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(54) **Title:** ENHANCEMENT OF LINEAR COMBINATION CODEBOOKS IN FD-MIMO

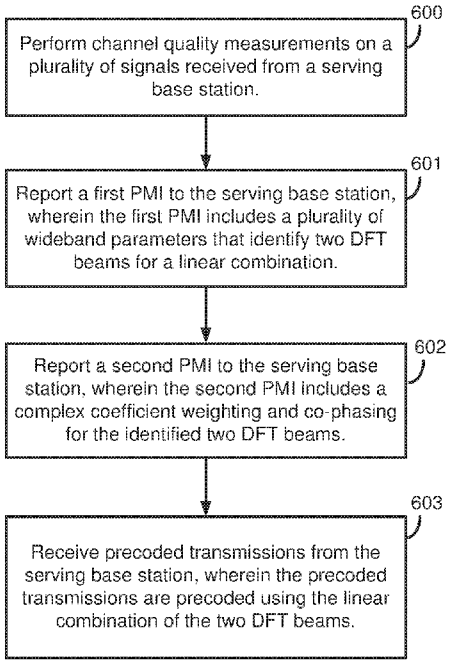


FIG. 6

(57) **Abstract:** An enhanced linear combination codebook is disclosed using a composite precoder represented by a linear combination of two DFT precoding vectors. In a first option with wideband beam pair selection, precoders from a W_1 codebook allows for identification of the two DFT beams, which may or may not be orthogonal or non-orthogonal to each other. In this first option, a new W_1/W_2 codebook may be used. The second option includes a wideband primary beam selection, in which the legacy W_1 codebook may be reused to define the grid of beams along with a new W_2 codebook design for beam selection. The third option provides for subband beam pair selection with a common co-phasing ($\varphi_1 = \varphi_2$), which also reuses the legacy W_1 codebook to define the grid of beams along with a new W_2 codebook design for beam selection.

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ENHANCEMENT OF LINEAR COMBINATION CODEBOOKS IN FD-MIMO

BACKGROUND

Field

[0001] Aspects of the present disclosure relate generally to wireless communication systems, and more particularly, to enhancement of linear combination codebooks in full dimension multiple input, multiple output (FD-MIMO) systems.

Background

[0002] Wireless communication networks are widely deployed to provide various communication services such as voice, video, packet data, messaging, broadcast, and the like. These wireless networks may be multiple-access networks capable of supporting multiple users by sharing the available network resources. Such networks, which are usually multiple access networks, support communications for multiple users by sharing the available network resources. One example of such a network is the Universal Terrestrial Radio Access Network (UTRAN). The UTRAN is the radio access network (RAN) defined as a part of the Universal Mobile Telecommunications System (UMTS), a third generation (3G) mobile phone technology supported by the 3rd Generation Partnership Project (3GPP). Examples of multiple-access network formats include Code Division Multiple Access (CDMA) networks, Time Division Multiple Access (TDMA) networks, Frequency Division Multiple Access (FDMA) networks, Orthogonal FDMA (OFDMA) networks, and Single-Carrier FDMA (SC-FDMA) networks.

[0003] A wireless communication network may include a number of base stations or node Bs that can support communication for a number of user equipments (UEs). A UE may communicate with a base station via downlink and uplink. The downlink (or forward link) refers to the communication link from the base station to the UE, and the uplink (or reverse link) refers to the communication link from the UE to the base station.

[0004] A base station may transmit data and control information on the downlink to a UE and/or may receive data and control information on the uplink from the UE. On the downlink, a transmission from the base station may encounter interference due to transmissions from neighbor base stations or from other wireless radio frequency (RF) transmitters. On the uplink, a transmission from the UE may encounter interference from uplink transmissions of other UEs communicating with the neighbor base stations or from other wireless RF transmitters. This interference may degrade performance on both the downlink and uplink.

[0005] As the demand for mobile broadband access continues to increase, the possibilities of interference and congested networks grows with more UEs accessing the long-range wireless communication networks and more short-range wireless systems being deployed in communities. Research and development continue to advance the UMTS technologies not only to meet the growing demand for mobile broadband access, but to advance and enhance the user experience with mobile communications.

SUMMARY

[0006] In one aspect of the disclosure, a method of wireless communication includes performing channel state information (CSI) measurements on a plurality of signals received from a serving base station, reporting a first precoding matrix indicator (PMI) to the serving base station, wherein the first PMI includes a plurality of wideband parameters that identify two discrete Fourier transform (DFT) beams for a linear combination, wherein the two DFT beams are selected from a plurality of DFT beams forming the plurality of signals, reporting a second PMI to the serving base station, wherein the second PMI includes a complex coefficient weighting and co-phasing for the linear combination of the identified two DFT beams, and receiving precoded transmissions from the serving base station, wherein the precoded transmissions are precoded using the linear combination of the two DFT beams.

[0007] In one aspect of the disclosure, a method of wireless communication includes performing CSI on a plurality of signals from a serving base station, reporting a first PMI to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of DFT beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters, reporting a second PMI to the serving base station, wherein the second PMI includes first and second parameters that identify a primary beam and a secondary beam from the grid of beams determined from the first PMI, and receiving precoded transmissions from the serving base station, wherein the precoded transmissions are precoded based on one or more of the two DFT beams.

[0008] In one aspect of the disclosure, a method of wireless communication includes performing CSI measurements on a plurality of signals from a serving base station, reporting a first PMI to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of DFT beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters, reporting a second PMI to the serving base station, wherein the second PMI includes a first

parameter that provides beam selection of two DFT beams from the grid of beams, complex coefficient, and a common co-phasing for the two DFT beams, and receiving precoded transmissions from the serving base station, wherein the precoded transmissions are precoded based on a linear combination of the two DFT beams.

[0009] In one aspect of the disclosure, an apparatus configured for wireless communication includes means for performing CSI measurements on a plurality of signals received from a serving base station, means for reporting a first PMI to the serving base station, wherein the first PMI includes a plurality of wideband parameters that identify two DFT beams for a linear combination, wherein the two DFT beams are selected from a plurality of DFT beams forming the plurality of signals, means for reporting a second PMI to the serving base station, wherein the second PMI includes a complex coefficient weighting and co-phasing for the linear combination of the identified two DFT beams, and means for receiving precoded transmissions from the serving base station, wherein the precoded transmissions are precoded using the linear combination of the two DFT beams.

[0010] In one aspect of the disclosure, an apparatus configured for wireless communication includes means for performing CSI on a plurality of signals from a serving base station, means for reporting a first PMI to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of DFT beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters, means for reporting a second PMI to the serving base station, wherein the second PMI includes first and second parameters that identify a primary beam and a secondary beam from the grid of beams determined from the first PMI, and means for receiving precoded transmissions from the serving base station, wherein the precoded transmissions are precoded based on one or more of the two DFT beams.

[0011] In one aspect of the disclosure, an apparatus configured for wireless communication includes means for performing CSI measurements on a plurality of signals from a serving base station, means for reporting a first PMI to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of DFT beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters, means for reporting a second PMI to the serving base station, wherein the second PMI includes a first parameter that provides beam selection of two DFT beams from the grid of beams, complex coefficient, and a common co-phasing for the two DFT beams, and means for receiving precoded transmissions from the serving base station,

wherein the precoded transmissions are precoded based on a linear combination of the two DFT beams.

[0012] In an additional aspect of the disclosure, a non-transitory computer-readable medium having program code recorded thereon. The program code further includes code to perform CSI measurements on a plurality of signals received from a serving base station, code to report a first PMI to the serving base station, wherein the first PMI includes a plurality of wideband parameters that identify two DFT beams for a linear combination, wherein the two DFT beams are selected from a plurality of DFT beams forming the plurality of signals, code to report a second PMI to the serving base station, wherein the second PMI includes a complex coefficient weighting and co-phasing for the linear combination of the identified two DFT beams, and code to receive precoded transmissions from the serving base station, wherein the precoded transmissions are precoded using the linear combination of the two DFT beams.

[0013] In an additional aspect of the disclosure, a non-transitory computer-readable medium having program code recorded thereon. The program code further includes code to perform CSI on a plurality of signals from a serving base station, code to report a first PMI to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of DFT beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters, code to report a second PMI to the serving base station, wherein the second PMI includes first and second parameters that identify a primary beam and a secondary beam from the grid of beams determined from the first PMI, and code to receive precoded transmissions from the serving base station, wherein the precoded transmissions are precoded based on one or more of the two DFT beams.

[0014] In an additional aspect of the disclosure, a non-transitory computer-readable medium having program code recorded thereon. The program code further includes code to perform CSI measurements on a plurality of signals from a serving base station, code to report a first PMI to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of DFT beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters, code to report a second PMI to the serving base station, wherein the second PMI includes a first parameter that provides beam selection of two DFT beams from the grid of beams, complex coefficient, and a common co-phasing for the two DFT beams, and code to receive precoded

transmissions from the serving base station, wherein the precoded transmissions are precoded based on a linear combination of the two DFT beams.

[0015] In an additional aspect of the disclosure, an apparatus configured for wireless communication is disclosed. The apparatus includes at least one processor, and a memory coupled to the processor. The processor is configured to perform CSI measurements on a plurality of signals received from a serving base station, to report a first PMI to the serving base station, wherein the first PMI includes a plurality of wideband parameters that identify two DFT beams for a linear combination, wherein the two DFT beams are selected from a plurality of DFT beams forming the plurality of signals, to report a second PMI to the serving base station, wherein the second PMI includes a complex coefficient weighting and co-phasing for the linear combination of the identified two DFT beams, and to receive precoded transmissions from the serving base station, wherein the precoded transmissions are precoded using the linear combination of the two DFT beams.

[0016] In an additional aspect of the disclosure, an apparatus configured for wireless communication is disclosed. The apparatus includes at least one processor, and a memory coupled to the processor. The processor is configured to perform CSI on a plurality of signals from a serving base station, to report a first PMI to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of DFT beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters, to report a second PMI to the serving base station, wherein the second PMI includes first and second parameters that identify a primary beam and a secondary beam from the grid of beams determined from the first PMI, and to receive precoded transmissions from the serving base station, wherein the precoded transmissions are precoded based on one or more of the two DFT beams.

[0017] In an additional aspect of the disclosure, an apparatus configured for wireless communication is disclosed. The apparatus includes at least one processor, and a memory coupled to the processor. The processor is configured to perform CSI measurements on a plurality of signals from a serving base station, to report a first PMI to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of DFT beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters, to report a second PMI to the serving base station, wherein the second PMI includes a first parameter that provides beam selection of two DFT beams from the grid of beams, complex coefficient, and a common co-phasing for the two DFT beams, and to receive precoded transmissions from the serving base

station, wherein the precoded transmissions are precoded based on a linear combination of the two DFT beams.

[0018] The foregoing has outlined rather broadly the features and technical advantages of examples according to the disclosure in order that the detailed description that follows may be better understood. Additional features and advantages will be described hereinafter. The conception and specific examples disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present disclosure. Such equivalent constructions do not depart from the scope of the appended claims. Characteristics of the concepts disclosed herein, both their organization and method of operation, together with associated advantages will be better understood from the following description when considered in connection with the accompanying figures. Each of the figures is provided for the purpose of illustration and description, and not as a definition of the limits of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] A further understanding of the nature and advantages of the present disclosure may be realized by reference to the following drawings. In the appended figures, similar components or features may have the same reference label. Further, various components of the same type may be distinguished by following the reference label by a dash and a second label that distinguishes among the similar components. If just the first reference label is used in the specification, the description is applicable to any one of the similar components having the same first reference label irrespective of the second reference label.

[0020] FIG. 1 is a block diagram illustrating details of a wireless communication system.

[0021] FIG. 2 is a block diagram conceptually illustrating a design of a base station/eNB and a UE configured according to one aspect of the present disclosure.

[0022] FIG. 3 is a block diagram illustrating a typical 2D active antenna array.

[0023] FIG. 4A is a block diagram illustrating an example base station transmitting non-precoded CSI-RS.

[0024] FIG. 4B is a block diagram illustrating an example base station transmitting beamformed CSI-RS using CSI-RS resources.

[0025] FIGs. 5A and 5B are block diagrams illustrating beam configurations for a 2D active antenna array of an eNB in communications with a UE.

[0026] FIG. 6 is a block diagram illustrating example blocks executed to implement one aspect of the present disclosure.

[0027] FIG. 7 is a block diagram illustrating an eNB and a UE configured according to aspects of the present disclosure.

[0028] FIG. 8 is a block diagram illustrating example blocks executed to implement one aspect of the present disclosure.

[0029] FIG. 9 is a block diagram illustrating an eNB and a UE configured according to one aspect of the present disclosure.

[0030] FIG. 10 is a block diagram illustrating example blocks executed to implement one aspect of the present disclosure.

[0031] FIG. 11 is a block diagram illustrating a UE configured according to one aspect of the present disclosure.

[0032] FIG. 12 is a block diagram illustrating an eNB configured according to one aspect of the present disclosure.

[0033] FIGs. 13A and 13B are block diagrams illustrating an eNB and a UE configured according to various aspects of the present disclosure for providing non-linear combination type codebooks.

DETAILED DESCRIPTION

[0034] The detailed description set forth below, in connection with the appended drawings, is intended as a description of various possible configurations and is not intended to limit the scope of the disclosure. Rather, the detailed description includes specific details for the purpose of providing a thorough understanding of the inventive subject matter. It will be apparent to those skilled in the art that these specific details are not required in every case and that, in some instances, well-known structures and components are shown in block diagram form for clarity of presentation.

[0035] This disclosure relates generally to providing or participating in authorized shared access between two or more wireless communications systems, also referred to as wireless communications networks. In various embodiments, the techniques and apparatus may be used for wireless communication networks such as code division multiple access (CDMA) networks, time division multiple access (TDMA) networks, frequency division multiple access (FDMA) networks, orthogonal FDMA (OFDMA) networks, single-carrier FDMA (SC-FDMA) networks, LTE networks, GSM networks, as well as other communications networks. As described herein, the terms “networks” and “systems” may be used interchangeably.

[0036] A CDMA network may implement a radio technology such as universal terrestrial radio access (UTRA), cdma2000, and the like. UTRA includes wideband-CDMA (W-CDMA) and low chip rate (LCR). CDMA2000 covers IS-2000, IS-95, and IS-856 standards.

[0037] A TDMA network may implement a radio technology such as Global System for Mobile Communications (GSM). 3GPP defines standards for the GSM EDGE (enhanced data rates for GSM evolution) radio access network (RAN), also denoted as GERAN. GERAN is the radio component of GSM/EDGE, together with the network that joins the base stations (for example, the Ater and Abis interfaces) and the base station controllers (A interfaces, etc.). The radio access network represents a component of a GSM network, through which phone calls and packet data are routed from and to the public switched telephone network (PSTN) and Internet to and from subscriber handsets, also known as user terminals or user equipments (UEs). A mobile phone operator's network may comprise one or more GERANs, which may be coupled with UTRANs in the case of a UMTS/GSM network. An operator network may also include one or more LTE networks, and/or one or more other networks. The various different network types may use different radio access technologies (RATs) and radio access networks (RANs).

[0038] An OFDMA network may implement a radio technology such as evolved UTRA (E-UTRA), IEEE 802.11, IEEE 802.16, IEEE 802.20, flash-OFDM and the like. UTRA, E-UTRA, and GSM are part of universal mobile telecommunication system (UMTS). In particular, long term evolution (LTE) is a release of UMTS that uses E-UTRA. UTRA, E-UTRA, GSM, UMTS and LTE are described in documents provided from an organization named “3rd Generation Partnership Project” (3GPP), and cdma2000 is described in documents from an organization named “3rd Generation Partnership Project 2” (3GPP2). These various radio technologies and standards are known or are being developed. For example, the 3rd Generation Partnership Project (3GPP) is a collaboration between groups of telecommunications associations that aims to define a globally applicable third generation (3G) mobile phone specification. 3GPP long term evolution (LTE) is a 3GPP project aimed at improving the universal mobile telecommunications system (UMTS) mobile phone standard. The 3GPP may define specifications for the next generation of mobile networks, mobile systems, and mobile devices. For clarity, certain aspects of the apparatus and techniques may be described below for LTE implementations or in an LTE-centric way, and LTE terminology may be used as illustrative examples in portions of the description below; however, the description is not intended to be limited to LTE applications. Indeed, the

present disclosure is concerned with shared access to wireless spectrum between networks using different radio access technologies or radio air interfaces.

[0039] A new carrier type based on LTE/LTE-A including in unlicensed spectrum has also been suggested that can be compatible with carrier-grade WiFi, making LTE/LTE-A with unlicensed spectrum an alternative to WiFi. LTE/LTE-A, when operating in unlicensed spectrum, may leverage LTE concepts and may introduce some modifications to physical layer (PHY) and media access control (MAC) aspects of the network or network devices to provide efficient operation in the unlicensed spectrum and meet regulatory requirements. The unlicensed spectrum used may range from as low as several hundred Megahertz (MHz) to as high as tens of Gigahertz (GHz), for example. In operation, such LTE/LTE-A networks may operate with any combination of licensed or unlicensed spectrum depending on loading and availability. Accordingly, it may be apparent to one of skill in the art that the systems, apparatus and methods described herein may be applied to other communications systems and applications.

[0040] System designs may support various time-frequency reference signals for the downlink and uplink to facilitate beamforming and other functions. A reference signal is a signal generated based on known data and may also be referred to as a pilot, preamble, training signal, sounding signal, and the like. A reference signal may be used by a receiver for various purposes such as channel estimation, coherent demodulation, channel quality measurement, signal strength measurement, and the like. MIMO systems using multiple antennas generally provide for coordination of sending of reference signals between antennas; however, LTE systems do not in general provide for coordination of sending of reference signals from multiple base stations or eNBs.

[0041] In some implementations, a system may utilize time division duplexing (TDD). For TDD, the downlink and uplink share the same frequency spectrum or channel, and downlink and uplink transmissions are sent on the same frequency spectrum. The downlink channel response may thus be correlated with the uplink channel response. Reciprocity may allow a downlink channel to be estimated based on transmissions sent via the uplink. These uplink transmissions may be reference signals or uplink control channels (which may be used as reference symbols after demodulation). The uplink transmissions may allow for estimation of a space-selective channel via multiple antennas.

[0042] In LTE implementations, orthogonal frequency division multiplexing (OFDM) is used for the downlink – that is, from a base station, access point or eNodeB (eNB) to a user terminal or UE. Use of OFDM meets the LTE requirement for spectrum flexibility and

enables cost-efficient solutions for very wide carriers with high peak rates, and is a well-established technology. For example, OFDM is used in standards such as IEEE 802.11a/g, 802.16, High Performance Radio LAN-2 (HIPERLAN-2, wherein LAN stands for Local Area Network) standardized by the European Telecommunications Standards Institute (ETSI), Digital Video Broadcasting (DVB) published by the Joint Technical Committee of ETSI, and other standards.

[0043] Time frequency physical resource blocks (also denoted here in as resource blocks or "RBs" for brevity) may be defined in OFDM systems as groups of transport carriers (e.g. sub-carriers) or intervals that are assigned to transport data. The RBs are defined over a time and frequency period. Resource blocks are comprised of time-frequency resource elements (also denoted here in as resource elements or "REs" for brevity), which may be defined by indices of time and frequency in a slot. Additional details of LTE RBs and REs are described in the 3GPP specifications, such as, for example, 3GPP TS 36.211.

[0044] UMTS LTE supports scalable carrier bandwidths from 20 MHz down to 1.4 MHZ. In LTE, an RB is defined as 12 sub-carriers when the subcarrier bandwidth is 15 kHz, or 24 sub-carriers when the sub-carrier bandwidth is 7.5 kHz. In an exemplary implementation, in the time domain there is a defined radio frame that is 10 ms long and consists of 10 subframes of 1 millisecond (ms) each. Every subframe consists of 2 slots, where each slot is 0.5 ms. The subcarrier spacing in the frequency domain in this case is 15 kHz. Twelve of these subcarriers together (per slot) constitute an RB, so in this implementation one resource block is 180 kHz. Six Resource blocks fit in a carrier of 1.4 MHz and 100 resource blocks fit in a carrier of 20 MHz.

[0045] Various other aspects and features of the disclosure are further described below. It should be apparent that the teachings herein may be embodied in a wide variety of forms and that any specific structure, function, or both being disclosed herein is merely representative and not limiting. Based on the teachings herein one of an ordinary level of skill in the art should appreciate that an aspect disclosed herein may be implemented independently of any other aspects and that two or more of these aspects may be combined in various ways. For example, an apparatus may be implemented or a method may be practiced using any number of the aspects set forth herein. In addition, such an apparatus may be implemented or such a method may be practiced using other structure, functionality, or structure and functionality in addition to or other than one or more of the aspects set forth herein. For example, a method may be implemented as part of a system, device, apparatus, and/or as instructions stored on a

computer readable medium for execution on a processor or computer. Furthermore, an aspect may comprise at least one element of a claim.

