = \begin{bmatrix} 1 & e^{j2\pi\left(\frac{O_2 n_2^i + q_2}{O_2 N_2}\right)} & \dots & e^{j2\pi\left(\frac{(N_2-1)O_2 n_2^i + q_2}{O_2 N_2}\right)} \end{bmatrix}^T,$$

$$\mathbf{v}_{l^i, m^i} = \begin{bmatrix} \mathbf{u}_{m^i} & e^{j2\pi\left(\frac{O_1 n_1^i + q_1}{O_1 N_1}\right)} \mathbf{u}_{m^i} & \dots & e^{j2\pi\left(\frac{(N_1-1)O_1 n_1^i + q_1}{O_1 N_1}\right)} \mathbf{u}_{m^i} \end{bmatrix}^T, \text{ respectively.}$$

In some implementations BS 102 may configure the number of bases, L , for the CSI feedback reporting and may inform the UE 104 of L in a DL control signaling. In some arrangements, L may be common or individual per UE 102. In some arrangements, the BS 102 may support two or more ranges of L . For example, L may be chosen from a first set $\{2, 3, 4, 6\}$, a subset of the first set (e.g., $\{2, 4, 6\}$), a second set $\{2, 3, 4, 5, 6, 7, 8, \dots\}$,

$L_{BS}\}$ (where integer $L_{BS} > 6$), or a subset of the second set (e.g., $\{4, 6, 8, 10\}$). Furthermore, in some arrangements, a signaling indication from the UE 104 may decide which range is used for L in a CSI feedback procedure when a multi-range mode of L is enabled. In some arrangements, the range indication may be added from signaling reuse.

When modulation and coding scheme (MCS), mapped to CQI is less than a specific threshold, a second set, or a subset of the second set may be used; Otherwise, a first set or a subset of the first set may be selected. Optionally, the MCS mapped to CQI may be replaced by data throughput estimated based on duration, data size of packets e.g., wireless data packets, or frames to the UE 104 and related responses from the UE 104, such as the number of acknowledgement (ACK) and/or non-acknowledgement (NACK) counted in a period of time. Completely different from implicit range indication described previously, an explicit range indication may be performed after adding a new signaling field into a DL control indicator. For example, if a 1-bit signaling for range indication is added and set to 1, a second set, or a subset of the second may be enabled for L at the BS 102. Otherwise, the second set will not be enabled for L at the BS 102.

In some implementations, the UE 104 may communicate an indicator associated with CSI to the BS 102. In some arrangements, an indicator may contain a plurality of feedback quantities for identifying reported bases and/or corresponding coefficients of channel response matrix associated with one or more basic resource elements. Herein, one basic resource element may be one time-frequency resource unit. In some arrangements, the reported bases may include bases with the strongest coefficients. In some arrangements, the number of reported bases (e.g., L') may be same as the number of requested bases (e.g., L). In some arrangements, reported bases consist of L requested bases and ΔL additional bases.

In some arrangements, the UE 104 may configure ΔL with one or more capabilities, evaluations, and/or measurements in terms of data throughput, overhead, and/or latency. In some arrangements, an increment-type CSI feedback may be used for improving the performance of a DL MU (channel) precoding. Particularly, increment-type feedback may need one or more rounds of CSI reporting for incrementally updating the number and/or precision of quantities. For example, a two-round/stage CSI feedback procedure may be provided such that at a first round, the UE 104 numerically projects channel response matrix onto bases of $\mathbf{W}_1$ and saves respective basis coefficients to form a coefficient matrix $\mathbf{W}_2$. Next, the UE 104 implements X -bit ($X=1, 2, \dots$) magnitude quantization and/or $\hat{X}$ -bit ($\hat{X}=1, 2, \dots$) phase quantization of each element of $\mathbf{W}_2$ (in some arrangements a normalized $\mathbf{W}_2, \mathbf{W}_2'$), and then feeds back quantization results related to L' selected bases and entries of $\mathbf{W}_2$ or $\mathbf{W}_2'$ to the BS 102. In some arrangements, $\mathbf{W}_2'$ may be denoted as,

$$\mathbf{W}_2' = \mathbf{S} \circ \mathbf{W}_2.$$

where $\circ$ represents the dot product operation and $\mathbf{S}$ is a scaling matrix. In some arrangements,

$$\mathbf{S} = \mathbf{S}'.$$

Where $\mathbf{S}'$ may include one or more values associated with $\mathbf{W}_2$. In some arrangements, $\mathbf{S}'$ may be a matrix of the inverses of $|\mathbf{W}_2|^{\max}$ (e.g., a maximal magnitude of complex elements/ entries of $\mathbf{W}_2$). For example, an equation for $\mathbf{S}'$ may be,

$$\mathbf{S}' = \begin{bmatrix} \frac{1}{|W_2|^{\max}} & \frac{1}{|W_2|^{\max}} & \cdots & \frac{1}{|W_2|^{\max}} \\ \frac{1}{|W_2|^{\max}} & \frac{1}{|W_2|^{\max}} & \cdots & \frac{1}{|W_2|^{\max}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{|W_2|^{\max}} & \frac{1}{|W_2|^{\max}} & \cdots & \frac{1}{|W_2|^{\max}} \end{bmatrix}.$$

In some arrangements, the i th column of $\mathbf{S}'$ is a vector of $|W_2^i|^{\max}$ (e.g., a maximal magnitude of complex elements of the i th column of W_2, W_2^i). For example an equation for $\mathbf{S}'$ may be,

$$\mathbf{S}' = \begin{bmatrix} \frac{1}{|W_2^1|^{\max}} & \frac{1}{|W_2^2|^{\max}} & \cdots & \frac{1}{|W_2^i|^{\max}} & \cdots \\ \frac{1}{|W_2^1|^{\max}} & \frac{1}{|W_2^2|^{\max}} & \cdots & \frac{1}{|W_2^i|^{\max}} & \cdots \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \frac{1}{|W_2^1|^{\max}} & \frac{1}{|W_2^2|^{\max}} & \cdots & \frac{1}{|W_2^i|^{\max}} & \cdots \end{bmatrix}.$$

In some arrangements, $\mathbf{S} = \mathbf{S}'' \circ \mathbf{S}'$, where $\mathbf{S}''$ is a predetermined constant matrix. In some arrangements, an X-bit uniform quantization converter $\mathbf{Q}$ ($\mathbf{Q}$ may also be referred to as a quantizer) for magnitude may be defined as,

$$\mathbf{Q}(x) = \begin{cases} 0, x < C_1 \\ \vdots \\ \frac{i}{2^x}, C_{i-1} \leq x < C_i \\ \vdots \\ 1, x > C_{2^x-1} \end{cases} \quad (2.1).$$

or an X-bit non-uniform quantization converter may be given by,

$$\mathbf{Q}(x) = \begin{cases} 0, x \leq C_0 \\ \left(\frac{1}{\sqrt{2}}\right)^{2^x-1}, C_0 \leq x < C_1 \\ \vdots \\ \left(\frac{1}{\sqrt{2}}\right)^i, C_{i-1} \leq x < C_i \\ \vdots \\ \frac{1}{\sqrt{2}}, C_{2^x-2} \leq x < C_{2^x-1} \\ 1, x \geq C_{2^x-1} \end{cases} \quad (2.2).$$

where $i = 0, 1, \dots, 2^{\hat{X}} - 1$ and C_i is a decision threshold for magnitude quantization. In some arrangements, if $X = 1$, one element of W_2 (or W'_2), may be converted into,

$$Q(x) = \begin{cases} 0, & x < C_1 \\ 1, & x \geq C_1 \end{cases}.$$

In some arrangements, quantity C_i may be a variable determined by the BS 102 or, C_i may be a predetermined variable. C_i may be set per quantizer and/or UE 104. In some arrangements, an $\hat{X}$ -bit uniform converter P for phase may be specified by,

$$P(\eta) = \begin{cases} 1, 0 \leq \text{ang}(\eta) < D_0 \\ \vdots \\ e^{j \frac{2\pi}{2^{\hat{X}}}}, D_{i-1} \leq \text{ang}(\eta) < D_i \\ \vdots \\ e^{j \frac{2\pi(2^{\hat{X}}-1)}{2^{\hat{X}}}}, D_{2^{\hat{X}}-1} \leq \text{ang}(\eta) < 2\pi \end{cases} \quad (2.3).$$

or an $\hat{X}$ -bit non-uniform converter P may be used for phase quantization,

$$P(\eta) = \begin{cases} 1, 0 \leq \text{ang}(\eta) < D_0 \\ e^{j 2\pi \left(\frac{1}{\sqrt{2}}\right)^{2^{\hat{X}}-1}}, D_0 \leq \text{ang}(\eta) < D_1 \\ \vdots \\ e^{j 2\pi \left(\frac{1}{\sqrt{2}}\right)^i}, D_{i-1} \leq \text{ang}(\eta) < D_i \\ \vdots \\ e^{j 2\pi \left(\frac{1}{\sqrt{2}}\right)}, D_{2^{\hat{X}}-1} \leq \text{ang}(\eta) < 1 \end{cases} \quad (2.4).$$

where $\hat{i} = 0, 1, \dots, 2^{\hat{X}} - 1$, the imaginary unit, j , amounts to a squared root of -1, D_i is a decision threshold for phase quantization, and a function $\text{ang}(\cdot)$ can output an angle of an inputted phase η (e.g., $\text{ang}(\eta = \sqrt{2}/2 + j\sqrt{2}/2) = \pi/4$). Analogous to C_i , D_i may be dynamically indicated by the BS 102 or set to a fixed value. In some arrangements, D_i may be different from quantizer to quantizer or from UE 104 to UE 104. In some arrangements, feedback on magnitude information may be mandated and phase information may be excluded from a CSI reporting at the first stage. At a second stage, the BS 102 may evaluate the necessity of requesting another CSI feedback. For example, it may be necessary to trigger another CSI feedback, magnitude and phase of target elements of W_2 may be quantized by the UE 104 respectively using Y bits and $\hat{Y}$ bits and then sends quantization results to the BS 102 again.