[0046] FIG. 1 shows a wireless network 100 for communication, which may be an LTE-A network. The wireless network 100 includes a number of evolved node Bs (eNBs) 105 and other network entities. An eNB may be a station that communicates with the UEs and may also be referred to as a base station, a node B, an access point, and the like. Each eNB 105 may provide communication coverage for a particular geographic area. In 3GPP, the term "cell" can refer to this particular geographic coverage area of an eNB and/or an eNB subsystem serving the coverage area, depending on the context in which the term is used.

[0047] An eNB may provide communication coverage for a macro cell or a small cell, such as a pico cell or a femto cell, and/or other types of cell. A macro cell generally covers a relatively large geographic area (e.g., several kilometers in radius) and may allow unrestricted access by UEs with service subscriptions with the network provider. A small cell, such as a pico cell, would generally cover a relatively smaller geographic area and may allow unrestricted access by UEs with service subscriptions with the network provider. A small cell, such as a femto cell, would also generally cover a relatively small geographic area (e.g., a home) and, in addition to unrestricted access, may also provide restricted access by UEs having an association with the femto cell (e.g., UEs in a closed subscriber group (CSG), UEs for users in the home, and the like). An eNB for a macro cell may be referred to as a macro eNB. An eNB for a small cell may be referred to as a small cell eNB, a pico eNB, a femto eNB or a home eNB. In the example shown in FIG. 1, the eNBs 105a, 105b and 105c are macro eNBs for the macro cells 110a, 110b and 110c, respectively. The eNBs 105x, 105y, and 105z are small cell eNBs, which may include pico or femto eNBs that provide service to small cells 110x, 110y, and 110z, respectively. An eNB may support one or multiple (e.g., two, three, four, and the like) cells.

[0048] The wireless network 100 may support synchronous or asynchronous operation. For synchronous operation, the eNBs may have similar frame timing, and transmissions from different eNBs may be approximately aligned in time. For asynchronous operation, the eNBs may have different frame timing, and transmissions from different eNBs may not be aligned in time.

[0049] The UEs 115 are dispersed throughout the wireless network 100, and each UE may be stationary or mobile. A UE may also be referred to as a terminal, a mobile station, a subscriber unit, a station, or the like. A UE may be a cellular phone, a personal digital assistant (PDA), a wireless modem, a wireless communication device, a handheld device, a

tablet computer, a laptop computer, a cordless phone, a wireless local loop (WLL) station, or the like. A UE may be able to communicate with macro eNBs, pico eNBs, femto eNBs, relays, and the like. In FIG. 1, a lightning bolt (e.g., communication links 125) indicates wireless transmissions between a UE and a serving eNB, which is an eNB designated to serve the UE on the downlink and/or uplink, or desired transmission between eNBs. Wired backhaul communication 134 indicate wired backhaul communications that may occur between eNBs.

[0050] LTE/-A utilizes orthogonal frequency division multiplexing (OFDM) on the downlink and single-carrier frequency division multiplexing (SC-FDM) on the uplink. OFDM and SC-FDM partition the system bandwidth into multiple (X) orthogonal subcarriers, which are also commonly referred to as tones, bins, or the like. Each subcarrier may be modulated with data. In general, modulation symbols are sent in the frequency domain with OFDM and in the time domain with SC-FDM. The spacing between adjacent subcarriers may be fixed, and the total number of subcarriers (X) may be dependent on the system bandwidth. For example, X may be equal to 72, 180, 300, 600, 900, and 1200 for a corresponding system bandwidth of 1.4, 3, 5, 10, 15, or 20 megahertz (MHz), respectively. The system bandwidth may also be partitioned into sub-bands. For example, a sub-band may cover 1.08 MHz, and there may be 1, 2, 4, 8 or 16 sub-bands for a corresponding system bandwidth of 1.4, 3, 5, 10, 15, or 20MHz, respectively.

[0051] FIG. 2 shows a block diagram of a design of a base station/eNB 105 and a UE 115, which may be one of the base stations/eNBs and one of the UEs in FIG. 1. For a restricted association scenario, the eNB 105 may be the small cell eNB 105z in FIG. 1, and the UE 115 may be the UE 115z, which in order to access small cell eNB 105z, would be included in a list of accessible UEs for small cell eNB 105z. The eNB 105 may also be a base station of some other type. The eNB 105 may be equipped with antennas 234a through 234t, and the UE 115 may be equipped with antennas 252a through 252r.

[0052] At the eNB 105, a transmit processor 220 may receive data from a data source 212 and control information from a controller/processor 240. The control information may be for the PBCH, PCFICH, PHICH, PDCCH, etc. The data may be for the PDSCH, etc. The transmit processor 220 may process (e.g., encode and symbol map) the data and control information to obtain data symbols and control symbols, respectively. The transmit processor 220 may also generate reference symbols, e.g., for the PSS, SSS, and cell-specific reference signal. A transmit (TX) multiple-input multiple-output (MIMO) processor 230 may perform spatial processing (e.g., precoding) on the data symbols, the control symbols, and/or the

reference symbols, if applicable, and may provide output symbol streams to the modulators (MODs) 232a through 232t. Each modulator 232 may process a respective output symbol stream (e.g., for OFDM, etc.) to obtain an output sample stream. Each modulator 232 may further process (e.g., convert to analog, amplify, filter, and upconvert) the output sample stream to obtain a downlink signal. Downlink signals from modulators 232a through 232t may be transmitted via the antennas 234a through 234t, respectively.

[0053] At the UE 115, the antennas 252a through 252r may receive the downlink signals from the eNB 105 and may provide received signals to the demodulators (DEMODs) 254a through 254r, respectively. Each demodulator 254 may condition (e.g., filter, amplify, downconvert, and digitize) a respective received signal to obtain input samples. Each demodulator 254 may further process the input samples (e.g., for OFDM, etc.) to obtain received symbols. A MIMO detector 256 may obtain received symbols from all the demodulators 254a through 254r, perform MIMO detection on the received symbols if applicable, and provide detected symbols. A receive processor 258 may process (e.g., demodulate, deinterleave, and decode) the detected symbols, provide decoded data for the UE 115 to a data sink 260, and provide decoded control information to a controller/processor 280.

[0054] On the uplink, at the UE 115, a transmit processor 264 may receive and process data (e.g., for the PUSCH) from a data source 262 and control information (e.g., for the PUCCH) from the controller/processor 280. The transmit processor 264 may also generate reference symbols for a reference signal. The symbols from the transmit processor 264 may be precoded by a TX MIMO processor 266 if applicable, further processed by the modulators 254a through 254r (e.g., for SC-FDM, etc.), and transmitted to the eNB 105. At the eNB 105, the uplink signals from the UE 115 may be received by the antennas 234, processed by the demodulators 232, detected by a MIMO detector 236 if applicable, and further processed by a receive processor 238 to obtain decoded data and control information sent by the UE 115. The processor 238 may provide the decoded data to a data sink 239 and the decoded control information to the controller/processor 240.

[0055] The controllers/processors 240 and 280 may direct the operation at the eNB 105 and the UE 115, respectively. The controller/processor 240 and/or other processors and modules at the eNB 105 may perform or direct the execution of various processes for the techniques described herein. The controllers/processor 280 and/or other processors and modules at the UE 115 may also perform or direct the execution of the functional blocks illustrated in FIGs. 6, 8, and 10, and/or other processes for the techniques described herein. The memories 242

and 282 may store data and program codes for the eNB 105 and the UE 115, respectively. A scheduler 244 may schedule UEs for data transmission on the downlink and/or uplink.

[0056] Multiple-input multiple-output (MIMO) technology generally allows communication to take advantage of the spatial dimension through use of channel state information (CSI) feedback at the eNB. An eNB may broadcast cell-specific CSI reference signals (CSI-RS) for which the UE measures CSI based on configurations signaled by eNB via RRC, such as CSI-RS resource configuration and transmission mode. The CSI-RS are periodically transmitted at periodicities of 5, 10, 20, 40, 80 ms, or the like. A UE may report CSI at CSI reporting instances also configured by the eNB. As a part of CSI reporting the UE generates and reports channel quality indicator (CQI), precoding matrix indicator (PMI), and rank indicator (RI). The CSI can be reported either via PUCCH or via PUSCH and may be reported either periodically or aperiodically, with potentially different granularity. When reported via PUCCH, the payload size for CSI may be limited.

[0057] In order to increase system capacity, full-dimensional (FD)-MIMO technology has been considered, in which an eNB uses a two-dimensional (2D) active antenna array with a large number of antennas with antenna ports having both horizontal and vertical axes, and has a larger number of transceiver units. For conventional MIMO systems, beamforming has typically implemented using only azimuth dimension, although of a 3D multi-path propagation. However, for FD-MIMO each transceiver unit has its own independent amplitude and phase control. Such capability together with the 2D active antenna array allows the transmitted signal to be steered not only in the horizontal direction, as in conventional multi-antenna systems, but also simultaneously in both the horizontal and the vertical direction, which provides more flexibility in shaping beam directions from an eNB to a UE. Providing dynamic beam steering in the vertical direction has been shown to result in significant gain in interference avoidance. Thus, FD-MIMO technologies may take advantage of both azimuth and elevation beamforming, which would greatly improve MIMO system capacity and signal quality.

[0058] FIG. 3 is a block diagram illustrating a typical 2D active antenna array 30. Active antenna array 30 is a 64-transmitter, cross-polarized uniform planar antenna array comprising four columns, in which each column includes eight cross-polarized vertical antenna elements. Active antenna arrays are often described according to the number of antenna columns (N), the polarization type (P), and the number of vertical elements having the same polarization

type in one column (M). Thus, active antenna array 30 has four columns ($N = 4$), with eight vertical ($M = 8$) cross-polarized antenna elements ($P = 2$).

[0059] For a 2D array structure, in order to exploit the vertical dimension by elevation beamforming the CSI is needed at the base station. The CSI, in terms of PMI, RI, and CQI, can be fed back to the base station by a mobile station based on downlink channel estimation and predefined PMI codebook(s). However, different from the conventional MIMO system, the eNB capable of FD-MIMO is typically equipped with a large scale antenna system and, thus, the acquisition of full array CSI from the UE is quite challenging due to the complexity of channel estimation and both excessive downlink CSI-RS overhead and uplink CSI feedback overhead.

[0060] For CSI reporting in systems having FD-MIMO, a CSI process may be configured with either of two CSI reporting classes, class A non-precoded or class B beamformed. FIG. 4A is a block diagram illustrating an example base station 400 transmitting non-precoded CSI-RS 401. In class A non-precoded reporting, one non-zero power (NZP) CSI-RS resource per CSI process may be used for channel measurement in which the number of CSI-RS ports may be 8, 12, or 16. Interference measurement in class A reporting may include one CSI-interference measurement (IM) resource per CSI process.

[0061] Base station 400 serves UEs 403 and 404 and UEs 405 and 406 in structure 40. 2D CSI-RS ports transmit non-precoded CSI-RS 401 and PDSCH 402 to UEs 403-406. In reporting CSI feedback, UEs 403-406 measure the non-precoded CSI-RS and reports CQI, precoding matrix indicator (PMI) (2D codebook), and rank indicator to base station 400.

[0062] FIG. 4B is a block diagram illustrating an example base station 407 transmitting beamformed CSI-RS using CSI-RS resources 408-410. CSI-RS resources 408-410 may be directed to serve different UE groups, such as UE group 415, including UEs 411 and 412, and UE group 416, including UEs 413 and 414 in structure 41. Because different CSI-RS resources are used for different UE groups, when providing CSI feedback, UEs 411-414 report CQI, PMI (1D codebook), rank indicator, as well as the CSI-RS resource indicator (CRI), if $K > 1$, which identifies to base station 407 which of the CSI-RS resources the UE has measured and provided channel state information (CSI) feedback for.

[0063] In class B beamformed CSI reporting, each CSI process may be associated with K NZP CSI-RS resources/configurations, with N_k ports for the k^{th} CSI-RS resource (K could be ≥ 1), in which N_k may be 1, 2, 4, or 8, and may be different for each CSI-RS resource. Each CSI-RS resource may also have different CSI-RS port virtualization, e.g., virtualized from

different sets of antenna elements or from the same set of antenna elements but with different beamforming weights. Multiple CSI-IM per CSI process is also possible, with one-to-one linkage to each NZP CSI-RS resource.

[0064] In LTE Rel. 13, the class A rank 1-2 codebook is generally a dual codebook defined as:

$$\boldsymbol{W} = \boldsymbol{W_1 W_2}$$

Where the precoder $\boldsymbol{W}$ is a composite of $\boldsymbol{W_1}$, which includes a grid of beams (e.g., a Kronecker product of discrete Fourier transform (DFT) beams of each dimension) indicated by parameters from a first antenna dimension, i_{11} and i_{12}, and determined by the RRC parameters of N_1, N_2, O_1, O_2 (the number ports and oversampling rates per dimension) and also the particular configuration of the grid, and $\boldsymbol{W_2}$, which provides the beam selection within the grid of beams along with the polarization co-phase indicated by a parameter from a second antenna dimension, i_2.

[0065] FIGs. 5A and 5B are block diagrams illustrating beam configurations for a 2D active antenna array of eNB 105 in communications with UE 115. The number of ports for each dimension, N_1 and N_2, along with the oversampling rates per dimension, O_1 and O_2, operate to define a collection of beams 50 having a first dimension of $N_1 * O_1$ and a second dimension of $N_2 * O_2$. The $\boldsymbol{W_1}$ codebook allows for a selection of a grid of beams 500 out of the collection of beams 50. $\boldsymbol{W_1}$ constructs the grid of beams according to:

$$W_1 = \begin{pmatrix} X_1 \otimes X_2 & \\ & X_1 \otimes X_2 \end{pmatrix}$$

Where $\boldsymbol{X_1}$ is an N_1 x L_1 matrix with L_1 column vectors being an O_1 times oversampled DFT vector of length N_1, and $\boldsymbol{X_2}$ is an N_2 x L_2 matrix with L_2 column vectors being an O_2 times oversampled DFT vector of length N_2. When sending CSI feedback, UE 115 will transmit a precoding matrix indicator (PMI) selected from the $\boldsymbol{W_1}$ codebook that allows eNB 105 to select the particular beams that make up grid of beams 500. Grid of beams 500 includes the Kronecker product of DFT beams of each dimension indicated by parameters, i_{11} and i_{12}. A predetermined CSI reporting mode configuration, CSI reporting configurations 501, will identify the particular beams within grid of beams 500 from which beam selection will occur. The $\boldsymbol{W_2}$ codebook, along with one of CSI reporting configurations 501, defines the beam selection within grid of beams 500 along with the polarization co-phase, indicated by i_2.

[0066] CSI reporting configurations 501 include configuration 1 through configuration 4 for selection of various dimensions of beams in orthogonal and non-orthogonal orientations.

Configuration 1 of CSI reporting configurations 501 provides for only a single beam from which to perform beam selection from grid of beams 500. Configuration 2 provides four beams with a beam offset, p, of 1 for each beam. Configuration 3 provides orthogonal selections for beams when the number of antenna ports of one antenna dimension is greater than or equal to the number of antenna ports in the other antenna dimension ($N_1 \geq N_2$). Configuration 4 provide non-orthogonal selections for beams when $N_1 \geq N_2$.

[0067] High resolution CSI feedback is a potential area of enhancement to MIMO technologies in new and future 3GPP releases that may improve the viability of massive MIMO and FD-MIMO. The Rel.13 codebook is defined by a single DFT(or KP-DFT) beam. However, a linear combination codebook based on weighted DFT beams corresponding to multi-paths may capture more channel information. The performance of MU-MIMO is expected to benefit more from linear combined codebooks considering the additional information on the multiple paths may be used to calculate multi-user precoders to avoid large intra-cell interference (e.g., transmit nulling gain).

[0068] One such example solution for higher resolution CSI feedback provides for a linear combination codebook that uses a linear combination of a set of four adjacent DFT basis vectors or beams with corresponding sets of cross-polarization co-phase and complex coefficient values selected from respective co-phase and coefficient codebooks. However, such existing proposals suffer from high complexity and a potentially lower performance in scenarios having a small angular spread. Assuming use of a quadrature phase shift keying (QPSK) for the complex coefficients and co-phasing, for each selected beam there would be four coefficient hypotheses and four co-phasing hypotheses for a total of 16 hypotheses. Considering the four adjacent basis vectors (L = 4) in the existing proposals, the total hypotheses for the $\boldsymbol{W_2}$ codebook would be $16^4 = 65536$. This very large codebook size would create considerable complexity and feedback overhead issues for any participating and compatible UE. Additionally, for scenarios having small angular spread, use of such linear combination codebook proposals may cause performance loss through additional interference caused because of the small angular spread. Moreover, existing linear combination codebook based CSI feedback systems support a fallback to the legacy, non-linear combination Rel.13 codebook via higher layer signaling, which is not very flexible.

[0069] Various aspects of the present disclosure are directed to a linear combination codebook using a composite precoder represented by a linear combination of two DFT precoding vectors. The composite precoder is represented by the following equations:

$$p = \begin{bmatrix} b_1 \\ e^{j\phi_1} b_1 \end{bmatrix} + c \begin{bmatrix} b_2 \\ e^{j\phi_2} b_2 \end{bmatrix} \quad (1)$$

where

$$w = \frac{p}{\|p\|} \quad (2)$$

where p represents the composite precoder, b_1 and b_2 are the selected DFT vectors for combination, ϕ_1 and ϕ_2 are the co-phasing angles, and c is the complex coefficient. The composite precoder for the linear combination of two DFT vectors provides a higher resolution CSI feedback for FD-MIMO systems while maintaining a more manageable computational complexity and CSI overhead.

[0070] Multiple aspects of the present disclosure are proposed for selecting the DFT beams and the complex weight for linear combination. Each proposed aspect may consider a different tradeoff between performance and complexity. In a first option with wideband beam pair selection, precoders from the $\boldsymbol{W_1}$ codebook allows for identification of two DFT beams, which may or may not be orthogonal or non-orthogonal to each other. In this first option, a new $\boldsymbol{W_1/W_2}$ codebook may be used. The second option includes a widebank primary beam selection, in which the legacy $\boldsymbol{W_1}$ codebook may be reused to define the grid of beams along with a new $\boldsymbol{W_2}$ codebook design for beam selection. The third option provides for subband beam pair selection with a common co-phasing ($\phi_1 = \phi_2$), which also reuses the legacy $\boldsymbol{W_1}$ codebook to define the grid of beams along with a new $\boldsymbol{W_2}$ codebook design for beam selection.

[0071] FIG. 6 is a block diagram illustrating example blocks executed to implement one aspect of the present disclosure. The example blocks will also be described with respect to UE 115 as illustrated in FIG. 11. FIG. 11 is a block diagram illustrating UE 115 configured according to one aspect of the present disclosure. UE 115 includes the structure, hardware, and components as illustrated for UE 115 of FIG. 2. For example, UE 115 includes controller/processor 280, which operates to execute logic or computer instructions stored in memory 282, as well as controlling the components of UE 115 that provide the features and functionality of UE 115. UE 115, under control of controller/processor 280, transmits and receives signals via wireless radios 1100a-t and antennas 252a-r. Wireless radios 1100a-t includes various components and hardware, as illustrated in FIG. 2 for eNB 105, including modulator/demodulators 254a-r, MIMO detector 256, receive processor 258, transmit processor 264, and TX MIMO processor 266.

[0072] At block 600, a UE performs channel quality measurements on a plurality of signals received from a serving base station. The UE, such as UE 115, performs measurements and makes estimates of signals received from a serving base station in order to provide various CSI feedback on the channel quality. For example, UE 115, under control of controller/processor 280, executes measurement logic 1101, stored in memory 282, to measure the various signals received from the base station. The signals received may be data signals or control signals, such as CSI-RS. UE 115 performs such measurements and estimates to obtain information on the state of the communication channel between itself and the serving base station.