In some arrangements, the target elements are indexed by a signaling indication from the BS 102. In some arrangements, the BS 102 may implement another CSI feedback if the number of common bases among

UEs 102 is greater than a threshold. In some arrangements, whether reported bases from multiple UEs 102 are common, may be established by conditions that parameters for identifying a basis are identical and/or energy (or, magnitude) difference among corresponding elements of $\mathbf{W}_2$ meets a requirement (e.g. the energy difference is not beyond a predetermined threshold). During another CSI feedback, the UE 102 may make an incremental update to the coefficient magnitude or phase quantization of a reported basis depending on one from a previous CSI feedback. For instance, in a CSI feedback, the coefficient magnitude of a reported basis may be mapped to a discrete quantization or representative level varying from C_{i-1} to C_i when it is converted into $i/2^x$ using the quantizer in equation (2.1) in a previous CSI feedback. For example, using the quantizer in equation (2.1), the CSI feedback may be,

$$\mathbf{Q}(x) = \begin{cases} C_{i-1}, C_{i-1} \leq x < C'_0 \\ \vdots \\ C_{i-1} + \frac{t}{2^Y} (C_i - C_{i-1}), C'_{t-1} \leq x < C'_t \\ \vdots \\ C_i, C'_{2^Y-1} \leq x < C_i \end{cases} \quad (2.5).$$

or the CSI feedback may be quantized in a non-uniform way such as,

$$\mathbf{Q}(x) = \begin{cases} C_{i-1}, C_{i-1} \leq x < C'_0 \\ C_{i-1} + \left(\frac{1}{\sqrt{2}}\right)^{2^Y-1} (C_i - C_{i-1}), C'_0 \leq x < C'_1 \\ \vdots \\ C_{i-1} + \left(\frac{1}{\sqrt{2}}\right)^{t-1} (C_i - C_{i-1}), C'_{t-1} \leq x < C'_t \\ \vdots \\ C_{i-1} + \left(\frac{1}{\sqrt{2}}\right) (C_i - C_{i-1}), C'_{2^Y-2} \leq x < C'_{2^Y-1} \\ C_i, C'_{2^Y-1} \leq x < C_i \end{cases} \quad (2.6).$$

where $t = 0, 1, \dots, 2^Y - 1$ and C'_t is a decision threshold for the magnitude quantization. In some arrangements, C'_t may be dynamically indicated by the BS 102 set to a fixed value. In some arrangements, C'_t may be different from quantizer to quantizer or from UE 102 to UE 102. In some arrangements, a coefficient-phase quantizer in CSI feedback may be obtained with,

$$\mathbf{P}(\eta) = \begin{cases} D_{i-1}, D_{i-1} \leq \text{ang}(\eta) < D'_0 \\ \vdots \\ D_{i-1} e^{j\hat{t} \frac{D_i - D_{i-1}}{2^Y}}, D'_{t-1} \leq \text{ang}(\eta) < D'_t \\ \vdots \\ D_i, D'_{2^Y-1} \leq \text{ang}(\eta) < D_i \end{cases} \quad (2.7).$$

or a non-uniform coefficient phase quantizer may be constructed by,

$$P(\eta) = \begin{cases} D_{\hat{i}-1}, D_{\hat{i}-1} \leq \text{ang}(\eta) < D'_0 \\ \vdots \\ D_{\hat{i}-1} e^{j(D_{\hat{i}} - D_{\hat{i}-1}) \frac{(\sqrt{2})^{\hat{i}}}{(\sqrt{2})^{2^{\hat{Y}}-1}}}, D'_{\hat{i}-1} \leq \text{ang}(\eta) < D'_i \\ \vdots \\ D_{\hat{i}}, D'_{2^{\hat{Y}}-1} \leq \text{ang}(\eta) < D_{\hat{i}} \end{cases} \quad (2.8).$$

where $\hat{i} = 0, 1, 2, \dots, 2^{\hat{Y}} - 1$ and D'_i is a decision threshold set for phase quantization. In some arrangements, D'_i may be dynamically indicated by the BS 102 or set to a fixed value. In some arrangements, D'_i may be different from quantizer to quantizer or from UE 104 to UE 104. In some arrangements, a quantizer applied to a coefficient magnitude in current CSI feedback may be independent of a previous CSI feedback. For example,