[0073] At block 601, the UE reports a first precoding matrix indicator (PMI) to the serving base station, wherein the first PMI includes a plurality of wideband parameters that identify two DFT beams for a linear combination, wherein the two DFT beams are selected from a plurality of DFT beams forming the plurality of signals. For example, UE 115, under control of controller/processor 280, executes CSI report generator 1102, which generates the first PMI report. UE 115 reports a first PMI associated with $\boldsymbol{W_1}$ that may include, as determined by the execution environment of CSI report generator 1102, wideband i_{11}, i_{12}, k_1, and k_2, where the value range of i_{11} and i_{12} may be dependent on the configured N_1, N_2, O_1, O_2. The first PMI will be reported via wireless radios 1100a-r and antennas 252a-r. In some alternative aspects, joint coding of i_{11}, i_{12}, k_1, and k_2, may be supported in the $\boldsymbol{W_1}$ associated PMI reported by UE 115.

[0074] At block 602, the UE reports a second PMI to the serving base station, wherein the second PMI includes a complex coefficient weighting and co-phasing for the linear combination of the identified two DFT beams. For example, UE 115, under control of controller/processor 280 executing CSI report generator 1102, reports a second PMI associated with $\boldsymbol{W_2}$ that may include a 6-bit i_2, either wideband or subband, based on predetermined CSI reporting configuration 1103, stored in memory 282. The additional CSI feedback (e.g., CQI and RI) may be provided by UE 115 via wireless radios 1100a-r and antennas 252a-4, according to the same procedures as in the legacy Rel. 13 CSI feedback.

[0075] At block 603, the UE receives precoded or beamformed transmissions from the serving base station via antennas 252a-r and wireless radios 1100a-r, wherein the precoded or beamformed transmissions are precoded based on a channel estimation using the linear combination of the two DFT beams. The purpose of CSI feedback is for the base station to adjust its transmissions to a UE in order to increase the efficiency and reliability of the

communications. As the serving base station receives the CSI feedback, it may adjust the precoding selections and transmission parameters to accommodate the existing channel conditions.

[0076] In the first option with wideband beam pair selection, the orientational relationship between the two DFT beam may be identified and signaled with an identifier, k_1. The value of k_1 indicates the grid of beams dependency for beam pair selection. For example, k_1=0 indicates two beams within the grid that are non-orthogonal, k_1= 1 indicates two beams within the grid of beams orthogonal on the horizontal dimension, k_1= 2 indicates two beams within the grid of beam orthogonal on the vertical dimension, and k_1= 3 indicates two beams orthogonal on both horizontal and vertical dimensions.

[0077] The $\boldsymbol{W_1}$ codebook of the first option, then, identifies the two DFT beams according to:

$$W_1 = \begin{pmatrix} X_n & \\ & X_n \end{pmatrix}$$

where X_n identifies each beam according to:

$$X_n = \left[v_{l_1,m_1} v_{l_2,m_2} \right]$$

where l and m are the beam indices in the 2D antenna array, and in which

$$v_{l,m} = \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1 N_1}} u_m & \cdots & e^{j\frac{2\pi m(N_1-1)}{O_1 N_1}} u_m \end{bmatrix}$$

where

$$u_m = \begin{bmatrix} 1 & e^{j\frac{2\pi m}{O_2 N_2}} & \cdots & e^{j\frac{2\pi m(N_2-1)}{O_2 N_2}} \end{bmatrix}$$

and the $\boldsymbol{W_2}$ codebook identifies the complex coefficient weighting, c, and co-phasing, ϕ_1 and ϕ_2, according to:

$$W_2 = \begin{bmatrix} 1 \\ c \\ e^{j\phi_1} \\ ce^{j\phi_2} \end{bmatrix}$$

where

$$c \in [1, -1, j, -j]$$

and

$$\phi_1 \text{ and } \phi_2 \in \left[0, \frac{\pi}{2}, \pi, -\frac{\pi}{2} \right]$$

With four possible elements for the complex coefficient, c, and four possible elements for each of the two co-phasing, ϕ_1 and ϕ_2, there will be a total of 64 hypotheses (4x4x4 = 64).

[0078] In the design of the $\boldsymbol{W_1}$ codebook, at a first step, a set of DFT beams is determined based on the predetermined CSI reporting configuration and the parameters i_{11}, i_{12}, k_1, which a base station would receive as a first PMI related to $\boldsymbol{W_1}$.

[0079] FIG. 7 is a block diagram illustrating eNB 105 and UE 115 configured according to aspects of the present disclosure. eNB 105 and UE 115 are configured with an enhanced linear combination codebook for high resolution feedback according to a first optional aspect. UE 115 transmits a first PMI associated with W1 to eNB 105. According to the illustrated first optional aspect, the first PMI sent by UE 115 includes i_{11}, i_{12}, k_1. Additionally, a predetermined CSI reporting configuration would be set and known to both eNB 105 and UE 115. Upon receipt of the first PMI, eNB 105 identifies a grid of beams from the collection of DFT beams associated with the 2D antenna array at eNB 105. As indicated above, i_{11} and i_{12} assist in defining the grid of beams, while the predetermined CSI reporting configuration defines which of the beams within the defined grid of beams the DFT beam pair, b_1 and b_2, will be selected from. For example, when defined according to configuration 1, b_1 will be selected from beam 0 of grid of beams 700, while b_2 will be selected from beam 1 of grid of beams 701. When defined according to configuration 2, b_1 will be selected from beams 0-3 of grid of beams 702, while b_2 will be selected from beams 4-7 of grid of beams 703. Similarly, with configurations 3 and 4 are selected from the numbered beams of grid of beams 704-707, respectively. Once selected, a linear combination of the DFT beam pair may be used to adjust transmissions from eNB 105 to UE 115.

[0080] Using the $\boldsymbol{W_1}$ codebook according to the first option, two beams would be selected from the set of DFT beams according to a predefined beam pair combination set indicated by the parameters k_1 and k_2, where k_2 is a parameter used to select one of the defined beam pairs from the set of beam pairs indicated by k_1. Table 1 below identifies the beam offset for a selected beam pair according to the value of parameters k_1 and k_2.

k_2 (k_1=0)	0	1	2	3
(δ_1,δ_2)	(0,1)	(1,2)	(0,3)	(1,3)

k_2 (k_1=1)	0	1	2	3
(δ_1,δ_2)	(0,4)	(1,5)	(2,6)	(3,7)
k_2 (k_1=2)	0	1	2	3
(δ_1,δ_2)	(0,4)	(1,5)	(2,6)	(3,7)

Table 1

Note that (δ_1, δ_2) indicates the beam offset of selected beam pair (b_1, b_2) in the set of DFT beams indicated by (i_{11}, i_{12}, k_1) of the $\boldsymbol{W_1}$ codebook according to the aspects described herein with the first option.

[0081] Table 2 below is just one example of a $\boldsymbol{W_1}$ codebook for a predetermined CSI reporting mode configuration of configuration 3. The selected beam pair (b_1, b_2) are jointly determined by i_{11}, i_{12}, k_1, and k_2, where l_1, and m_1 are the associated beam index for the primary beam, b_1.

k_2	0	1	2	3
i_{11} i_{12} k_1=0	l_1=s1 i_{11}+2p_1 m_1=s2 i_{12} l_2=s1 i_{11}+3p_1 m_2=s2 i_{12}	l_1=s1 i_{11}+3p_1 m_1=s2 i_{12} l_2=s1 i_{11} m_2=s2 i_{12}+p_2	l_1=s1 i_{11}+2p_1 m_1=s2 i_{12} l_2=s1 i_{11}+p_1 m_2=s2 i_{12}+p_2	l_1=s1 i_{11}+3p_1 m_1=s2 i_{12} l_2=s1 i_{11}+p_1 m_2=s2 i_{12}+p_2
k_2	0	1	2	3
i_{11} i_{12} k_1=1	l_1=s1 i_{11}+2p_1 m_1=s2 i_{12} l_2=s1 i_{11}+2p_1+O_1 m_2=s2 i_{12}	l_1=s1 i_{11}+3p_1 m_1=s2 i_{12} l_2=s1 i_{11}+3p_1+O_1 m_2=s2 i_{12}	l_1=s1 i_{11} m_1=s2 i_{12}+p_2 l_2=s1 i_{11}+O_1 m_2=s2 i_{12}+p_2	l_1=s1 i_{11}+p_1 m_1=s2 i_{12}+p_2 i_{11}+2p_1+O_1 m_2=s2 i_{12}+p_2
k_2	0	1	2	3
i_{11} i_{12} k_1=2	l_1=s1 i_{11}+2p_1 m_1=s2 i_{12} l_2=s1 i_{11}+2p_1	l_1=s1 i_{11}+3p_1 m_1=s2 i_{12} l_2=s1 i_{11}+3p_1	l_1=s1 i_{11} m_1=s2 i_{12}+p_2 l_2=s1 i_{11} m_2=s2 i_{12}+p_2+	l_1=s1 i_{11}+p_1 m_1=s2 i_{12}+p_2 l_2=s1 i_{11}+p_1 m_2=s2 i_{12}+p_2+

	m_2=s2 i_{12}+ O_2	m_2=s2 i_{12}+ O_2	O_2	O_2

Table 2

It should be noted that Table 2 is only one example of a W_1 codebook and is only an example for a codebook where the predetermined CSI reporting configuration is set to configuration 3. Other W_1 codebooks for different configurations, such as configuration 1, configuration 2, and the like, would exist, but are not necessary for disclosure in order to adequately describe example aspects.

[0082] The codebook parameters (s_1,s_2) and (p_1,p_2) can be the same as the legacy non-linear combination codebook, for example, where (s_1,s_2) indicates beam group spacing and (p_1,p_2) indicates beam offset. Table 3 below reflects an example beam group spacing and beam offsets for W_1 codebooks of CSI reporting configurations according to various aspects of the present disclosure.

CSI Reporting Mode Configuration	(s_1,s_2)	(p_1,p_2)
1	(1,1)	(-,-)
2	$(O_1/2,O_2/2)$	$(O_1/4,O_2/4)$
3	$(O_1,O_2/2)$	$(O_1/4,O_2/4)$
4	$(O_1,O_2/4)$	$(O_1/4,-)$

Table 3

[0083] In order to control CSI overhead, various aspects of the present disclosure provide for codebook subsampling when the feedback overhead becomes excessive and reaches the available CSI capacity of PUCCH. Thus, in order to fit within the PUCCH capacity, the PMI feedback may be subsampled. For example, UE 115, under control of controller/processor 280, executes codebook subsampler 1104, stored in memory 282. Within the execution environment of codebook subsampler 1104, when the PMI feedback includes i_{11} and i_{12}, the oversampling factor may be reduced on each dimension to fit within an i_1 limit. When the PMI feedback is k_1 and k_2, the beam selection hypotheses may be reduced by UE 115. Finally, when the PMI feedback is i_2, UE 115 may subsample the W_2 by fixing the co-phase to $[0,\pi]$, for example, by changing from QPSK to BPSK, or reducing the complex coefficient.

[0084] FIG. 8 is a block diagram illustrating example blocks executed to implement one aspect of the present disclosure. The example blocks will also be described with respect to UE 115 as illustrated in FIG. 11.

[0085] At block 800, a UE performs channel quality measurements on a plurality of signals from a serving base station. As indicated with respect to the first option described in FIG. 6, the UE, such as UE 115, under control of controller/processor 280, executes measurement logic 1101, stored in memory 282, to measure the various signals received from the base station. UE 115 performs the measurements and makes estimates of signals, such as CSI-RS, received from a serving base station in order to provide various CSI feedback on the channel quality.

[0086] At block 801, the UE reports a first PMI to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of DFT beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters of a first antenna dimension. In the wideband primary beam selection of the second option, PMI feedback from the UE, such as UE 115, is associated with both precoders $\boldsymbol{W_1}$ and $\boldsymbol{W_2}$. For example, UE 115, under control of controller/processor 280, executes CSI report generator 1102, which generates the first PMI report and transmits the PMI via wireless radios 1100a-r and antennas 252a-r. For the PMI associated with $\boldsymbol{W_1}$, wideband i_{11}, i_{12}, where the value range of i_{11} and i_{12} may be dependent on the configured N_1, N_2, O_1, O_2.

[0087] At block 802, the UE reports a second PMI to the serving base station, wherein the second PMI includes first and second parameters of a second antenna dimension that identify a primary beam and a secondary beam from the grid of beams determined from the first PMI. The second PMI reported by the UE, such as UE 115, under control of controller/processor 280 executing CSI report generator 1102, reports the second PMI associated with $\boldsymbol{W_2}$ that includes a 4-bit wideband i_{21} and a 6-bit i_{22}, which may be either wideband or subband, depending on the configured reporting mode identified in predetermined CSI reporting configuration 1103, stored in memory 282. The CQI and RI feedback from UE 115 will be the same as legacy feedback.

[0088] At block 803, the UE receives precoded or beamformed transmissions from the serving base station via antennas 252a-r and wireless radios 1100a-r, wherein the precoded or beamformed transmissions are precoded based on one or more of the two DFT beams. As indicated above, the purpose of CSI feedback is for the base station to adjust its transmissions

to UE 115 in order to increase the efficiency and reliability of the communications. As the serving base station receives the CSI feedback, transmissions are adjusted to accommodate the existing channel conditions.

[0089] In the second optional aspect, a wideband primary beam selection is used in which the legacy $\boldsymbol{W_1}$ codebook may be reused along with a new $\boldsymbol{W_2}$ codebook design. The primary beam indicated by (i_{11}, i_{12}, i_{21}) may be wideband selected. For example, the first precoder, $\boldsymbol{W_1}$ may be represented according to the following equation:

$$w_1 = \begin{bmatrix} b_1 \\ e^{j\phi_1} b_1 \end{bmatrix}$$

along with a 4-bit i_{21}. The secondary beam, and also the complex weighting indicated by (i_{11}, i_{12}, i_{21}), may be selected in either widebeam or subband based on the predetermined CSI reporting mode configuration. For example, the second precoder, $\boldsymbol{W_2}$, may be represented according to the following equation:

$$w_2 = \begin{bmatrix} c \cdot b_2 \\ c \cdot e^{j\phi_2} b_2 \end{bmatrix}$$

along with a 6-bit i_{22} (assuming a QPSK based coefficient c). Both the primary and secondary beams use the same $\boldsymbol{W_1}$ precoding matrix indicated by (i_{11}, i_{12}) and may also reuse the legacy $\boldsymbol{W_1}$ codebook. The composite precoder may then be represented by a combination of the selected two beam precoders according to $w' = w_1 + w_2$, where $w = w'/\|w'\|$.

[0090] FIG. 9 is a block diagram illustrating eNB 105 and UE 115 configured according to one aspect of the present disclosure. UE 115 transmits a first PMI associated with $\boldsymbol{W_1}$ including i_{11}, i_{12} to eNB 105. eNB 105 uses i_{11}, i_{12} to identify grid of beams 900a within the beams of the antenna array of eNB 105. According to the predetermined CSI reporting configuration, the beams from which the primary and secondary beams will be selected are indicated at beams 0-3 of grid of beams 900a.

[0091] For the $\boldsymbol{W_2}$ codebook design, the second PMI feedback from UE 115 of i_2 includes i_{21} for the beam selection and co-phasing of the first primary beam, and i_{22} for the beam selection, co-phasing and coefficient of the second beam, which may be either dependent or independent of i_{21}. Thus, eNB 105 identifies secondary beam 902 out of beams 1-2 of grid of beams 900b using i_{22} and identifies primary beam 902 from beam 3 of grid of beams 900b

using i_{21}. It should be noted that when i_{22} is dependent on i_{21}, different beams may be selected for the first and second beams. The composite precoder, p, may be determined according to equation (1):

$$p = \begin{bmatrix} b_1 & b_2 \\ e^{j\phi_1} b_1 & +c\, e^{j\phi_2} b_2 \end{bmatrix}$$

where b_1 and $e^{j\phi_1} b_1$ are associated with i_{21} for the beam selection and co-phasing of the primary beam and c, b_2, and $e^{j\phi_2} b_2$ are associated with i_{22} for the beam selection, co-phasing and coefficient of the secondary beam.

[0092] The second option includes a joint $\boldsymbol{W_2}$ codebook designed for instances in which different beams are used for the linear combination. For example, when based on the lower numbered antenna ports, e.g., i_{22}=0…15 (irrespective of i_{21}), the $\boldsymbol{W_2}$ codebook may be based on beam selection and polarization co-phasing, thus, falling back to a non-linear combination codebook with 16 codewords with beam selection and co-phasing. For i_{22}=16…43, the $\boldsymbol{W_2}$ codebook may be based on a linear combination of a primary beam indicated by i_{21} and a secondary beam indicated by i_{22}. The linear combination codebook for the second option may be based on three secondary beam selection hypotheses and 16 QPSK coefficients and co-phases for a total of 48 codewords (3 * 16 = 48). Thus, the 16 codewords of the legacy non-linear combination codebook and the 48 codewords of the linear combination codebook combine into the joint $\boldsymbol{W_2}$ codebook of 64 codewords.

[0093] Table 4 below is an example $\boldsymbol{W_1}$ codebook table for configuration 3 of the second option wideband primary beam selection when i_{22}=0…15, e.g., falling back to the non-linear combination codebook according to:

$$w = \begin{bmatrix} v_{l,m} \\ e^{j\phi} v_{l,m} \end{bmatrix}$$

where index (l, m) and co-phasing ϕ are only determined by i_{11} and i_{12}, irrespective of i_{22}.

i_{22}	0	1	2	3
i_{21} = 0..15	l=s1 i_{11}+2p_1 m=s2 i_{12} ϕ=0	l=s1 i_{11}+2p_1 m=s2 i_{12} ϕ=$\pi/2$	l=s1 i_{11}+2p_1 m=s2 i_{12} ϕ=π	l=s1 i_{11}+2p_1 m=s2 i_{12} ϕ=-$\pi/2$
i_{22}	4	5	6	7

i_{21} = 0..15	l=$s1$ i_{11}+3p_1 m=$s2$ i_{12} ϕ=0	l=$s1$ i_{11}+3p_1 m=$s2$ i_{12} ϕ=π/2	l=$s1$ i_{11}+3p_1 m=$s2$ i_{12} ϕ=π	l=$s1$ i_{11}+3p_1 m=$s2$ i_{12} ϕ=-π/2
i_{22}	8	9	10	11
i_{21} = 0..15	l=$s1$ i_{11} m=$s2$ i_{12}+p_2 ϕ=0	l=$s1$ i_{11} m=$s2$ i_{12}+p_2 ϕ=π/2	l=$s1$ i_{11} m=$s2$ i_{12}+p_2 ϕ=π	l=$s1$ i_{11} m=$s2$ i_{12}+p_2 ϕ=-π/2
i_{22}	12	13	14	15
i_{21} = 0..15	l=$s1$ i_{11}+p_1 m=$s2$ i_{12}+p_2 ϕ=0	l=$s1$ i_{11}+p_1 m=$s2$ i_{12}+p_2 ϕ=π/2	l=$s1$ i_{11}+p_1 m=$s2$ i_{12}+p_2 ϕ=π	l=$s1$ i_{11}+p_1 m=$s2$ i_{12}+p_2 ϕ=π

Table 4

It should be noted that Table 4 is only one example of a $\boldsymbol{W_1}$ codebook for the second option of the present disclosure and is only an example for a codebook where the predetermined CSI reporting configuration is set to configuration 3. Other $\boldsymbol{W_1}$ codebooks for the second option that reflect different configurations, such as configuration 1, configuration 2, and the like, would exist, but are not necessary for disclosure in order to adequately describe example aspects.

[0094] Table 5 below is an example codebook table for configuration 3 of the second option wideband primary beam selection when i_{22}=16…63 , with a linear combination codebook according to:

$$w = \begin{bmatrix} v_{l_1,m_1} & c \cdot v_{l_2,m_2} \\ e^{j\phi_1} v_{l_1,m_1} & c \cdot e^{j\phi_2} v_{l_2,m_2} \end{bmatrix}$$

where $\phi_1 \in \left[0, \frac{\pi}{2}, \pi, -\frac{\pi}{2}\right]$ and is based on i_{21}, $\phi_2 \in \left[0, \frac{\pi}{2}, \pi, -\frac{\pi}{2}\right]$, and $c \in [1, -1, j, -j]$ and is based on i_{22}.

i_{22}	16 … 31	32 … 47	48 … 63
i_{21} = 0..3	l_1=$s1$ i_{11}+2p_1 m_1=$s2$ i_{12} l_2=$s1$ i_{11} m_2=$s2$ i_{12}+p_2	l_1=$s1$ i_{11}+2p_1 m_1=$s2$ i_{12} l_2=$s1$ i_{11}+p_1 m_2=$s2$ i_{12}+p_2	l_1=$s1$ i_{11}+2p_1 m_1=$s2$ i_{12} l_2=$s1$ i_{11}+3p_1 m_2=$s2$ i_{12}

i_{22}	16 … 31	32 … 47	48 … 63
i_{21} = 4..7	$l_1=s1\ i_{11}+3p_1$ $m_1=s2\ i_{12}$ $l_2=s1\ i_{11}$ $m_2=s2\ i_{12}$	$l_1=s1\ i_{11}+3p_1$ $m_1=s2\ i_{12}$ $l_2=s1\ i_{11}+p_1$ $m_2=s2\ i_{12}+p_2$	$l_1=s1\ i_{11}+3p_1$ $m_1=s2\ i_{12}$ $l_2=s1\ i_{11}+2p_1$ $m_2=s2\ i_{12}$
i_{22}	16 … 31	32 … 47	48 … 63
i_{21} = 8..11	$l_1=s1\ i_{11}$ $m_1=s2\ i_{12}+p_2$ $l_2=s1\ i_{11}+p_1$ $m_2=s2\ i_{12}+p_2$	$l_1=s1\ i_{11}$ $m_1=s2\ i_{12}+p_2$ $l_2=s1\ i_{11}+2p_1$ $m_2=s2\ i_{12}$	$l_1=s1\ i_{11}$ $m_1=s2\ i_{12}+p_2$ $l_2=s1\ i_{11}+3p_1$ $m_2=s2\ i_{12}$
i_{22}	16 … 31	32 … 47	48 … 63
i_{21} = 12..15	$l_1=s1\ i_{11}+p_1$ $m_1=s2\ i_{12}+p_2$ $l_2=s1\ i_{11}$ $m_2=s2\ i_{12}+p_2$	$l_1=s1\ i_{11}+p_1$ $m_1=s2\ i_{12}+p_2$ $l_2=s1\ i_{11}+2p_1$ $m_2=s2\ i_{12}$	$l_1=s1\ i_{11}+p_1$ $m_1=s2\ i_{12}+p_2$ $l_2=s1\ i_{11}+3p_1$ $m_2=s2\ i_{12}$

Table 5

It should be noted that Table 5 is only one example of a codebook for the second option of the present disclosure and is only an example for a codebook where the predetermined CSI reporting configuration is set to configuration 3. Other codebooks for the second option that reflect different configurations, such as configuration 1, configuration 2, and the like, would exist, but are not necessary for disclosure in order to adequately describe example aspects.

[0095] When feedback overhead becomes excessive and reaches the PUCCH upper bound, subsampling of certain PMI according to the second option may be performed in order to fit PUCCH overhead. For example, UE 115, under control of controller/processor 280, executes codebook subsampler 1104, stored in memory 282. Within the execution environment of codebook subsampler 1104, when the PMI feedback is i_{11}, the oversampling factor may be reduced on each dimension to fit within an i_1 limit. When the PMI feedback is i_{21} or i_{22}, either the beam selection hypotheses may be reduced or the co-phase may be reduced by UE 115, such as by changing from QPSK to BPSK. Furthermore, UE 115 may fix i_{21} at 0 and, thus, not reported, while UE 115 may fall back to the legacy non-linear combination codebook, with the fall back feedback and restriction of $i_{22} < 16$.

[0096] FIG. 10 is a block diagram illustrating example blocks executed to implement one aspect of the present disclosure. The example blocks will also be described with respect to UE 115 as illustrated in FIG. 11.

[0097] At block 1000, a UE performs channel quality measurements on a plurality of signals from a serving base station. As indicated with respect to the first and second options described in FIGs. 6 and 8, the UE, such as UE 115, under control of controller/processor 280, executes measurement logic 1101, stored in memory 282, to measure the various signals received from the base station in order to provide various CSI feedback on the channel quality.

[0098] At block 1001, the UE reports a first PMI to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of DFT beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters of a first antenna dimension. The subband beam pair selection may also reuse the legacy $\boldsymbol{W_1}$ codebook along with a new $\boldsymbol{W_2}$ codebook design. The first PMI (i_{11}, i_{12}) associated with $\boldsymbol{W_1}$ and transmitted by the UE, such as UE 115, may determine a set of four DFT beams according to the codebook set parameter of selected CSI reporting configuration 1103, stored in memory 282. For example, UE 115, under control of controller/processor 280, executes CSI report generator 1102, which generates the first PMI report with the four DFT beams and transmits the PMI via wireless radios 1100a-r and antennas 252a-r.

[0099] At block 1002, the UE reports a second PMI to the serving base station, wherein the second PMI includes a first parameter of a second antenna dimension that provides beam selection of two DFT beams from the grid of beams, complex coefficient, and a common co-phasing for the two DFT beams. In the third optional aspect, a subband beam pair selection is made using a common co-phasing ($\phi_1 = \phi_2$). The second PMI, associated with $\boldsymbol{W_2}$ and transmitted by UE 115 via wireless radios 1100a-r and antennas 252a-r, under control of controller/processor 280 executing CSI report generator 1102, may be a 6-bit i_2 which performs beam pair selection, weighting, and co-phasing, using a common co-phase. The third optional aspect of the present disclosure includes four beam pair selection, e.g., (δ_1,δ_2) = (0, 1), (1, 2), (0, 3), and (1, 3), four QPSK co-phasing hypotheses, and four QPSK based complex weighting. The PMI parameters (i_{11}, i_{12}, i_{21}) associated with the $\boldsymbol{W_1}$ and $\boldsymbol{W_2}$ codebooks jointly indicate a linear combination precoding vector with a common polarization

co-phasing ($\phi_1 = \phi_2$). The CQI and RI feedback are the same as in the legacy feedback. The composite precoder, p, for the third option may be determined according to the following equation:

$$p = \begin{bmatrix} b_1 + cb_2 \\ e^{j\phi}(b_1 + cb_2) \end{bmatrix}$$

and

$$w = \frac{p}{\|p\|}$$

[00100] At block 1003, the UE receives precoded or beamformed transmissions from the serving base station via antennas 252a-r and wireless radios 1100a-r, wherein the precoded or beamformed transmissions are precoded based on a linear combination of the two DFT beams. As indicated above, the purpose of CSI feedback is for the base station to adjust its transmissions to UE 115 in order to increase the efficiency and reliability of the communications. As the serving base station receives the CSI feedback, transmissions are adjusted to accommodate the existing channel conditions.

[00101] Table 6 below is an example codebook for the configuration 4 of the third option of subband beam pair selection. (l_1, m_1) and (l_2, m_2) are the associated beam indices for the selected beam pair (b_1, b_2), where $\phi \in \left[0, \frac{\pi}{2}, \pi, -\frac{\pi}{2}\right]$, $c \in [1, -1, j, -j]$ and are based on i_2.

i_2	0 … 15	16 … 31	32 … 47	48 … 64
i_{11} i_{12}	l_1=s1 i_{11} m_1=s2 i_{12} l_2=s1 i_{11}+p_1 m_2=s2 i_{12}	l_1=s1 i_{11}+p_1 m_1=s2 i_{12} l_2=s1 i_{11}+2p_1 m_2=s2 i_{12}	l_1=s1 i_{11} m_1=s2 i_{12} l_2=s1 i_{11}+3p_1 m_2=s2 i_{12}	l_1=s1 i_{11}+p_1 m_1=s2 i_{12} l_2=s1 i_{11}+3p_1 m_2=s2 i_{12}

Table 6

It should be noted that Table 6 is only one example of a codebook for the third option of the present disclosure and is only an example for a codebook where the predetermined CSI reporting configuration is set to configuration 4. Other codebooks for the second option that reflect different configurations, such as configuration 1, configuration 2, and the like, would exist, but are not necessary for disclosure in order to adequately describe example aspects.

[00102] For the PMI associated with W_1, wideband i_{11}, i_{12}, are fed back by UE 115, where the value range of i_{11} and i_{12} may be dependent on the configured N_1, N_2, O_1, O_2. For the PMI associated with W_2, a 6-bit i_{12}, which may be either wideband or subband based on configured reporting mode, is fed back by UE 115.

[00103] When feedback overhead becomes excessive in the third option and reaches the CSI feedback capacity of PUCCH, UE 115 may subsample certain PMI in order to fit within the available PUCCH CSI overhead. For example, UE 115, under control of controller/processor 280, executes codebook subsampler 1104, stored in memory 282. Within the execution environment of codebook subsampler 1104, when the PMI feedback is i_{11} and $i_{12,}$ the oversampling factor may be reduced on each dimension to fit within an i_1 limit. When the PMI feedback is i_2, either the beam selection hypotheses may be reduced by UE 115, for example from 4 to 2, or the co-phase may be reduced, such as by changing from QPSK to BPSK.

[00104] It should be noted that, in cases where the linear combination codebook may be intended for multi-user MIMO (MU-MIMO) precoder calculation (transmitter side nulling), there would be no need to supported a high rank codebook design for a linear combination codebook. In such aspects, the eNB may fall back to the Rel. 13 class A high rank codebook if needed.

[00105] Additionally, the linear combination codebook can be also extended to class B beamformed CSI-RS with K=1 (single CSI-RS resource) by setting $i_{11} = i_{12,} = 0$ (which results in no reporting of For example, UE 115, under control of controller/processor 280, executes codebook subsampler 1104, stored in memory 282. Within the execution environment of codebook subsampler 1104, Additionally, $v_{l,m} = e^{(N_p/2)}_{\mathrm{mod}(l,\frac{N_p}{2})}$, where $e_i^{(N)}$ is a length-N selection vector with '1' on the i^{th} element, and '0' on the other elements. N_p is the number of antenna ports for BF CSI-RS. The determination of beam index (l_1, m_1) and (l_2, m_2) is the same as the codebook table for configuration 4 for the non-precoded CSI-RS. The options for the first and second PMI are provided in the following table 7.

	Option 1	Option 2	Option 3
1st PMI	Wideband feedback of k_1 and k_2	Not reported	Not reported

2nd PMI	Wideband/subband feedback i_2	Wideband feedback i_{21} Wideband/subband feedback i_{22}	Wideband/subband feedback i_2

Table 7

[00106] FIG. 12 is a block diagram illustrating eNB 105 configured according to one aspect of the present disclosure. eNB 105 includes the structure, hardware, and components as illustrated for eNB 105 of FIG. 2. For example, eNB 105 includes controller/processor 240, which operates to execute logic or computer instructions stored in memory 242, as well as controlling the components of eNB 105 that provide the features and functionality of eNB 105. eNB 105, under control of controller/processor 240, transmits and receives signals via wireless radios 1200a-t and antennas 234a-t. Wireless radios 1200a-t includes various components and hardware, as illustrated in FIG. 2 for eNB 105, including modulator/demodulators 232a-t, MIMO detector 236, receive processor 238, transmit processor 220, and TX MIMO processor 230.

[00107] For operating in accordance with the enhanced linear combination codebook, eNB 105 may receive CSI feedback from a served UE via antennas 234a-t and wireless radios 1200a-t. eNB 105 stores the received feedback at CSI feedback 1201 in memory 242. As the higher layers determine to change the predetermined CSI reporting mode configuration, the network would signal both eNB 105 and UE 115. eNB 105 stores the configuration at CSI reporting configuration 1202 in memory 242. After receiving a first PMI from a UE, eNB 105 executes beam configuration 1203, under control of controller/processor 242, to form the grid of beams based on the dimension parameters included in the first PMI. Depending on the option being run, either a PMI of i_{11} and $i_{12,}$ may be used with the collection of beams to form a grid of beams from which the DFT beams for combination may be selected. eNB 105, under control of controller/processor 240, executes beam configuration 1203, stored in memory 242, to form the grid of beams with the fed back i_{11} and $i_{12,}$ and in consideration of the CSI reporting configuration 1202. The second and third options reuse the legacy $\boldsymbol{W_1}$ codebook with to create the grid of beams. In the first option, i_{11} and $i_{12,}$ is used in addition to k_1 and the CSI reporting configuration 1202 to specifically select the two DFT beams for the linear combination.

[00108] Once the two DFT beams have been selected by either of the options, eNB 105, under control of controller/processor 240, executes CSI-RS generator to generate a CSI-RS using

the high resolution CSI received from the UE via antennas 234a-t and wireless radios 1200a-t. eNB 105, under control of controller/processor 240 operates the linear combination feedback and adjusts the transmission characteristics of the CSI-RS according to the feedback before transmitting via mobile radios 1200a-t and antennas 234a-t.

[00109] FIGs. 13A and 13B are block diagrams illustrating eNB 105 and UE 115 configured according to various aspects of the present disclosure for providing non-linear combination type codebooks. For non-linear combination type codebooks with up to 32 CSI-RS ports, two feedback options are presented. In a first non-linear combination codebook option, as illustrated in FIG. 13A, UE 115 transmits a first PMI associated with $\boldsymbol{W_1}$ to eNB 105, the first PMI includes i_{11}, i_{12}, k, where i_{11}, i_{12} defines the index of the grid of beams, k defines the beam offset within the grid of beams (p_1,p_2). In this first non-linear option, i_{11}, i_{12},and k are wideband feedback.

[00110] The codebook parameters (s_1,s_2) and (p_1,p_2) can be the same as the legacy codebook, for example, where (s_1,s_2) indicates beam group spacing and (p_1,p_2) indicates beam offset. Grid of beam size (L_1,L_2) and k jointly determine the value of (p_1,p_2) as illustrated in configurations 1300-1303. Table 8 below shows an example beam group spacings and beam offsets for $\boldsymbol{W_1}$ codebooks of codebook configurations according to various aspects of the present disclosure.

Codebook Configuration	(s_1,s_2)	(p_1,p_2)			
		$(L_1>=L_2)$		$(L_1<L_2)$	
		k=0	k=1	k=0	k=1
1	(1,1)	(-,-)	(-,-)	(-,-)	(-,-)
2	(2,2)	(1,1)	(2,1)	(1,1)	(1,2)
3	(2,2)	(1,1)	(2,1)	(1,1)	(1,2)
4	(2,2)	(1,1)	(2,1)	(1,1)	(1,2)

Table 8

[00111] In the second non-linear option, as illustrated in FIG. 13B, UE 115 transmits a first PMI associated with $\boldsymbol{W_1}$ to eNB 105, the first PMI includes i_{11}, i_{12}, where i_{11}, i_{12} defines the index of the grid of beams the beam selected from the grid of beams is dependent on the particular configuration, as illustrated in configurations 1304-1305. For example, when Config = 5, configuration 5 1304, beams with index of (0,1,2,3) are selected from figure.

When Config = 6, configuration 6 1305, beams with index of (0,1,2,3) are selected. (s_1,s_2) = (2,2), (p_1,p_2) = (1,1) are used for both of the newly-defined configurations, configuration 5 and configuration 6.

[00112] The present disclosure comprises a first aspect, such as a non-transitory computer-readable medium having program code recorded thereon, the program code comprising:

program code for causing a computer to perform channel state information (CSI) measurements on a plurality of signals received from a serving base station;

program code for causing the computer to report a first precoding matrix indicator (PMI) to the serving base station, wherein the first PMI includes a plurality of wideband parameters that identify two discrete Fourier transform (DFT) beams for a linear combination, wherein the two DFT beams are selected from a plurality of DFT beams forming the plurality of signals;

program code for causing the computer to report a second PMI to the serving base station, wherein the second PMI includes a complex coefficient weighting and co-phasing for the linear combination of the identified two DFT beams; and

program code for causing the computer to receive precoded transmissions from the serving base station, wherein the precoded transmissions are precoded using the linear combination of the two DFT beams.

[00113] Based on the first aspect, the non-transitory computer-readable medium of a second aspect, wherein the plurality of wideband parameters are jointly coded in the first PMI.

[00114] Based on the first aspect, the non-transitory computer-readable medium of a third aspect, wherein the plurality of wideband parameters of the first PMI includes wideband parameters identifying one of: two non-orthogonal beams, two orthogonal beams on a first antenna dimension, and two orthogonal beams on a second antenna dimension.

[00115] Based on the first aspect, the non-transitory computer-readable medium of a fourth aspect, wherein the plurality of wideband parameters of the first PMI are dependent on a number of ports in first and second dimensions of an antenna array and an oversampling rate per first and second dimensions.

[00116] Based on the first aspect, the non-transitory computer-readable medium of a fifth aspect, further including:

program code for causing the computer to detect feedback overhead exceeding an overhead limit on physical uplink control channel (PUCCH);

program code, executable in response to the feedback overhead exceeding the overhead limit, one of:

for causing the computer to subsample the first PMI by reducing a related oversampling factor;

for causing the computer to reduce a beam selection hypothesis of the first PMI; or

for causing the computer to subsample the second PMI by fixing a first co-phasing to 0 and a second co-phasing to π.

[00117] Based on the first aspect, the non-transitory computer-readable medium of a sixth, wherein the precoded transmissions are precoded using the linear combination in response to a rank being less than 3, and wherein the precoded transmissions are precoded using a non-linear combination beam selection of one of the two DFT beams in response to the rank being greater than or equal to 3.

[00118] Based on the first aspect, the non-transitory computer-readable medium of a seventh, wherein the plurality of signals are a plurality of beamformed channel state information (CSI) reference signals (CSI-RS), and wherein the plurality of wideband parameters of the first PMI include wideband beam pair combination parameters.

[00119] An eighth aspect of the non-transitory computer-readable medium of any combination of the first through seventh aspects.

[00120] The present disclosure comprises a ninth aspect, such as a non-transitory computer-readable medium having program code recorded thereon, the program code comprising:

program code for causing a computer to perform channel state information (CSI) on a plurality of signals from a serving base station;

program code for causing the computer to report a first precoding matrix indicator (PMI) to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of discrete Fourier transform (DFT) beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters;

program code for causing the computer to report a second PMI to the serving base station, wherein the second PMI includes first and second parameters that identify a primary beam and a secondary beam from the grid of beams determined from the first PMI; and

program code for causing the computer to receive precoded transmissions from the serving base station, wherein the precoded transmissions are precoded based on one or more of the two DFT beams.

[00121] Based on the ninth aspect, the non-transitory computer-readable medium of a tenth aspect, wherein the first and second parameters of the second PMI are one of: wideband or

subband, based on a predetermined CSI reporting mode configuration, wherein the first parameter identifies beam selection and co-phasing of the primary beam, and wherein the second parameter identifies beam selection, co-phasing, and complex coefficient of the secondary beam.

[00122] Based on the ninth aspect, the non-transitory computer-readable medium of an eleventh, wherein the plurality of wideband parameters of the first PMI are dependent on a number of ports in first and second dimensions of an antenna array and an oversampling rate per first and second dimensions.

[00123] Based on the ninth aspect, the non-transitory computer-readable medium of a twelfth, wherein the second parameter is one of: independent from or dependent on the first parameter.

[00124] Based on the twelfth aspect, the non-transitory computer-readable medium of a thirteenth aspect, wherein the second parameter is dependent on the first parameter, wherein the precoded transmissions are precoded based on a linear combination of the two DFT beams.

[00125] Based on the twelfth aspect, the non-transitory computer-readable medium of a fourteenth aspect, wherein the second parameter is independent of the first parameter, wherein the precoded transmissions are precoded based on a non-linear combination beam selection of one of the two DFT beams.

[00126] Based on the fourteenth aspect, the non-transitory computer-readable medium of fifteenth, wherein the precoded transmissions are precoded based on the non-linear combination beam selection of one of the two DFT beams when the second parameter is below a predefined threshold, and wherein the precoded transmissions are precoded based on the linear combination when the second parameter is greater than or equal to the predefined threshold.

[00127] Based on the ninth aspect, the non-transitory computer-readable medium of a sixteenth aspect, further including:

program code for causing the computer to detect feedback overhead exceeding an overhead limit on physical uplink control channel (PUCCH);

program code, executable in response to the feedback overhead exceeding the overhead limit, one of:

for causing the computer to subsample the first PMI by reducing a related oversampling factor on each antenna dimension;

for causing the computer to reduce a beam selection hypothesis of the second PMI;

for causing the computer to subsample the second PMI by fixing a first co-phasing to 0 and a second co-phasing to π; or

for causing the computer to fix the first parameter to 0 and restricting selection of the second parameter to antenna ports below the predefined threshold.

[00128] Based on the ninth aspect, the non-transitory computer-readable medium of a seventeenth aspect, wherein the precoded transmissions are precoded using the linear combination in response to a rank being less than 3, and wherein the precoded transmissions are precoded using a non-linear combination beam selection of one of the two DFT beams in response to the rank being greater than or equal to 3.

[00129] Based on the ninth aspect, the non-transitory computer-readable medium of an eighteenth aspect, wherein the plurality of signals are a plurality of beamformed channel state information (CSI) reference signals (CSI-RS), and wherein the second PMI includes a wideband first parameter that identifies beam selection and co-phasing of the primary beam and the second parameter that identifies beam selection, co-phasing, and complex coefficient of the secondary beam.