$$Q(x) = \begin{cases} 0, x < C'_0 \\ \frac{1}{2^{\hat{Y}}}, C'_0 \leq x < C'_1 \\ \vdots \\ \frac{t}{2^{\hat{Y}}}, C'_{t-1} \leq x < C'_t \\ \vdots \\ 1, x > C'_{2^{\hat{Y}}-1} \end{cases} \quad (2.9).$$

or a non-uniform magnitude quantizer may be,

$$Q(x) = \begin{cases} 0, x < C'_0 \\ \left(\frac{1}{\sqrt{2}}\right)^{2^{\hat{Y}}-1}, C'_0 \leq x < C'_1 \\ \vdots \\ \left(\frac{1}{\sqrt{2}}\right)^t, C'_{t-1} \leq x < C'_t \\ \vdots \\ \left(\frac{1}{\sqrt{2}}\right)^{2^{\hat{Y}}-2}, C'_{2^{\hat{Y}}-2} \leq x < C'_{2^{\hat{Y}}-1} \\ 1, x \geq C'_{2^{\hat{Y}}-1} \end{cases} \quad (2.10).$$

Furthermore, a coefficient phase quantizer in current CSI feedback may be defined as,

$$P(\eta) = \begin{cases} 1, 0 \leq \text{ang}(\eta) < D'_0 \\ \vdots \\ e^{j\frac{2\pi}{2^{\hat{Y}}}}, D_{i-1} \leq \text{ang}(\eta) < D_i \\ \vdots \\ e^{j\frac{2\pi(2^{\hat{Y}}-1)}{2^{\hat{Y}}}}, D_{2^{\hat{Y}}-1} \leq \text{ang}(\eta) < 2\pi \end{cases} \quad (2.11).$$

or a non-uniform phase quantizer may be shown by,

$$P(\eta) = \begin{cases} 1, \text{ang}(\eta) < D_0 \\ e^{j2\pi\left(\frac{1}{\sqrt{2}}\right)^{2^{\hat{Y}}-1}}, D_0 \leq \text{ang}(\eta) < D_1 \\ \vdots \\ e^{j2\pi\left(\frac{1}{\sqrt{2}}\right)^i}, D_{i-1} \leq \text{ang}(\eta) < D_i \\ \vdots \\ e^{j2\pi\left(\frac{1}{\sqrt{2}}\right)}, \text{ang}(\eta) > D_{2^{\hat{Y}}-1} \end{cases} \quad (2.12).$$

Notably, compared with quantizers from equations (2.5) to (2.8), no constraints from previous CSI feedback are imposed on the decision level of quantizers from equations (2.9) to (2.12).

In some implementations, the BS 102 utilizes a basis filter to refine feedback quantities from multiple UEs 104 and encodes a DL MU transmission at a subcarrier, symbol, or a constellation point, among others at a non-bit level (e.g., beamforming) in physical layer by pre-codes derived from the refined feedback quantities. In some arrangements, the BS 102 may be a distributed BS 102 comprising two or more independent/different/separated nodes. Specifically, a distributed node may be a transmission-reception point (TRP), antenna panel, access point (AP), or another kind of wireless device. In some arrangements, the dimension/length of a reported basis (e.g., a row or column vector) identified by feedback quantities for the distributed BS 102 may be the number of (available) antenna ports of all separated nodes.

In some arrangements, the basis filter may aim for recognizing and selecting expected bases, of which coefficients meet certain requirements. Such a selection process above may result in that a subset of feedback quantities of each UE 104 is eventually used for precoding a DL MU transmission. In some arrangements, a reported basis may be classified as an expected basis if it simultaneously belongs to the value space of a channel response (matrix) for one UE 104 and the null space (or, an approximated null space) of a channel response (matrix) for another UE 104. For ease of description, A BS 102 may plan to arrange a DL MU transmission to 3 UEs (e.g., UE_A, UE_B and UE_C) 104, and respective channel response matrices are notated by H_A , H_B , and H_C . In this context, a basis $\mathbf{v}$, a column vector, may be regarded as an expected basis if it satisfies requirements of,

$$\begin{aligned} \mathbf{v}^* H_A &= a \\ \mathbf{v}^* H_B &= 0. \\ \mathbf{v}^* H_C &= 0 \end{aligned}$$

Where $*$ is the conjugate transpose operation and a is a (real or complex) nonzero scalar. In some arrangements, the relaxed requirements may be specified by

$$\mathbf{v}^* \mathbf{H}_A = a$$

$$\mathbf{v}^* \mathbf{H}_B = b.$$

$$\mathbf{v}^* \mathbf{H}_C = c$$

For example, if (real or complex) scalar b and c are with modulus/absolute values smaller than that of a , to be more specific, related descriptions may be remedied that the basis $\mathbf{v}$ belongs to an approximated null space instead of a null space. In some arrangements, bases, or a combination of bases and corresponding coefficients, identified by the refined feedback quantities may be used to form required channel precodes of a DL MU transmission.