[00130] A nineteenth aspect of the present disclosure includes a non-transitory computer-readable medium of any combination of the ninth through eighteenth aspects.

[00131] The present disclosure comprises a twentieth aspect, such as a non-transitory computer-readable medium having program code recorded thereon, the program code comprising:

program code for causing a computer to perform channel state information (CSI) measurements on a plurality of signals from a serving base station;

program code for causing the computer to report a first precoding matrix indicator (PMI) to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of discrete Fourier transform (DFT) beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters;

program code for causing the computer to report a second PMI to the serving base station, wherein the second PMI includes a first parameter that provides beam selection of two DFT beams from the grid of beams, complex coefficient, and a common co-phasing for the two DFT beams; and

program code for causing the computer to receive precoded transmissions from the serving base station, wherein the precoded transmissions are precoded based on a linear combination of the two DFT beams.

[00132] Based on the twentieth aspect, the non-transitory computer-readable medium of a twenty-first aspect, wherein the plurality of wideband parameters of the first PMI are dependent on a number of ports in first and second dimensions of an antenna array and an oversampling rate per first and second dimensions.

[00133] Based on the twentieth aspect, the non-transitory computer-readable medium of a twenty-second aspect, wherein the second PMI is one of: wideband or subband, based on a predetermined CSI reporting mode configuration.

[00134] Based on the twentieth aspect, the non-transitory computer-readable medium of a twenty-third aspect, further including:

program code for causing the computer to detect feedback overhead exceeding an overhead limit on physical uplink control channel (PUCCH);

program code, executable in response to the feedback overhead exceeding the overhead limit, one of:

for causing the computer to subsample the first PMI by reducing a related oversampling factor on each antenna dimension;

for causing the computer to reduce a beam selection hypothesis of the second PMI; or

for causing the computer to subsample the second PMI by fixing a first co-phasing to 0 and a second co-phasing to π.

[00135] Based on the twentieth aspect, the non-transitory computer-readable medium of a twenty-fourth aspect, wherein the precoded transmissions are precoded using the linear combination in response to a rank being less than 3, and wherein the precoded transmissions are precoded using a non-linear combination beam selection of one of the two DFT beams in response to the rank being greater than or equal to 3.

[00136] Based on the twentieth aspect, the non-transitory computer-readable medium of a twenty-fifth aspect, wherein the plurality of signals are a plurality of beamformed channel state information (CSI) reference signals (CSI-RS), and wherein the first PMI is not reported.

[00137] A twenty-sixth aspect of the non-transitory computer-readable medium includes any combination of the twentieth through twenty-fifth aspects.

[00138] The present disclosure comprises a twenty-seventh aspect, such as an apparatus configured for wireless communication, the apparatus comprising:

at least one processor; and

a memory coupled to the at least one processor,

wherein the at least one processor is configured:

to perform channel state information (CSI) measurements on a plurality of signals received from a serving base station;

to report a first precoding matrix indicator (PMI) to the serving base station, wherein the first PMI includes a plurality of wideband parameters that identify two discrete Fourier transform (DFT) beams for a linear combination, wherein the two DFT beams are selected from a plurality of DFT beams forming the plurality of signals;

to report a second PMI to the serving base station, wherein the second PMI includes a complex coefficient weighting and co-phasing for the linear combination of the identified two DFT beams; and

to receive precoded transmissions from the serving base station, wherein the precoded transmissions are precoded using the linear combination of the two DFT beams.

[00139] Based on the twenty-seventh aspect, the apparatus of a twenty-eighth aspect, wherein the plurality of wideband parameters are jointly coded in the first PMI.

[00140] Based on the twenty-seventh aspect, the apparatus of a twenty-ninth aspect, wherein the plurality of wideband parameters of the first PMI includes wideband parameters identifying one of: two non-orthogonal beams, two orthogonal beams on a first antenna dimension, and two orthogonal beams on a second antenna dimension.

[00141] Based on the twenty-seventh aspect, the apparatus of a thirtieth aspect, wherein the plurality of wideband parameters of the first PMI are dependent on a number of ports in first and second dimensions of an antenna array and an oversampling rate per first and second dimensions.

[00142] Based on the twenty-seventh aspect, the apparatus of a thirty-first aspect, further including configuration of the at least one processor:

to detect feedback overhead exceeding an overhead limit on physical uplink control channel (PUCCH);

to, in response to the feedback overhead exceeding the overhead limit, one of:

subsample the first PMI by reducing a related oversampling factor;

reduce a beam selection hypothesis of the first PMI; or

subsample the second PMI by fixing a first co-phasing to 0 and a second co-phasing to π.

[00143] Based on the twenty-seventh aspect, the apparatus of a thirty-second aspect, wherein the precoded transmissions are precoded using the linear combination in response to a rank being less than 3, and wherein the precoded transmissions are precoded using a non-linear

combination beam selection of one of the two DFT beams in response to the rank being greater than or equal to 3.

[00144] Based on the twenty-seventh aspect, the apparatus of a thirty-third aspect, wherein the plurality of signals are a plurality of beamformed channel state information (CSI) reference signals (CSI-RS), and wherein the plurality of wideband parameters of the first PMI include wideband beam pair combination parameters.

[00145] A thirty-fourth aspect of the present disclosure includes an apparatus of any combination of the twenty-seventh through thirty-third aspects.

[00146] The present disclosure comprises a thirty-fifth aspect, such as an apparatus configured for wireless communication, the apparatus comprising:

at least one processor; and

a memory coupled to the at least one processor,

wherein the at least one processor is configured:

to perform channel state information (CSI) on a plurality of signals from a serving base station;

to report a first precoding matrix indicator (PMI) to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of discrete Fourier transform (DFT) beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters;

to report a second PMI to the serving base station, wherein the second PMI includes first and second parameters that identify a primary beam and a secondary beam from the grid of beams determined from the first PMI; and

to receive precoded transmissions from the serving base station, wherein the precoded transmissions are precoded based on one or more of the two DFT beams.

[00147] Based on the thirty-fifth aspect, the apparatus of a thirty-sixth aspect, wherein the first and second parameters of the second PMI are one of: wideband or subband, based on a predetermined CSI reporting mode configuration, wherein the first parameter identifies beam selection and co-phasing of the primary beam, and wherein the second parameter identifies beam selection, co-phasing, and complex coefficient of the secondary beam.

[00148] Based on the thirty-fifth aspect, the apparatus of a thirty-seventh aspect, wherein the plurality of wideband parameters of the first PMI are dependent on a number of ports in first and second dimensions of an antenna array and an oversampling rate per first and second dimensions.

[00149] Based on the thirty-fifth aspect, the apparatus of a thirty-eighth aspect, wherein the second parameter is one of: independent from or dependent on the first parameter.

[00150] Based on the thirty-eighth aspect, the apparatus of a thirty-ninth aspect, wherein the second parameter is dependent on the first parameter, wherein the precoded transmissions are precoded based on a linear combination of the two DFT beams.

[00151] Based on the thirty-eighth aspect, the apparatus of a fortieth aspect, wherein the second parameter is independent of the first parameter, wherein the precoded transmissions are precoded based on a non-linear combination beam selection of one of the two DFT beams.

[00152] Based on the fortieth aspect, the apparatus of a forty-first aspect, wherein the precoded transmissions are precoded based on the non-linear combination beam selection of one of the two DFT beams when the second parameter is below a predefined threshold, and wherein the precoded transmissions are precoded based on the linear combination when the second parameter is greater than or equal to the predefined threshold.

[00153] Based on the thirty-fifth aspect, the apparatus of a forty-second aspect, further including configuration of the at least one processor:

to detect feedback overhead exceeding an overhead limit on physical uplink control channel (PUCCH);

to, executable in response to the feedback overhead exceeding the overhead limit, one of:

subsample the first PMI by reducing a related oversampling factor on each antenna dimension;

reduce a beam selection hypothesis of the second PMI;

subsample the second PMI by fixing a first co-phasing to 0 and a second co-phasing to π; or

fix the first parameter to 0 and restricting selection of the second parameter to antenna ports below the predefined threshold.

[00154] Based on the thirty-fifth aspect, the apparatus of forty-third aspect, wherein the precoded transmissions are precoded using the linear combination in response to a rank being less than 3, and wherein the precoded transmissions are precoded using a non-linear combination beam selection of one of the two DFT beams in response to the rank being greater than or equal to 3.

[00155] Based on the thirty-fifth aspect, the apparatus of a forty-fourth aspect, wherein the plurality of signals are a plurality of beamformed channel state information (CSI) reference signals (CSI-RS), and wherein the second PMI includes a wideband first parameter that

identifies beam selection and co-phasing of the primary beam and the second parameter that identifies beam selection, co-phasing, and complex coefficient of the secondary beam.

[00156] A forty-fifth aspect includes an apparatus of any combination of the thirty-fifth through forty-fourth aspects.

[00157] The present disclosure comprises a forty-sixth aspect, such as an apparatus configured for wireless communication, the apparatus comprising:

at least one processor; and

a memory coupled to the at least one processor,

wherein the at least one processor is configured:

to perform channel state information (CSI) measurements on a plurality of signals from a serving base station;

to report a first precoding matrix indicator (PMI) to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of discrete Fourier transform (DFT) beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters;

to report a second PMI to the serving base station, wherein the second PMI includes a first parameter that provides beam selection of two DFT beams from the grid of beams, complex coefficient, and a common co-phasing for the two DFT beams; and

to receive precoded transmissions from the serving base station, wherein the precoded transmissions are precoded based on a linear combination of the two DFT beams.

[00158] Based on the forty-sixth aspect, the apparatus of a forty-seventh aspect, wherein the plurality of wideband parameters of the first PMI are dependent on a number of ports in first and second dimensions of an antenna array and an oversampling rate per first and second dimensions.

[00159] Based on the forty-sixth aspect, the apparatus of a forty-eighth aspect, wherein the second PMI is one of: wideband or subband, based on a predetermined CSI reporting mode configuration.

[00160] Based on the forty-sixth aspect, the apparatus of a forty-ninth aspect, further including configuration of the at least one processor:

to detect feedback overhead exceeding an overhead limit on physical uplink control channel (PUCCH);

to, executable in response to the feedback overhead exceeding the overhead limit, one of:

subsample the first PMI by reducing a related oversampling factor on each antenna dimension;

reduce a beam selection hypothesis of the second PMI; or

subsample the second PMI by fixing a first co-phasing to 0 and a second co-phasing to π.

[00161] Based on the forty-sixth aspect, the apparatus of a fiftieth aspect, wherein the precoded transmissions are precoded using the linear combination in response to a rank being less than 3, and wherein the precoded transmissions are precoded using a non-linear combination beam selection of one of the two DFT beams in response to the rank being greater than or equal to 3.

[00162] Based on the forty-sixth aspect, the apparatus of a fifty-first aspect, wherein the plurality of signals are a plurality of beamformed channel state information (CSI) reference signals (CSI-RS), and wherein the first PMI is not reported.

[00163] A fifty-second aspect of the present disclosure includes an apparatus of any combination of the forty-sixth through fifty-first aspects.

[00164] Those of skill in the art would understand that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

[00165] The functional blocks and modules described herein may comprise processors, electronics devices, hardware devices, electronics components, logical circuits, memories, software codes, firmware codes, etc., or any combination thereof.

[00166] Those of skill would further appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the disclosure herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware 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 or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present disclosure. Skilled artisans will also

readily recognize that the order or combination of components, methods, or interactions that are described herein are merely examples and that the components, methods, or interactions of the various aspects of the present disclosure may be combined or performed in ways other than those illustrated and described herein.

[00167] The various illustrative logical blocks, modules, and circuits described in connection with the disclosure herein may be implemented or performed with 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, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general-purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may 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 such configuration.

[00168] The steps of a method or algorithm described in connection with the disclosure herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An exemplary storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a user terminal. In the alternative, the processor and the storage medium may reside as discrete components in a user terminal.

[00169] In one or more exemplary designs, the functions described may be implemented through computer-executable instructions in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. Computer-readable storage media may be any available media that can be accessed by a general purpose or special purpose computer. By way of example, and not limitation, such computer-readable media can comprise 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 carry or store desired program code means in the form of instructions or data structures and that can be accessed by a general-purpose or special-purpose computer, or a general-purpose or special-purpose processor. Also, a connection may be properly termed a computer-readable medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, or digital subscriber line (DSL), then the coaxial cable, fiber optic cable, twisted pair, or DSL, are included in the definition of medium. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

[00170] As used herein, including in the claims, the term "and/or," when used in a list of two or more items, means that any one of the listed items can be employed by itself, or any combination of two or more of the listed items can be employed. For example, if a composition is described as containing components A, B, and/or C, the composition can contain A alone; B alone; C alone; A and B in combination; A and C in combination; B and C in combination; or A, B, and C in combination. Also, as used herein, including in the claims, "or" as used in a list of items prefaced by "at least one of" indicates a disjunctive list such that, for example, a list of "at least one of A, B, or C" means A or B or C or AB or AC or BC or ABC (i.e., A and B and C) or any of these in any combination thereof.

[00171] The previous description of the disclosure is provided to enable any person skilled in the art to make or use the disclosure. Various modifications to the disclosure will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other variations without departing from the spirit or scope of the disclosure. Thus, the disclosure is not intended to be limited to the examples and designs described herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

[00172] **WHAT IS CLAIMED IS:**

CLAIMS

1. A method of wireless communication, comprising:

performing channel state information (CSI) measurements on a plurality of signals received from a serving base station;

reporting a first precoding matrix indicator (PMI) to the serving base station, wherein the first PMI includes a plurality of wideband parameters that identify two discrete Fourier transform (DFT) beams for a linear combination, wherein the two DFT beams are selected from a plurality of DFT beams forming the plurality of signals;

reporting a second PMI to the serving base station, wherein the second PMI includes a complex coefficient weighting and co-phasing for the linear combination of the identified two DFT beams; and

receiving precoded transmissions from the serving base station, wherein the precoded transmissions are precoded using the linear combination of the two DFT beams.

2. The method of claim 1, wherein the plurality of wideband parameters are jointly coded in the first PMI.

3. The method of claim 1, wherein the plurality of wideband parameters of the first PMI includes wideband parameters identifying one of: two non-orthogonal beams, two orthogonal beams on a first antenna dimension, and two orthogonal beams on a second antenna dimension.

4. The method of claim 1, wherein the plurality of wideband parameters of the first PMI are dependent on a number of ports in first and second dimensions of an antenna array and an oversampling rate per first and second dimensions.

5. The method of claim 1, further including:

detecting feedback overhead exceeding an overhead limit on physical uplink control channel (PUCCH);

in response to the feedback overhead exceeding the overhead limit, one of:

subsampling the first PMI by reducing a related oversampling factor;

reducing a beam selection hypothesis of the first PMI; or

subsampling the second PMI by fixing a first co-phasing to 0 and a second co-phasing to π.

6. The method of claim 1, wherein the precoded transmissions are precoded using the linear combination in response to a rank being less than 3, and wherein the precoded transmissions are precoded using a non-linear combination beam selection of one of the two DFT beams in response to the rank being greater than or equal to 3.

7. The method of claim 1, wherein the plurality of signals are a plurality of beamformed channel state information (CSI) reference signals (CSI-RS), and wherein the plurality of wideband parameters of the first PMI include wideband beam pair combination parameters.

8. The method of any combination of claims 1-7.

9. A method of wireless communication, comprising:

performing channel state information (CSI) on a plurality of signals from a serving base station;

reporting a first precoding matrix indicator (PMI) to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of discrete Fourier transform (DFT) beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters;

reporting a second PMI to the serving base station, wherein the second PMI includes first and second parameters that identify a primary beam and a secondary beam from the grid of beams determined from the first PMI; and

receiving precoded transmissions from the serving base station, wherein the precoded transmissions are precoded based on one or more of the two DFT beams.

10. The method of claim 9, wherein the first and second parameters of the second PMI are one of: wideband or subband, based on a predetermined CSI reporting mode configuration, wherein the first parameter identifies beam selection and co-phasing of the primary beam, and wherein the second parameter identifies beam selection, co-phasing, and complex coefficient of the secondary beam.

11. The method of claim 9, wherein the plurality of wideband parameters of the first PMI are dependent on a number of ports in first and second dimensions of an antenna array and an oversampling rate per first and second dimensions.

12. The method of claim 9, wherein the second parameter is one of: independent from or dependent on the first parameter.

13. The method of claim 12, wherein the second parameter is dependent on the first parameter, wherein the precoded transmissions are precoded based on a linear combination of the two DFT beams.

14. The method of claim 12, wherein the second parameter is independent of the first parameter, wherein the precoded transmissions are precoded based on a non-linear combination beam selection of one of the two DFT beams.

15. The method of claim 14, wherein the precoded transmissions are precoded based on the non-linear combination beam selection of one of the two DFT beams when the second parameter is below a predefined threshold, and wherein the precoded transmissions are precoded based on the linear combination when the second parameter is greater than or equal to the predefined threshold.

16. The method of claim 9, further including:

detecting feedback overhead exceeding an overhead limit on physical uplink control channel (PUCCH);

in response to the feedback overhead exceeding the overhead limit, one of:

subsampling the first PMI by reducing a related oversampling factor on each antenna dimension;

reducing a beam selection hypothesis of the second PMI;

subsampling the second PMI by fixing a first co-phasing to 0 and a second co-phasing to π; or

fixing the first parameter to 0 and restricting selection of the second parameter to antenna ports below the predefined threshold.

17. The method of claim 9, wherein the precoded transmissions are precoded using the linear combination in response to a rank being less than 3, and wherein the precoded transmissions are precoded using a non-linear combination beam selection of one of the two DFT beams in response to the rank being greater than or equal to 3.

18. The method of claim 9, wherein the plurality of signals are a plurality of beamformed channel state information (CSI) reference signals (CSI-RS), and wherein the second PMI includes a wideband first parameter that identifies beam selection and co-phasing of the primary beam and the second parameter that identifies beam selection, co-phasing, and complex coefficient of the secondary beam.

19. The method of any combination of claims 9-18.

20. A method of wireless communication, comprising:

performing channel state information (CSI) measurements on a plurality of signals from a serving base station;

reporting a first precoding matrix indicator (PMI) to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of discrete Fourier transform (DFT) beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters;

reporting a second PMI to the serving base station, wherein the second PMI includes a first parameter that provides beam selection of two DFT beams from the grid of beams, complex coefficient, and a common co-phasing for the two DFT beams; and

receiving precoded transmissions from the serving base station, wherein the precoded transmissions are precoded based on a linear combination of the two DFT beams.

21. The method of claim 20, wherein the plurality of wideband parameters of the first PMI are dependent on a number of ports in first and second dimensions of an antenna array and an oversampling rate per first and second dimensions.

22. The method of claim 20, wherein the second PMI is one of: wideband or subband, based on a predetermined CSI reporting mode configuration.

23. The method of claim 20, further including:

detecting feedback overhead exceeding an overhead limit on physical uplink control channel (PUCCH);

in response to the feedback overhead exceeding the overhead limit, one of:

subsampling the first PMI by reducing a related oversampling factor on each antenna dimension;

reducing a beam selection hypothesis of the second PMI; or

subsampling the second PMI by fixing a first co-phasing to 0 and a second co-phasing to π.

24. The method of claim 20, wherein the precoded transmissions are precoded using the linear combination in response to a rank being less than 3, and wherein the precoded transmissions are precoded using a non-linear combination beam selection of one of the two DFT beams in response to the rank being greater than or equal to 3.

25. The method of claim 20, wherein the plurality of signals are a plurality of beamformed channel state information (CSI) reference signals (CSI-RS), and wherein the first PMI is not reported.

25. The method of any combination of claims 20-24.

26. An apparatus configured for wireless communication, comprising:

means for performing channel state information (CSI) measurements on a plurality of signals received from a serving base station;

means for reporting a first precoding matrix indicator (PMI) to the serving base station, wherein the first PMI includes a plurality of wideband parameters that identify two discrete Fourier transform (DFT) beams for a linear combination, wherein the two DFT beams are selected from a plurality of DFT beams forming the plurality of signals;

means for reporting a second PMI to the serving base station, wherein the second PMI includes a complex coefficient weighting and co-phasing for the linear combination of the identified two DFT beams; and

means for receiving precoded transmissions from the serving base station, wherein the precoded transmissions are precoded using the linear combination of the two DFT beams.

27. The apparatus of claim 26, wherein the plurality of wideband parameters are jointly coded in the first PMI.

28. The apparatus of claim 26, wherein the plurality of wideband parameters of the first PMI includes wideband parameters identifying one of: two non-orthogonal beams, two orthogonal beams on a first antenna dimension, and two orthogonal beams on a second antenna dimension.

29. The apparatus of claim 26, wherein the plurality of wideband parameters of the first PMI are dependent on a number of ports in first and second dimensions of an antenna array and an oversampling rate per first and second dimensions.

30. The apparatus of claim 26, further including:

means for detecting feedback overhead exceeding an overhead limit on physical uplink control channel (PUCCH);

means, executable in response to the feedback overhead exceeding the overhead limit, one of:

for subsampling the first PMI by reducing a related oversampling factor;

for reducing a beam selection hypothesis of the first PMI; or

for subsampling the second PMI by fixing a first co-phasing to 0 and a second co-phasing to π.

31. The apparatus of claim 26, wherein the precoded transmissions are precoded using the linear combination in response to a rank being less than 3, and wherein the precoded transmissions are precoded using a non-linear combination beam selection of one of the two DFT beams in response to the rank being greater than or equal to 3.

32. The apparatus of claim 26, wherein the plurality of signals are a plurality of beamformed channel state information (CSI) reference signals (CSI-RS), and wherein the plurality of wideband parameters of the first PMI include wideband beam pair combination parameters.

33. The apparatus of any combination of claims 26-32.

34. An apparatus configured for wireless communication, comprising:

means for performing channel state information (CSI) on a plurality of signals from a serving base station;

means for reporting a first precoding matrix indicator (PMI) to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of discrete Fourier transform (DFT) beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters;

means for reporting a second PMI to the serving base station, wherein the second PMI includes first and second parameters that identify a primary beam and a secondary beam from the grid of beams determined from the first PMI; and

means for receiving precoded transmissions from the serving base station, wherein the precoded transmissions are precoded based on one or more of the two DFT beams.

35. The apparatus of claim 34, wherein the first and second parameters of the second PMI are one of: wideband or subband, based on a predetermined CSI reporting mode configuration, wherein the first parameter identifies beam selection and co-phasing of the primary beam, and wherein the second parameter identifies beam selection, co-phasing, and complex coefficient of the secondary beam.

36. The apparatus of claim 34, wherein the plurality of wideband parameters of the first PMI are dependent on a number of ports in first and second dimensions of an antenna array and an oversampling rate per first and second dimensions.

37. The apparatus of claim 34, wherein the second parameter is one of: independent from or dependent on the first parameter.

38. The apparatus of claim 37, wherein the second parameter is dependent on the first parameter, wherein the precoded transmissions are precoded based on a linear combination of the two DFT beams.

39. The apparatus of claim 37, wherein the second parameter is independent of the first parameter, wherein the precoded transmissions are precoded based on a non-linear combination beam selection of one of the two DFT beams.

40. The apparatus of claim 39, wherein the precoded transmissions are precoded based on the non-linear combination beam selection of one of the two DFT beams when the second parameter is below a predefined threshold, and wherein the precoded transmissions are precoded based on the linear combination when the second parameter is greater than or equal to the predefined threshold.

41. The apparatus of claim 34, further including:

means for detecting feedback overhead exceeding an overhead limit on physical uplink control channel (PUCCH);

means, executable in response to the feedback overhead exceeding the overhead limit, one of:

for subsampling the first PMI by reducing a related oversampling factor on each antenna dimension;

for reducing a beam selection hypothesis of the second PMI;

for subsampling the second PMI by fixing a first co-phasing to 0 and a second co-phasing to π; or

for fixing the first parameter to 0 and restricting selection of the second parameter to antenna ports below the predefined threshold.

42. The apparatus of claim 34, wherein the precoded transmissions are precoded using the linear combination in response to a rank being less than 3, and wherein the precoded transmissions are precoded using a non-linear combination beam selection of one of the two DFT beams in response to the rank being greater than or equal to 3.

43. The apparatus of claim 34, wherein the plurality of signals are a plurality of beamformed channel state information (CSI) reference signals (CSI-RS), and wherein the second PMI includes a wideband first parameter that identifies beam selection and co-phasing of the primary beam and the second parameter that identifies beam selection, co-phasing, and complex coefficient of the secondary beam.

44. The apparatus of any combination of claims 34-43.

45. An apparatus configured for wireless communication, comprising:

means for performing channel state information (CSI) measurements on a plurality of signals from a serving base station;

means for reporting a first precoding matrix indicator (PMI) to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a plurality of discrete Fourier transform (DFT) beams forming the plurality of signals, wherein the determination is based on a plurality of wideband parameters;

means for reporting a second PMI to the serving base station, wherein the second PMI includes a first parameter that provides beam selection of two DFT beams from the grid of beams, complex coefficient, and a common co-phasing for the two DFT beams; and

means for receiving precoded transmissions from the serving base station, wherein the precoded transmissions are precoded based on a linear combination of the two DFT beams.

46. The apparatus of claim 45, wherein the plurality of wideband parameters of the first PMI are dependent on a number of ports in first and second dimensions of an antenna array and an oversampling rate per first and second dimensions.

47. The apparatus of claim 45, wherein the second PMI is one of: wideband or subband, based on a predetermined CSI reporting mode configuration.

48. The apparatus of claim 45, further including:

means for detecting feedback overhead exceeding an overhead limit on physical uplink control channel (PUCCH);

means, executable in response to the feedback overhead exceeding the overhead limit, one of:

for subsampling the first PMI by reducing a related oversampling factor on each antenna dimension;

for reducing a beam selection hypothesis of the second PMI; or

for subsampling the second PMI by fixing a first co-phasing to 0 and a second co-phasing to π.

49. The apparatus of claim 45, wherein the precoded transmissions are precoded using the linear combination in response to a rank being less than 3, and wherein the precoded transmissions are precoded using a non-linear combination beam selection of one of the two DFT beams in response to the rank being greater than or equal to 3.

50. The apparatus of claim 45, wherein the plurality of signals are a plurality of beamformed channel state information (CSI) reference signals (CSI-RS), and wherein the first PMI is not reported.

51. The apparatus of any combination of claims 45-50.

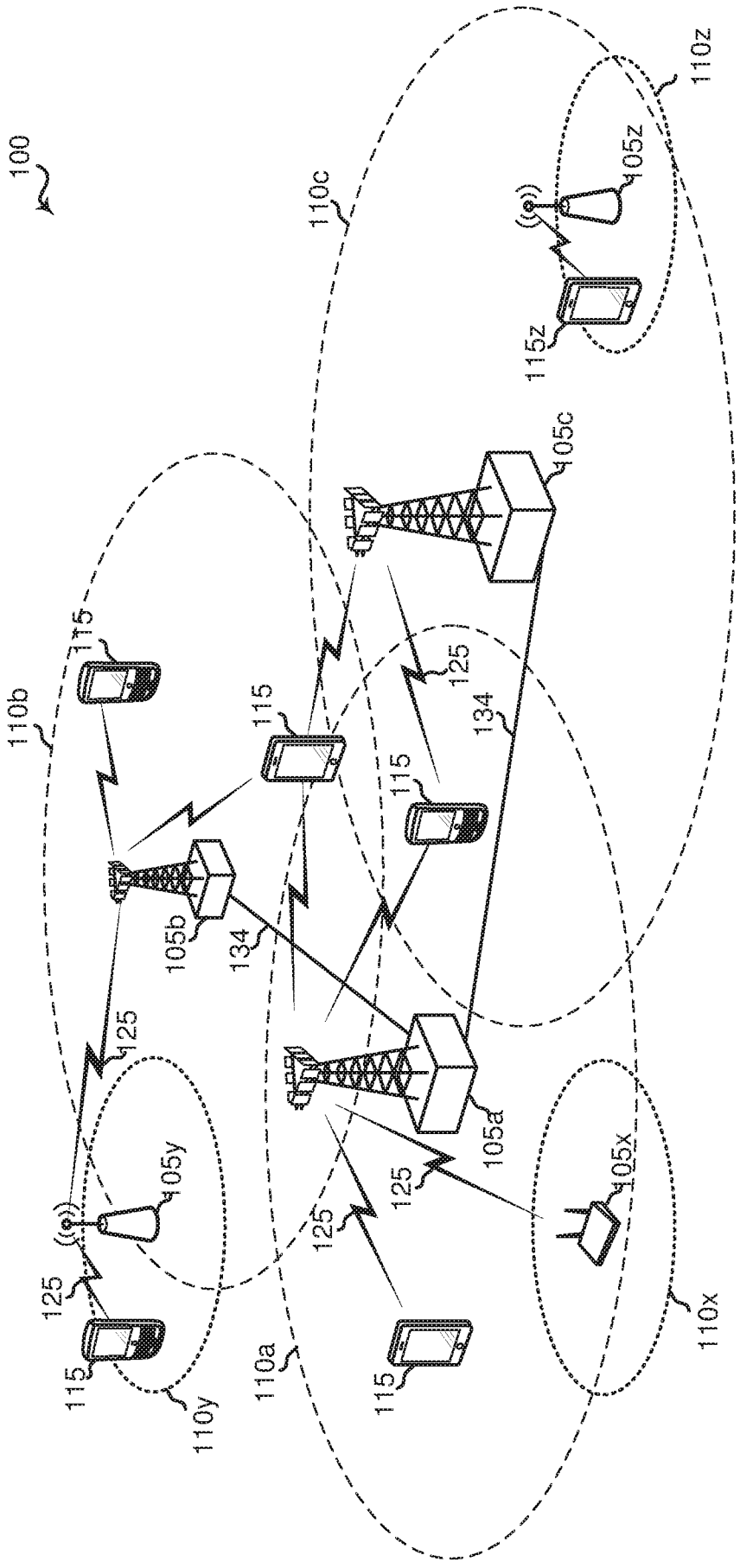

100
110a
110b
110c
110x
110y
110z
105a
105b
105c
105x
105y
105z
115
115z
125
134

FIG. 1

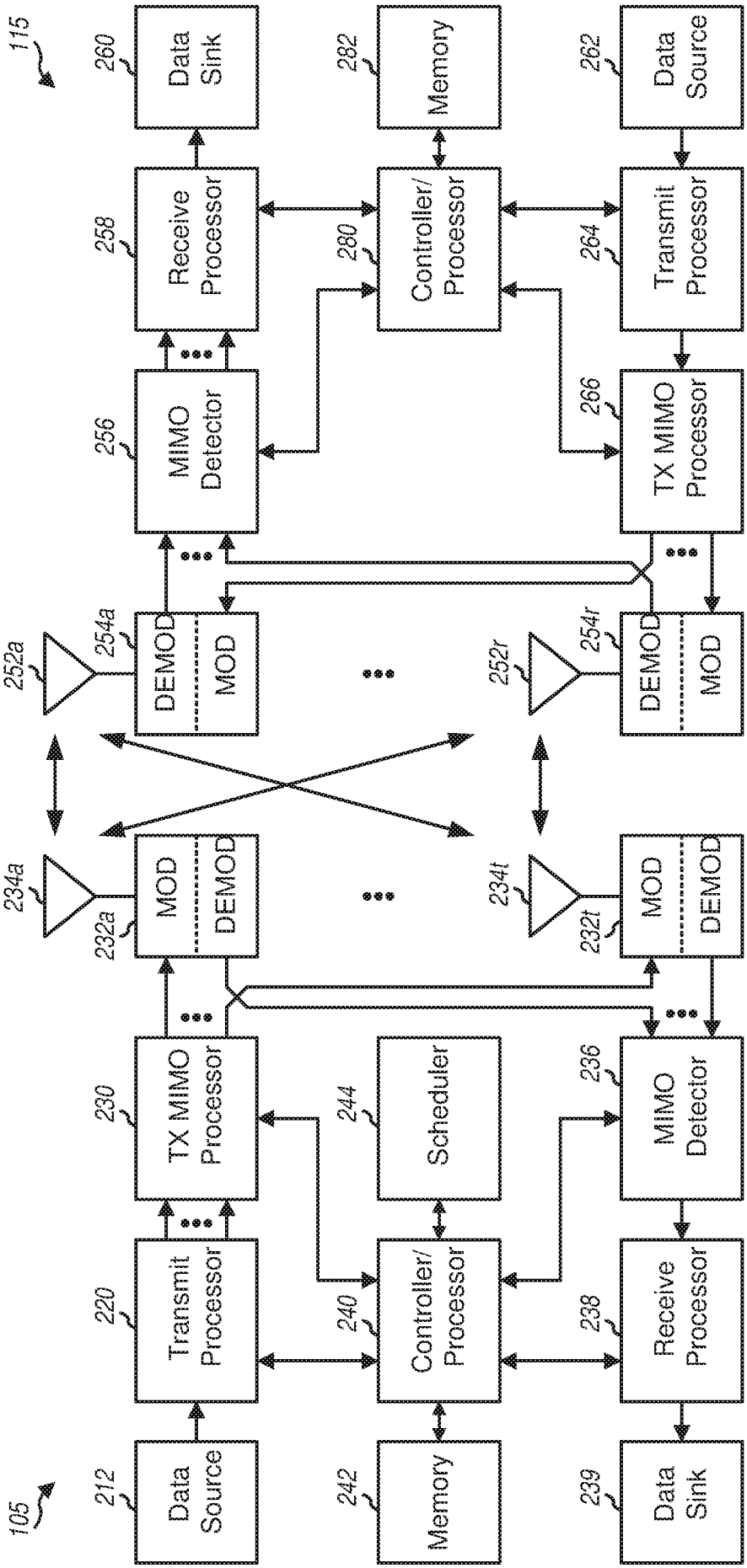

115
260
Data Sink
282
Memory
262
Data Source
258
Receive Processor
280
Controller/ Processor
264
Transmit Processor
256
MIMO Detector
266
TX MIMO Processor
252a
254a
DEMOD
MOD
252r
254r
DEMOD
MOD
234a
232a
MOD
DEMOD
234t
232t
MOD
DEMOD
230
TX MIMO Processor
244
Scheduler
236
MIMO Detector
220
Transmit Processor
240
Controller/ Processor
238
Receive Processor
105
212
Data Source
242
Memory
239
Data Sink