It should be understood that one or more features from the above/following implementation examples are not exclusive to the specific implementation examples, but can be combined in any manner (e.g., in any priority and/or order, concurrently or otherwise).

FIG. 4 illustrates a flow diagram of a method 400 for an energy control. The method 400 may be executed by any one or more of the components and devices detailed herein in conjunction with FIGs. 1–3. In overview, the method 400 may be performed by a wireless communication node (e.g., a base station (BS) 102), in some embodiments. Additional, fewer, or different operations may be performed in the method 400 depending on the embodiment. At least one aspect of the operations is directed to a system, method, apparatus, or a computer-readable medium.

A wireless communication method include a wireless communication node sending a first message encompassing indications of a first parameter in a first or second discrete set associated with basis selection, to at least a first wireless communication device in a plurality of wireless communication devices (e.g., user equipment (UE) 104). In some arrangements, the wireless communication node is a distributed base station including two or more different nodes (e.g., a transmission reception point, an antenna panel, an access point, or one wireless communication device in the plurality of wireless communication devices). The first message instructs the first wireless communication device in the plurality of wireless communication devices to send a second message associated with Channel State Information (CSI) feedback. The first parameter selected from the first or second discrete set may be less than or equal to the second parameter. In some arrangements, a maximal element of the second discrete set may be greater than the maximal element of the first discrete set.

The wireless communication node can receive the second message encompassing indications of a second parameter associated with basis selection, from each of the plurality of wireless communication devices, where the second parameter is a sum of the first parameter and the number of additional bases, determined by one wireless communication device in the plurality of wireless communication devices. The wireless communication node can further configure a filter to refine the selected bases reported in the second message for performing a channel precoding of the downlink multi-user transmission. The second message can encompass indications of a second parameter associated with basis selection. The second message can further encompass feedback quantities of identifying a plurality of bases and/or a plurality of respective combination/weight coefficients. The second message can be determined by quantities from one or more rounds of CSI feedback of at least one wireless communication device in the plurality of wireless communication devices. In some arrangements, the results of the basis selection are a subset of bases and/or corresponding

combination coefficients, used for completely or partially representing the wireless channel between the wireless communication node and the wireless communication device.

The wireless communication node can determine a third message for a downlink multi-user transmission, based on the second message received from each of the wireless communication devices. The wireless communication node can determine the third message for channel precoding of the downlink multi-user transmission by configuring a filter to refine the selected bases reported in the second message.

While various embodiments of the present solution have been described above, it should be understood that they have been presented by way of example only, and not by way of limitation. Likewise, the various diagrams may depict an example architectural or configuration, which are provided to enable persons of ordinary skill in the art to understand example features and functions of the present solution. Such persons would understand, however, that the solution is not restricted to the illustrated example architectures or configurations but can be implemented using a variety of alternative architectures and configurations. Additionally, as would be understood by persons of ordinary skill in the art, one or more features of one embodiment can be combined with one or more features of another embodiment described herein. Thus, the breadth and scope of the present disclosure should not be limited by any of the above-described illustrative embodiments.

It is also understood that any reference to an element herein using a designation such as "first," "second," and so forth does not generally limit the quantity or order of those elements. Rather, these designations can be used herein as a convenient means of distinguishing between two or more elements or instances of an element. Thus, a reference to first and second elements does not mean that only two elements can be employed, or that the first element must precede the second element in some manner.

Additionally, a person having ordinary skill in the art would understand that information and signals can be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, and symbols, for example, which may be referenced in the above description can be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

A person of ordinary skill in the art would further appreciate that any of the various illustrative logical blocks, modules, processors, means, circuits, methods and functions described in connection with the aspects disclosed herein can be implemented by electronic hardware (e.g., a digital implementation, an analog implementation, or a combination of the two), firmware, various forms of program or design code incorporating instructions (which can be referred to herein, for convenience, as "software" or a "software module"), or any combination of these techniques. To clearly illustrate this interchangeability of hardware, firmware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware, firmware or software, or a combination of these techniques, depends upon the particular application and design constraints imposed on the overall system. Skilled artisans can implement the described functionality in various ways for each particular application, but such implementation decisions do not cause a departure from the scope of the present disclosure.

Furthermore, a person of ordinary skill in the art would understand that various illustrative logical blocks, modules, devices, components and circuits described herein can be implemented within or performed by an integrated circuit (IC) that can include a general-purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable

logic device, or any combination thereof. The logical blocks, modules, and circuits can further include antennas and/or transceivers to communicate with various components within the network or within the device. A general-purpose processor can be a microprocessor, but in the alternative, the processor can be any conventional processor, controller, or state machine. A processor can also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other suitable configuration to perform the functions described herein.

If implemented in software, the functions can be stored as one or more instructions or code on a computer-readable medium. Thus, the steps of a method or algorithm disclosed herein can be implemented as software stored on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that can be enabled to transfer a computer program or code from one place to another. A storage media can be any available media that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can include RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to store desired program code in the form of instructions or data structures and that can be accessed by a computer.