FIG. 2

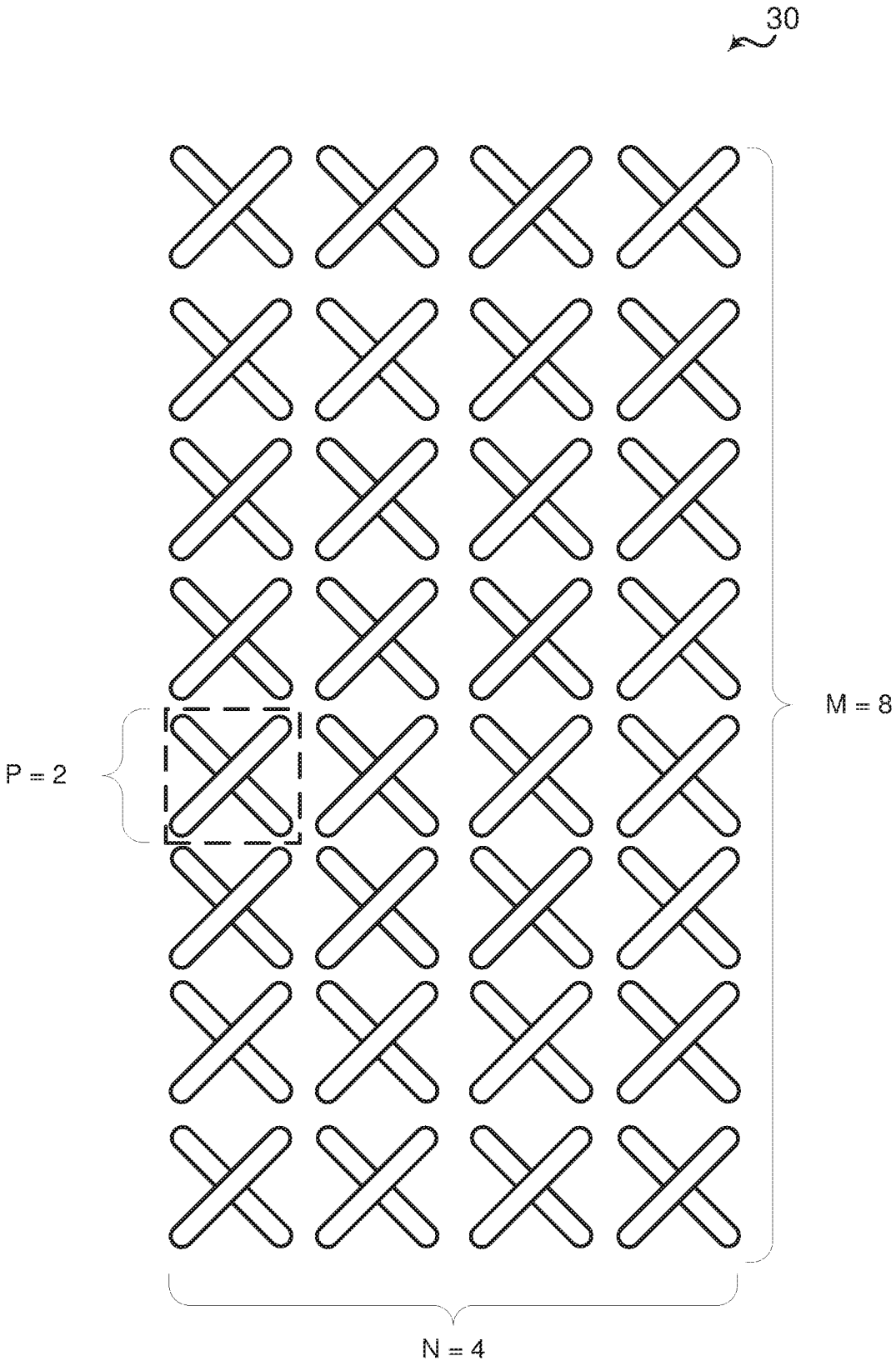


FIG. 3

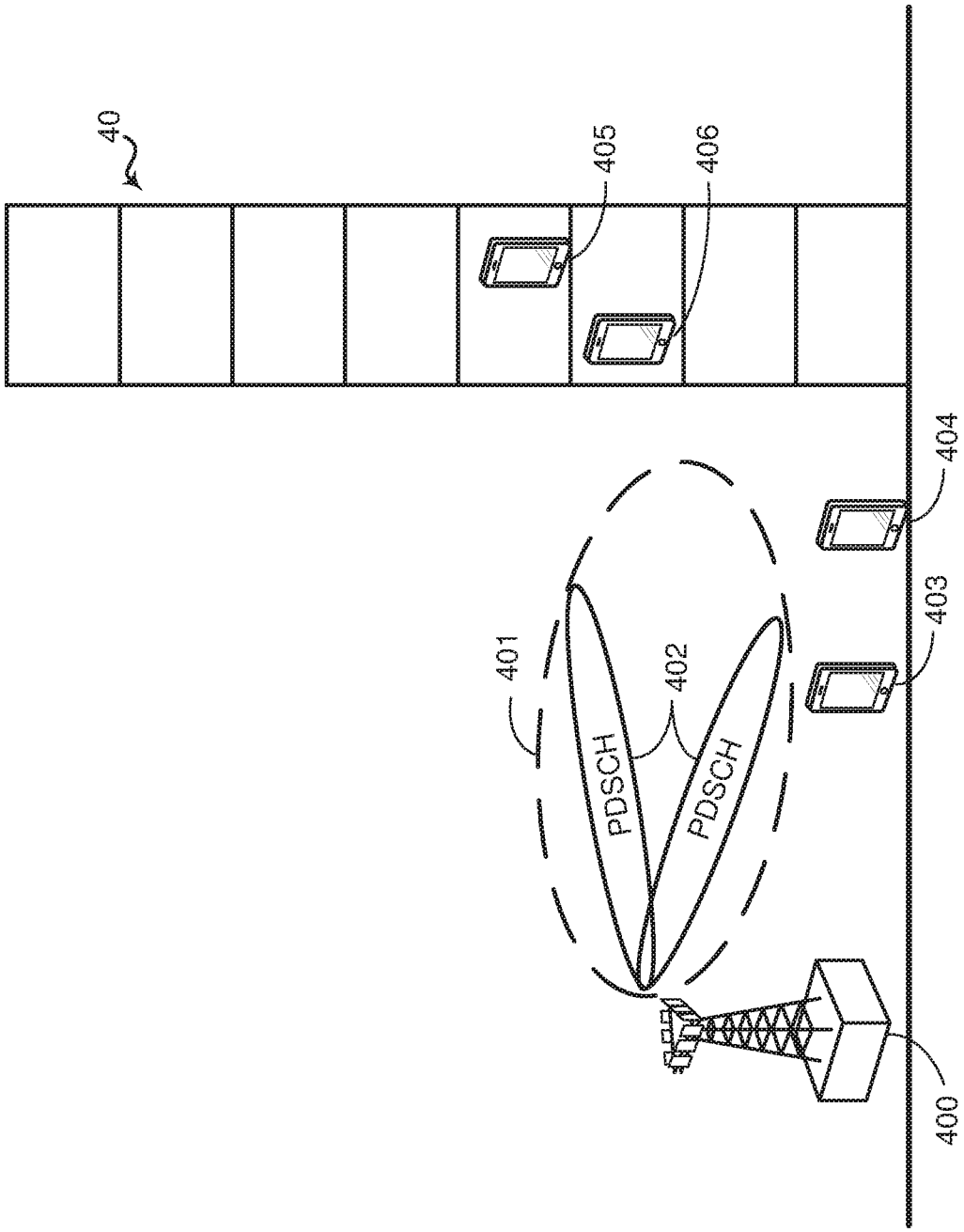


FIG. 4A

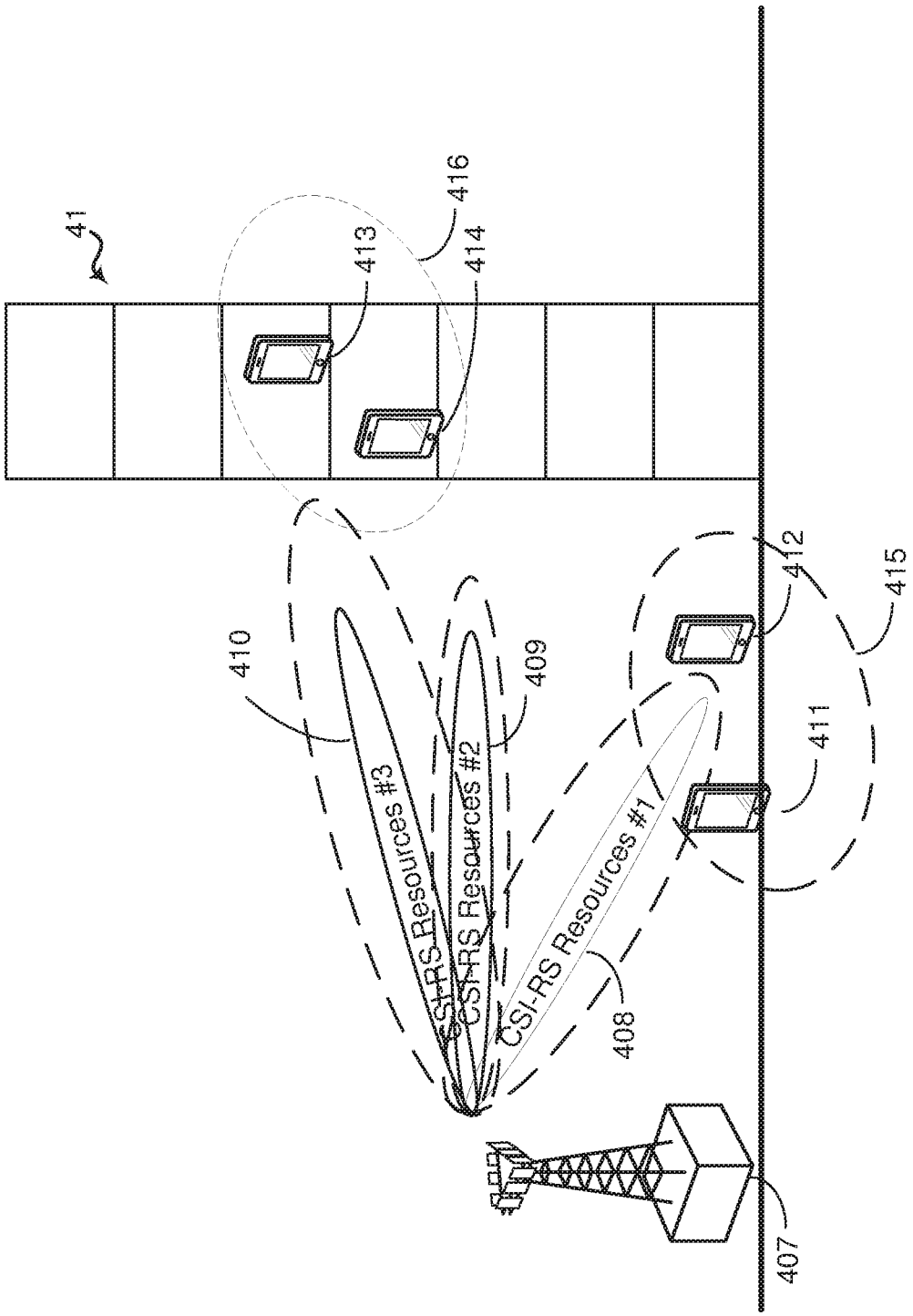

41
413
414
416
410
409
408
411
412
415
407
CSI-RS Resources #3
CSI-RS Resources #2
CSI-RS Resources #1

FIG. 4B

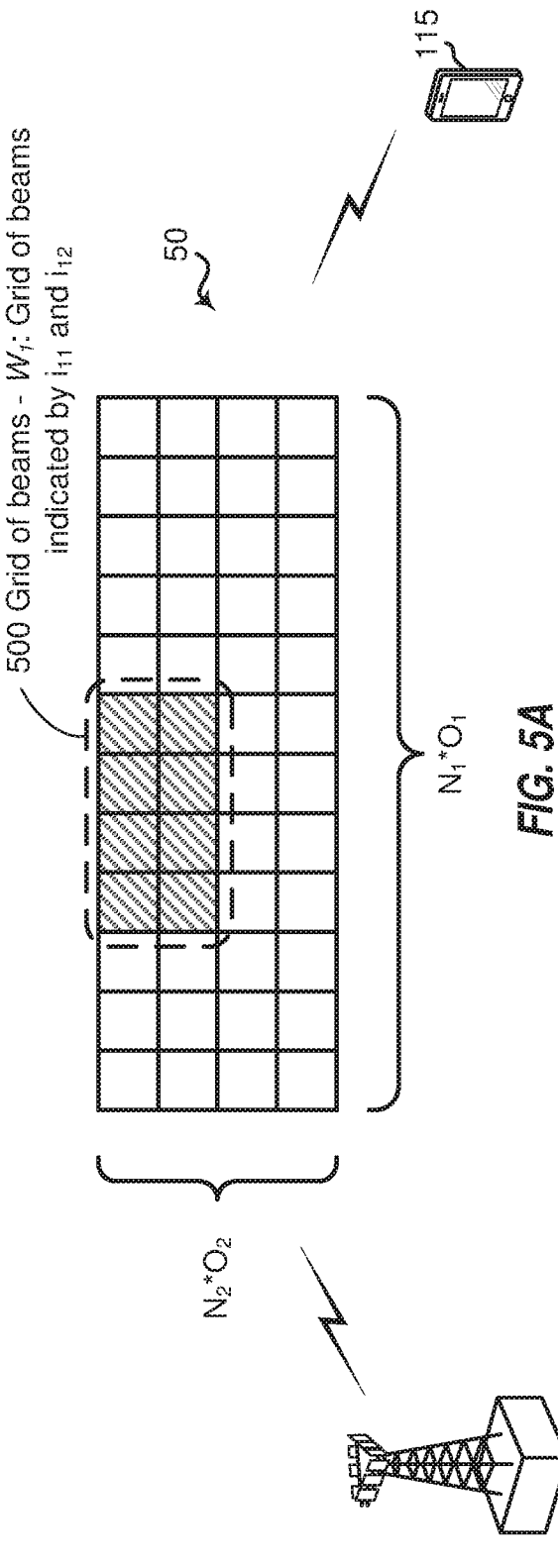

500 Grid of beams - W_1: Grid of beams indicated by i_{11} and i_{12}
50
115
N_1*O_1
N_2*O_2
105

FIG. 5A

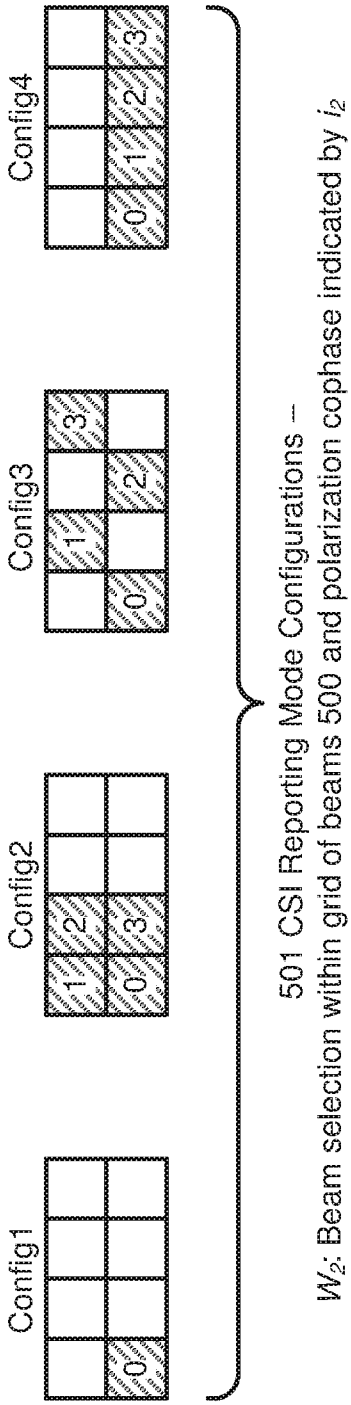

Config1
Config2
Config3
Config4
501 CSI Reporting Mode Configurations –
W_2: Beam selection within grid of beams 500 and polarization cophase indicated by i_2

FIG. 5B

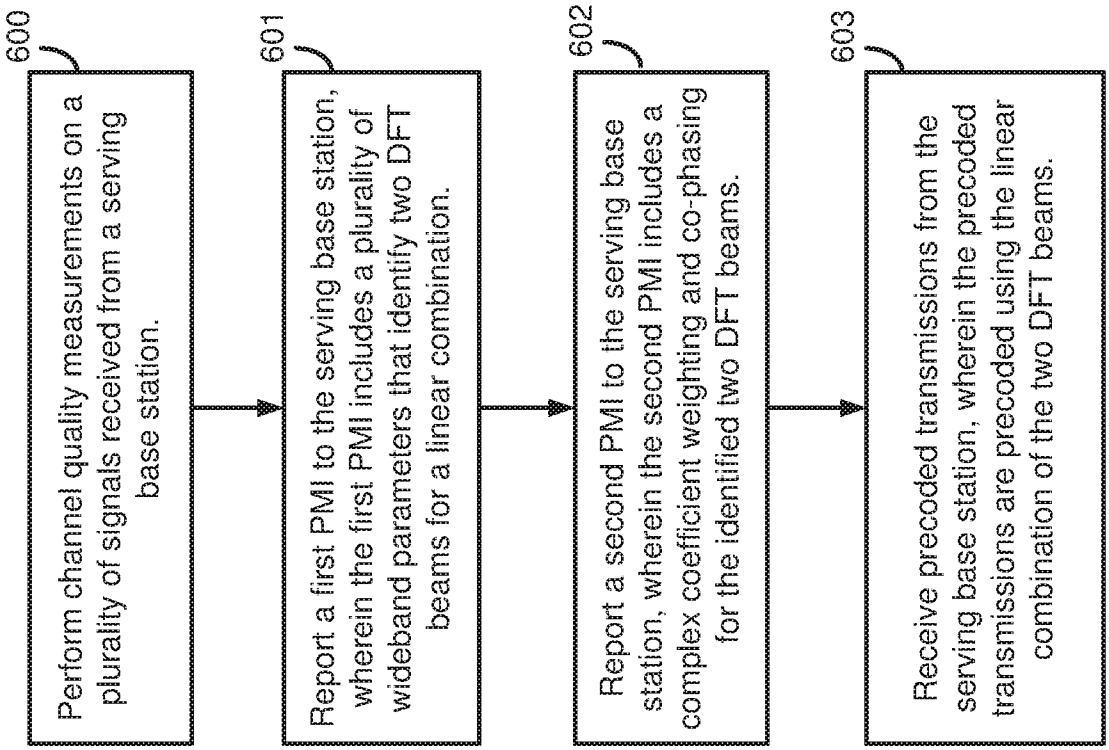

600
Perform channel quality measurements on a plurality of signals received from a serving base station.
601
Report a first PMI to the serving base station, wherein the first PMI includes a plurality of wideband parameters that identify two DFT beams for a linear combination.
602
Report a second PMI to the serving base station, wherein the second PMI includes a complex coefficient weighting and co-phasing for the identified two DFT beams.
603
Receive precoded transmissions from the serving base station, wherein the precoded transmissions are precoded using the linear combination of the two DFT beams.

FIG. 6

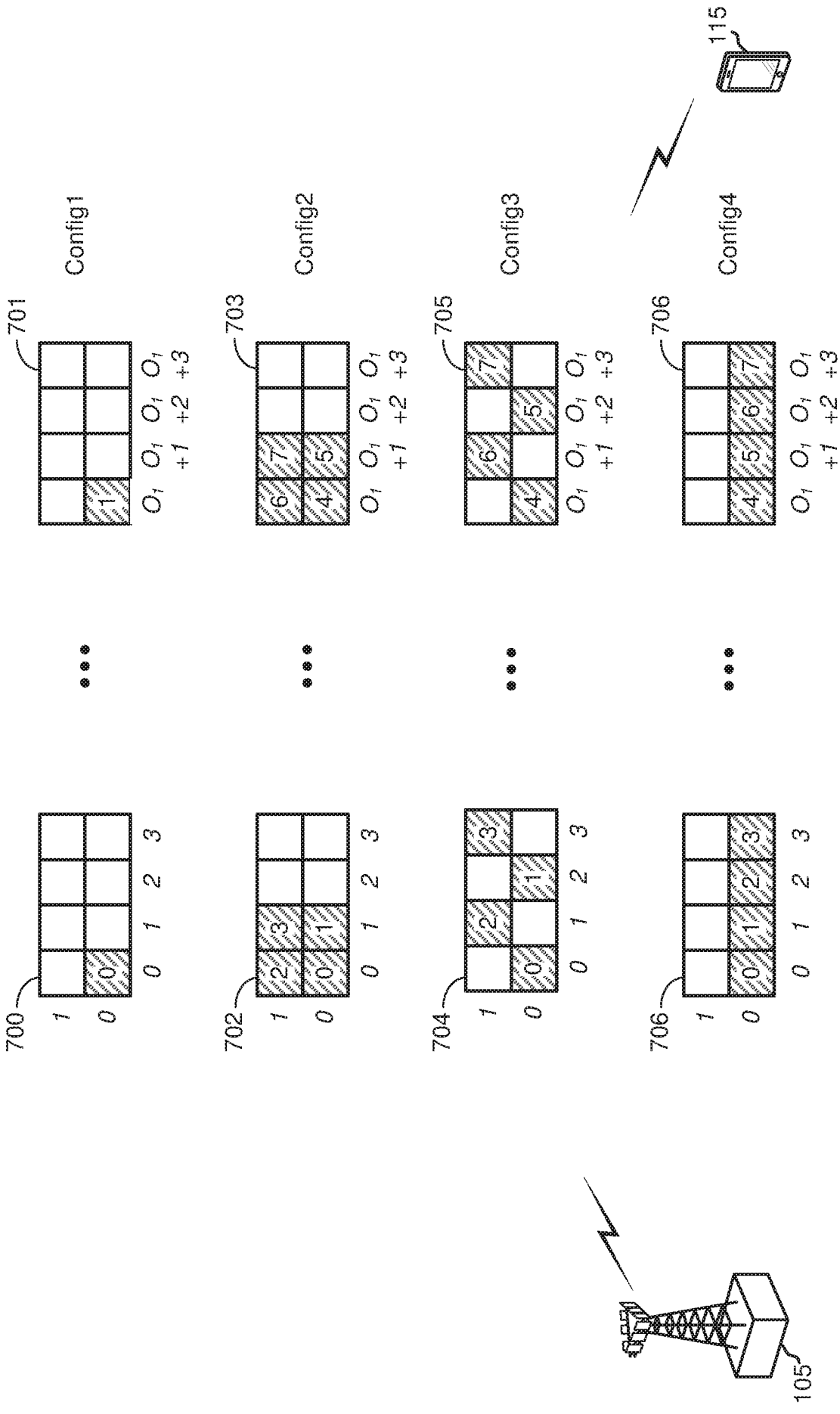

115
Config1
Config2
Config3
Config4
701
703
705
706
700
702
704
706
105

FIG. 7

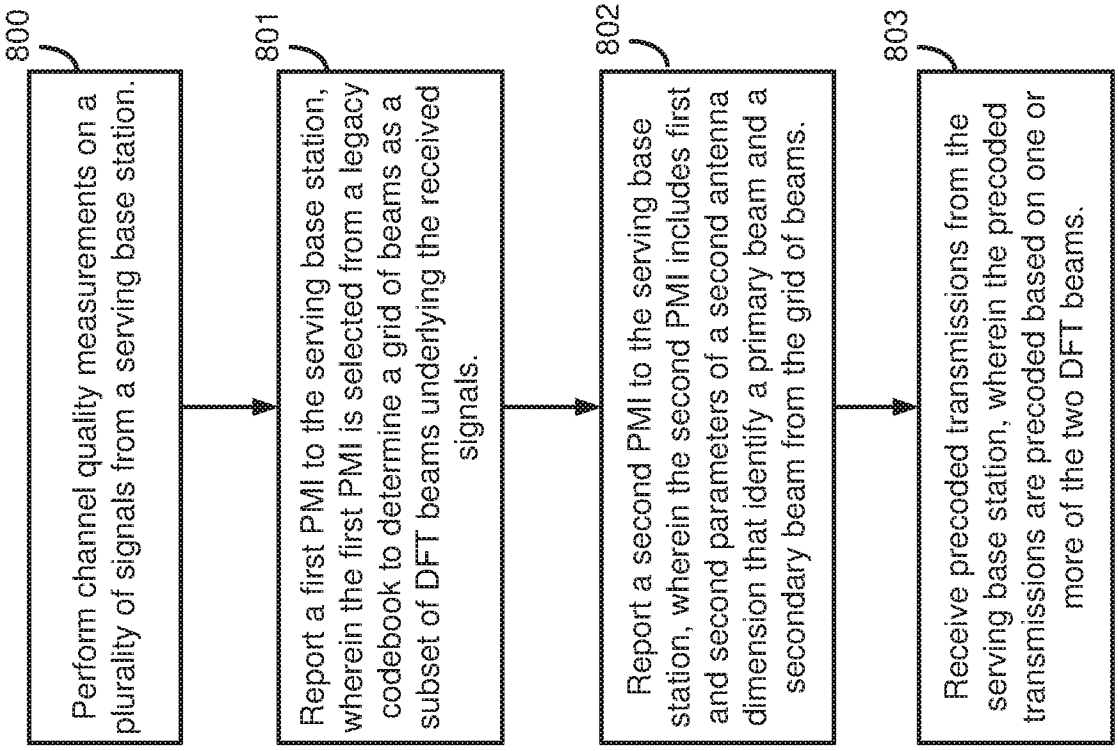

800
Perform channel quality measurements on a plurality of signals from a serving base station.
801
Report a first PMI to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of DFT beams underlying the received signals.
802
Report a second PMI to the serving base station, wherein the second PMI includes first and second parameters of a second antenna dimension that identify a primary beam and a secondary beam from the grid of beams.
803
Receive precoded transmissions from the serving base station, wherein the precoded transmissions are precoded based on one or more of the two DFT beams.

FIG. 8

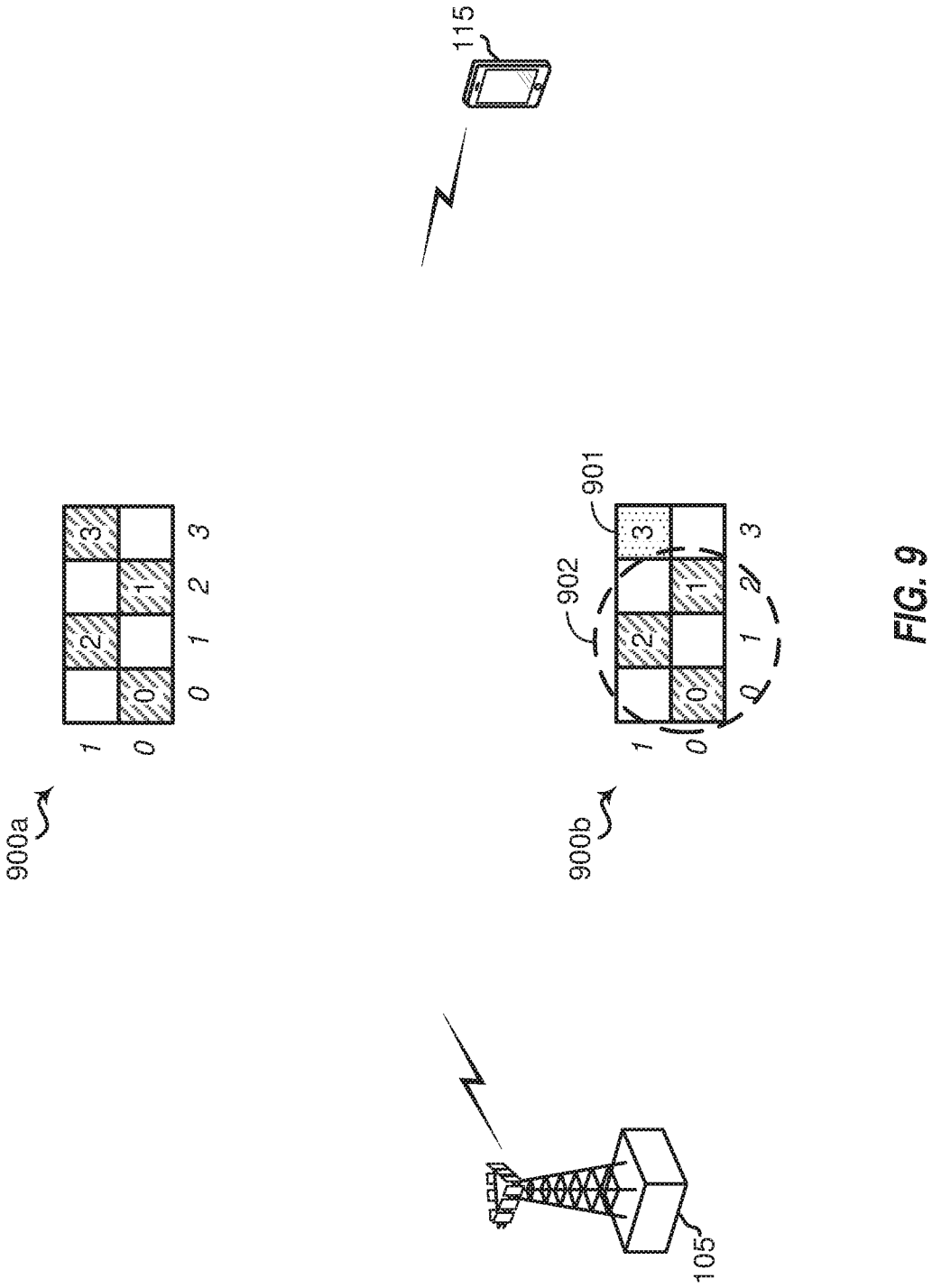


FIG. 9

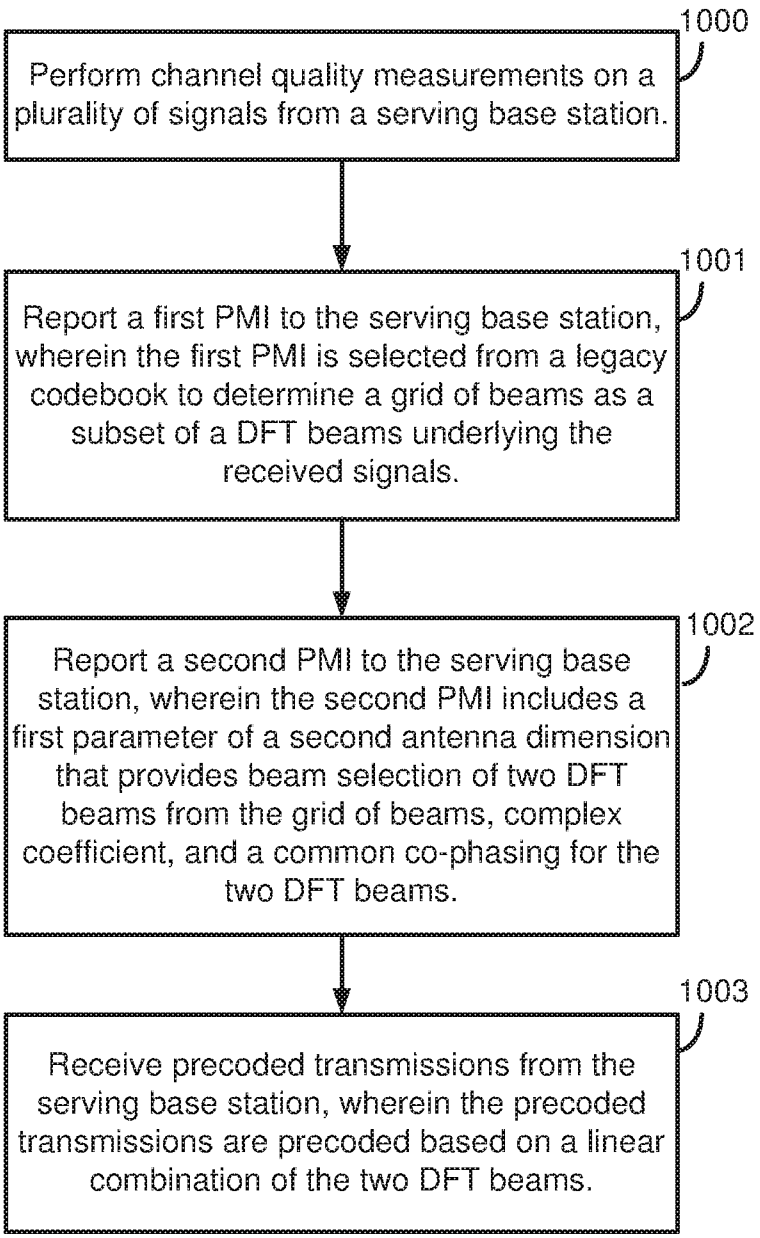

1000
Perform channel quality measurements on a plurality of signals from a serving base station.
1001
Report a first PMI to the serving base station, wherein the first PMI is selected from a legacy codebook to determine a grid of beams as a subset of a DFT beams underlying the received signals.
1002
Report a second PMI to the serving base station, wherein the second PMI includes a first parameter of a second antenna dimension that provides beam selection of two DFT beams from the grid of beams, complex coefficient, and a common co-phasing for the two DFT beams.
1003
Receive precoded transmissions from the serving base station, wherein the precoded transmissions are precoded based on a linear combination of the two DFT beams.

FIG. 10

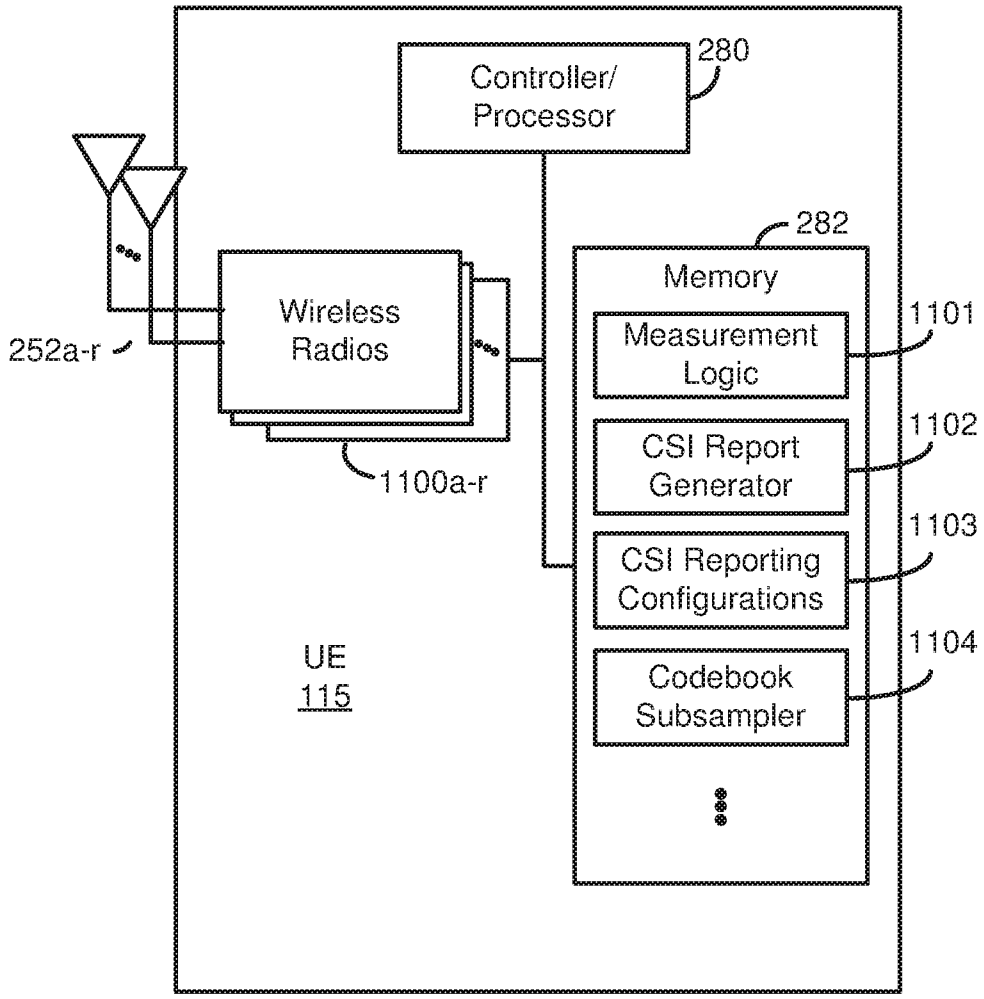

Controller/
Processor
280
282
Memory
Wireless
Radios
252a-r
1100a-r
Measurement
Logic
1101
CSI Report
Generator
1102
CSI Reporting
Configurations
1103
Codebook
Subsampler
1104
UE
115

FIG. 11

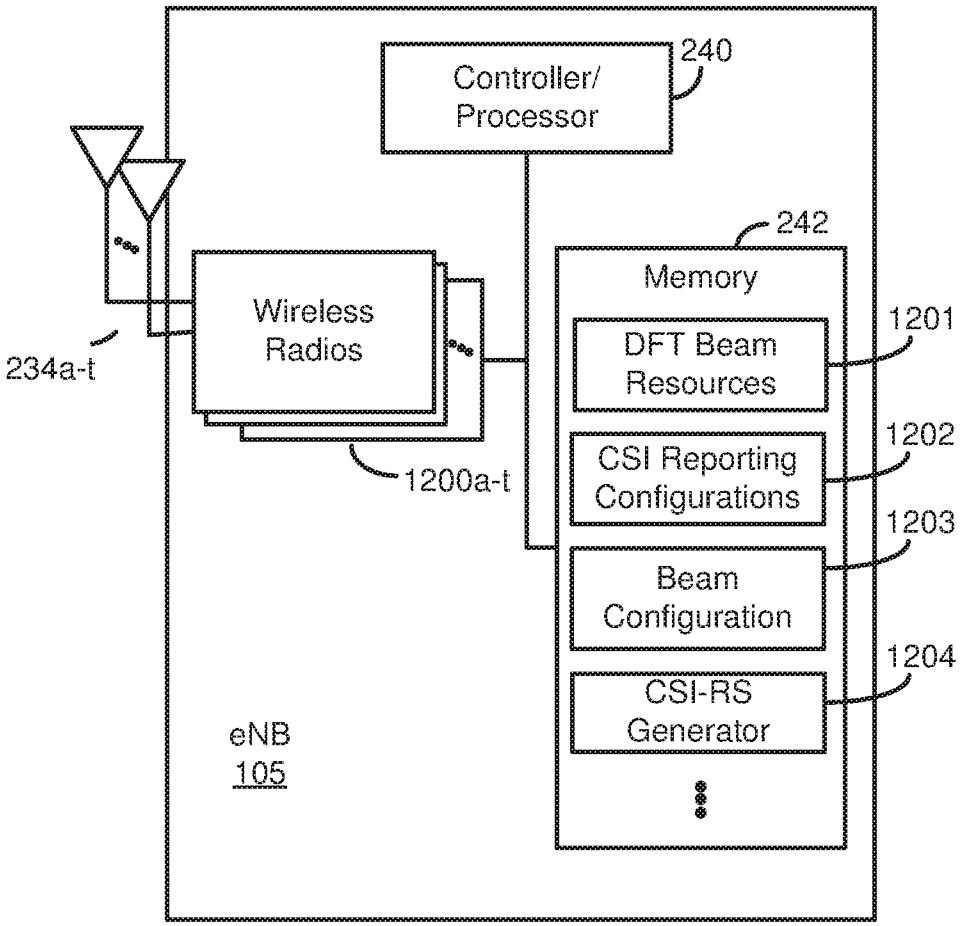

Controller/
Processor
240
242
Memory
Wireless
Radios
234a-t
1200a-t
DFT Beam
Resources
1201
CSI Reporting
Configurations
1202
Beam
Configuration
1203
CSI-RS
Generator
1204
eNB
105

FIG. 12

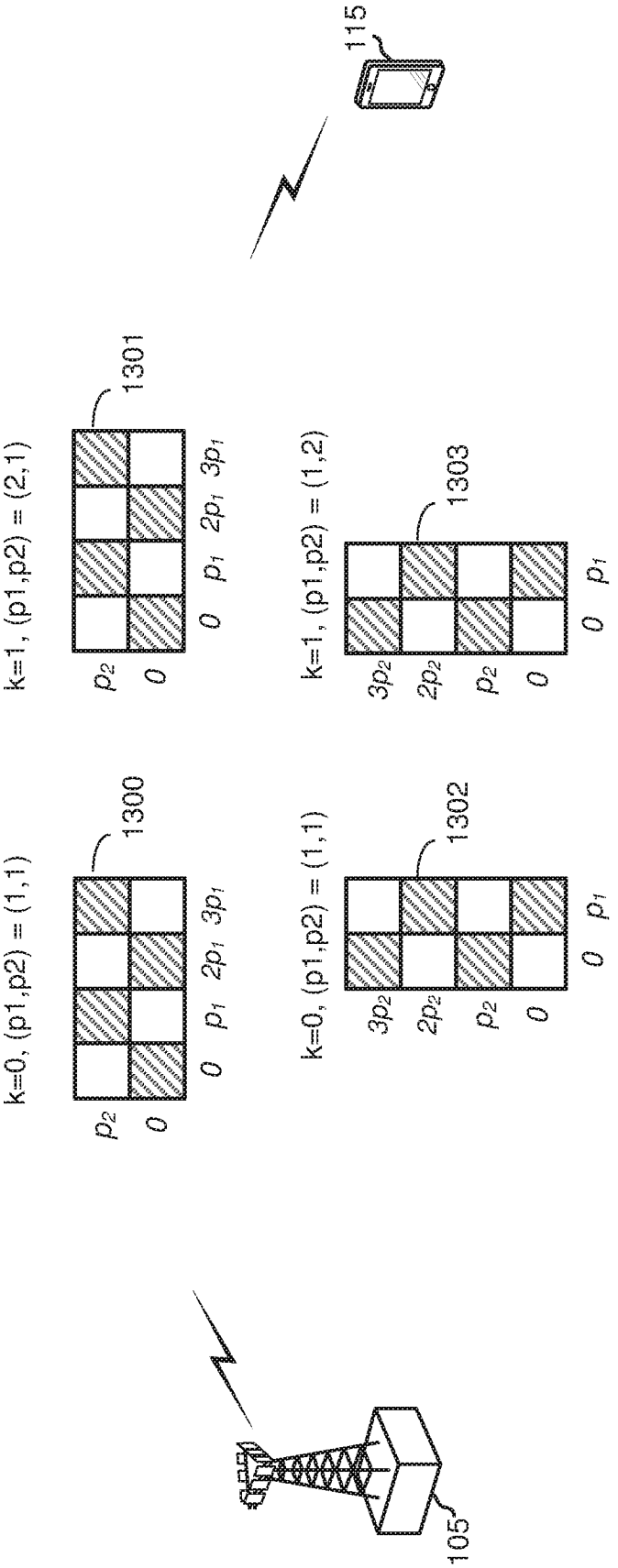


FIG. 13A

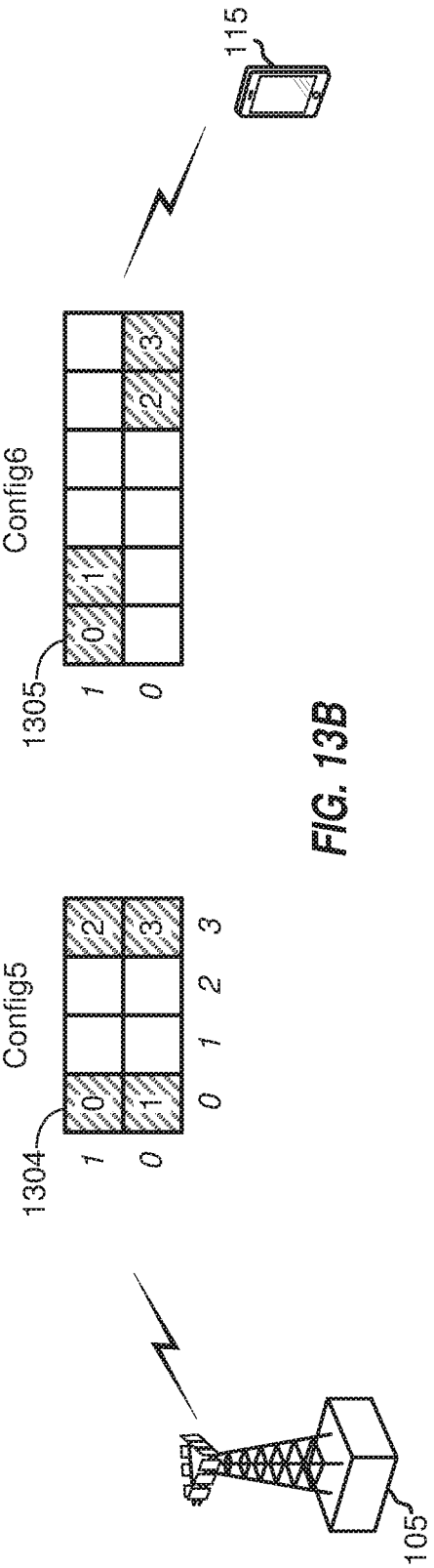


FIG. 13B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2016/081310

A. CLASSIFICATION OF SUBJECT MATTER

H04L 1/00(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04L; H04W; H04Q; 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)

WPI,EPODOC,CNPAT,3GPP:PMI, precoding matrix indicator, linear combination, co-phasing, primary beam, second beam, antenna dimension, overhead

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013343303 A1 (SAMSUNG ELECTRONICS CO., LTD.) 26 December 2013 (2013-12-26) claim 17	1-25, 25a, 26-51
A	ALCATEL-LUCENT et al. "Performance of coordinated beamforming with multiple PMI feedback" *3GPP TSG RAN WG1 #60 Meeting, R1-10-0944,* 26 February 2010 (2010-02-26), page 3, paragraph 2	1-25, 25a, 26-51
A	EP 2996272 A1 (FUJITSU LTD.) 16 March 2016 (2016-03-16) the whole document	1-25, 25a, 26-51
A	CN 103220087 A (HUAWEI TECH. CO., LTD.) 24 July 2013 (2013-07-24) the whole document	1-25, 25a, 26-51

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

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
09 January 2017	**24 January 2017**

Name and mailing address of the ISA/CN	Authorized officer
STATE INTELLECTUAL PROPERTY OFFICE OF THE P.R.CHINA **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088** **China**	**HE,Xiulian**
Facsimile No. **(86-10)62019451**	Telephone No. **(86-10)62413423**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2016/081310

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
US	2013343303	A1	26 December 2013	KR	20140000174	A	02 January 2014
				WO	2013191517	A1	27 December 2013
				CN	104396152	A	04 March 2015
				EP	2865104	A1	29 April 2015
				JP	2015521815	A	30 July 2015
EP	2996272	A1	16 March 2016	JP	2016523039	A	04 August 2016
				CN	105164957	A	16 December 2015
				WO	2014179996	A1	13 November 2014
				KR	20160003201	A	08 January 2016
				US	2016065276	A1	03 March 2016
CN	103220087	A	24 July 2013	US	2015256243	A1	10 September 2015
				US	2014334571	A1	13 November 2014
				EP	2525505	A1	21 November 2012
				EP	2985924	A1	17 February 2016
				CN	103248457	A	14 August 2013
				US	2013121437	A1	16 May 2013
				US	2012275500	A1	01 November 2012
				CN	102130752	A	20 July 2011
				WO	2011085695	A1	21 July 2011