In this document, the term "module" as used herein, refers to software, firmware, hardware, and any combination of these elements for performing the associated functions described herein. Additionally, for purpose of discussion, the various modules are described as discrete modules; however, as would be apparent to one of ordinary skill in the art, two or more modules may be combined to form a single module that performs the associated functions according to embodiments of the present solution.

Additionally, memory or other storage, as well as communication components, may be employed in embodiments of the present solution. It will be appreciated that, for clarity purposes, the above description has described embodiments of the present solution with reference to different functional units and processors. However, it will be apparent that any suitable distribution of functionality between different functional units, processing logic elements or domains may be used without detracting from the present solution. For example, functionality illustrated to be performed by separate processing logic elements, or controllers, may be performed by the same processing logic element, or controller. Hence, references to specific functional units are only references to a suitable means for providing the described functionality, rather than indicative of a strict logical or physical structure or organization.

Various modifications to the embodiments described in this disclosure will be readily apparent to those skilled in the art, and the general principles defined herein can be applied to other embodiments without departing from the scope of this disclosure. Thus, the disclosure is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the novel features and principles disclosed herein, as recited in the claims below.

CLAIMS

1. A wireless communication method, comprising:
 sending, by a wireless communication node to at least a first wireless communication device in a plurality of wireless communication devices, a first message encompassing indications of a first parameter in a first or second discrete set associated with basis selection, to instruct the first wireless communication device to send a second message associated with Channel State Information (CSI) feedback;
 receiving, by the wireless communication node from each wireless communication device in the plurality of wireless communication devices, the second message encompassing indications of a second parameter associated with basis selection; and
 determining, by the wireless communication node, based on the second message received from each of the wireless communication devices, a third message for a downlink multi-user transmission.
2. The wireless communication method of claim 1, wherein the first parameter selected from the first or second discrete set is smaller than or equal to the second parameter.
3. The wireless communication method of claim 1, wherein a maximal element of the second discrete set is greater than the maximal element of the first discrete set.
4. The wireless communication method of claim 1, wherein the second parameter is a sum of the first parameter and the number of additional bases, determined by one wireless communication device in the plurality of wireless communication devices.
5. The wireless communication method of claim 1, wherein the second message is determined by quantities associated with one or more rounds of CSI feedback performed by at least one wireless communication device in the plurality of wireless communication devices.
6. The wireless communication method of claim 1, wherein the second message encompasses feedback quantities of identifying a plurality of bases and/or a plurality of respective combination/weight coefficients.
7. The wireless communication method of claim 1, wherein the wireless communication node is a distributed base station with two or more different nodes.
8. The wireless communication method of claim 7, wherein each of the two or more different nodes is at least one of: a transmission reception point, an antenna panel, an access point, or one wireless communication device in the plurality of wireless communication devices.
9. The wireless communication method of claim 1, wherein the wireless communication node determines the third message for channel precoding of the downlink multi-user transmission by configuring a filter to refine the selected bases reported in the second message.
10. The wireless communication method of claim 1, wherein the results of the basis selection are a subset of bases and/or corresponding combination coefficients, used for completely or partially representing the wireless channel between the wireless communication node and the wireless communication device.

11. A wireless communication method comprising:
- receiving, by at least a first wireless communication device in a plurality of wireless communication devices, from a wireless communication node, a first message encompassing indications of a first parameter in a first or second discrete set associated with basis selection, to instruct the first wireless communication device to send a second message associated with Channel State Information (CSI) feedback; and
- sending, by each of the wireless communication devices to the wireless communication node, the second message encompassing indications of a second parameter associated with basis selection, wherein the wireless communication node determines a third message for a downlink multi-user transmission, based on the second message received from each of the wireless communication devices.
12. A wireless communications apparatus comprising a processor and a memory, wherein the processor is configured to read code from the memory and implement a method recited in any of claims 1 to 10.
13. A computer program product comprising a processor and a memory, wherein the processor is configured to read code from the memory and implement a method recited in any of claims 1 to 10.

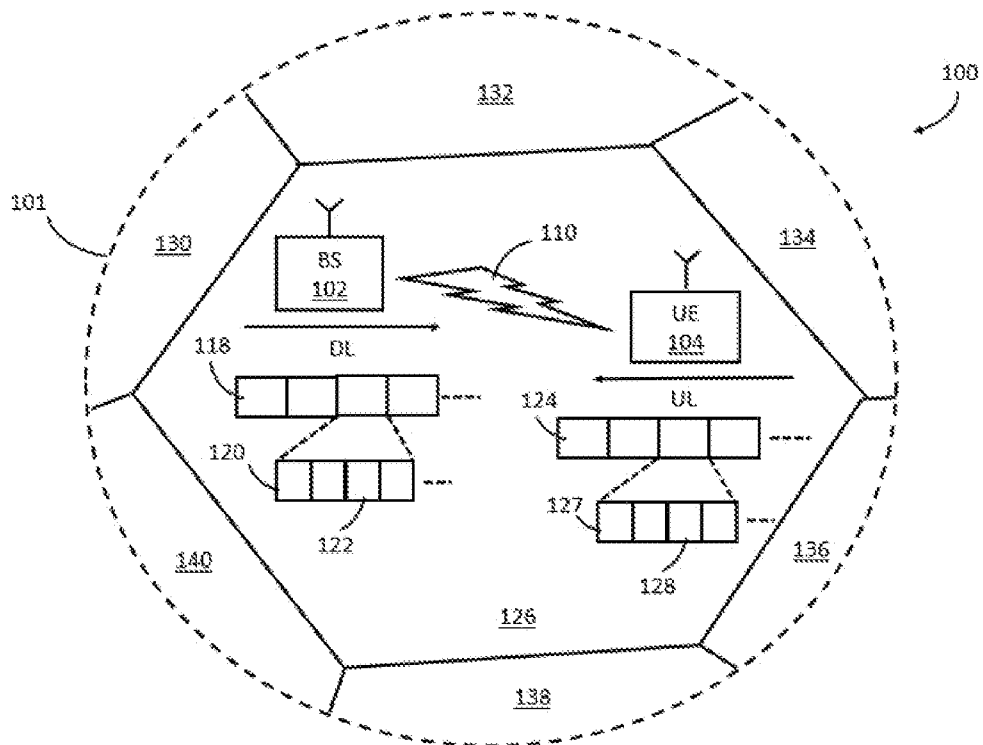


FIG. 1

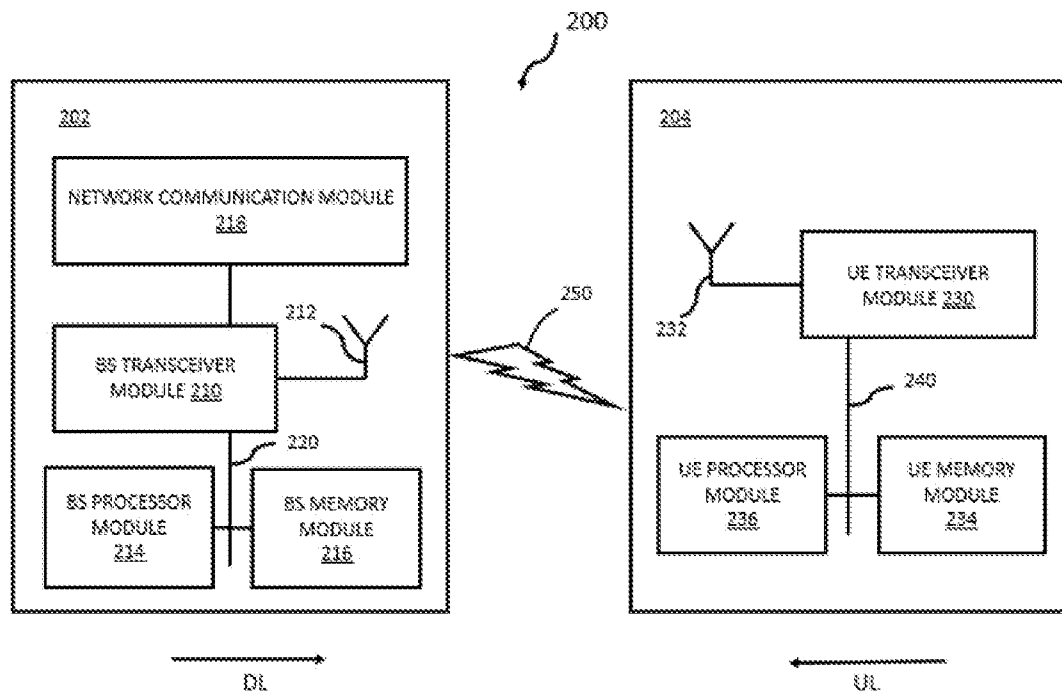


FIG. 2

300

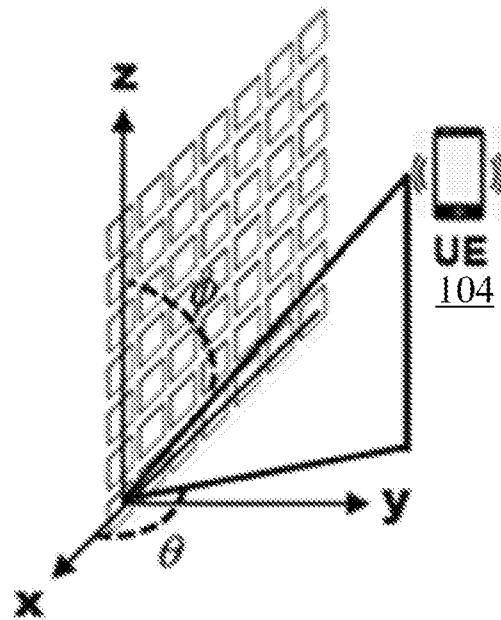


FIG. 3

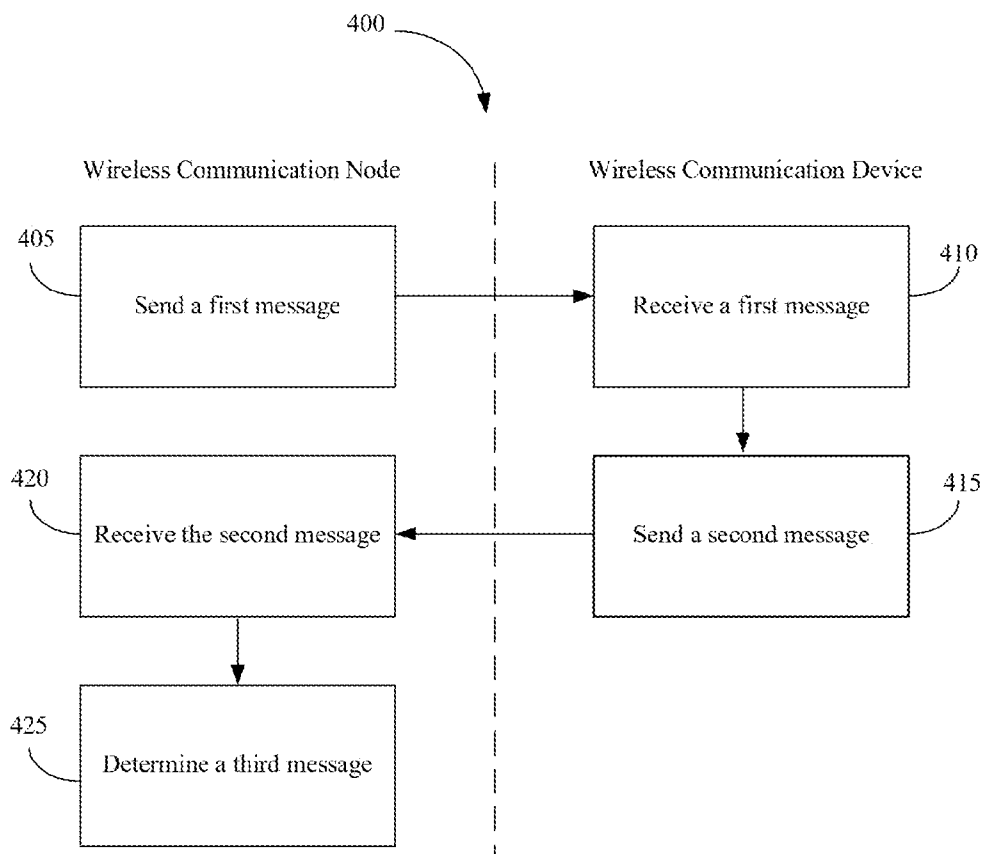


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2023/136200

A. CLASSIFICATION OF SUBJECT MATTER

H04W72/23(2023.01)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)

IPC:H04W H04L

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)

CNTXT,ENTXT,DWPL,3GPP:transmission,transmit,multi,report,feedback,feed,back,CSI,user,MIMO,basis

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2021209206 A1 (TELEFONAKTIEBOLAGET LM ERICSSON(PUBL)) 21 October 2021 (2021-10-21) paragraphs 62 and 83 in description	1-13
A	WO 2020118501 A1 (QUALCOMM INCORPORATED) 18 June 2020 (2020-06-18) the whole document	1-13
A	WO 2021044190 A1 (NOKIA TECHNOLOGIES OY) 11 March 2021 (2021-03-11) the whole document	1-13
A	RESEARCH IN MOTION, UK LIMITED. "Downlink CSI Feedback for Low Power Node" 3GPP TSG RAN WG1 Meeting #65 R1-111662, 13 May 2011 (2011-05-13), the whole document	1-13



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

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“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

12 July 2024

Date of mailing of the international search report

19 July 2024

Name and mailing address of the ISA/CN

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2023/136200

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
WO	2021209206	A1	21 October 2021	US	2023145057	A1	11 May 2023
				EP	4136767	A1	22 February 2023
				CN	115428354	A	02 December 2022
WO	2020118501	A1	18 June 2020	US	2022038159	A1	03 February 2022
				EP	3895337	A1	20 October 2021
				WO	2020119715	A1	18 June 2020
				CN	113169785	A	23 July 2021
WO	2021044190	A1	11 March 2021	US	2022329304	A1	13 October 2022
				EP	4026255	A1	13 July 2022
				CN	114631267	A	14 June 2022