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### RB/PRG-level precoder cycling based on virtual DMRS ports

#### Abstract

This disclosure provides systems, methods and apparatuses for transmissions with non-transparent precoder cycling. A network node generates a precoding matrix including a number of sub-matrices equal to a number of antenna groups. A first sub-matrix for a first antenna group is the same for each frequency domain resource unit of a frequency domain resource group. A phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal for each frequency domain resource unit. The network node applies the precoding matrix to both a data signal and a demodulation reference signal (DMRS) of a transmission for each frequency domain resource unit of the frequency domain resource group and transmits the precoded transmission via the antenna groups. A UE receives the transmission having non-transparent precoder cycling, estimates a channel of the transmission based on the precoding matrix, and demodulates the data signal based on the estimated channel.

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#### References Cited

##### U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
9264191	12/2015	Ellenbeck	N/A	H04B 15/00
10484223	12/2018	Hessler	N/A	H04L 5/001
2016/0212643	12/2015	Park	N/A	H04B 7/0478
2019/0357159	12/2018	Pan et al.	N/A	N/A

2021/0152303	12/2020	Hao et al.	N/A	N/A
2021/0337428	12/2020	Li	N/A	H04W 72/0446
2021/0376890	12/2020	Levy	N/A	H04B 7/0456
2022/0321180	12/2021	Huang	N/A	H04L 25/03343
2023/0318775	12/2022	Ferdinand et al.	N/A	N/A
2023/0353315	12/2022	Abdelghaffar	N/A	H04L 27/2613
2024/0349323	12/2023	Landis	N/A	H04L 5/0048

## OTHER PUBLICATIONS

International Search Report and Written Opinion—PCT/US2024/062012—ISA/EPO—Mar. 31, 2025. cited by applicant  
Qualcomm Incorporated: “On UL Diversity Transmission Scheme”, 3GPP Draft, 3GPP TSG RAN WG1 Meeting NR#3, R1-1716390, 3rd Generation Partnership Project, Mobile Competence Centre, 650, Route Des Lucioles, F-06921 Sophia-Antipolis Cedex, France, vol. RAN WG1, No. Nagoya, Japan, Sep. 18, 2017-Sep. 21, 2017, Sep. 12, 2017, XP051329979, pp. 1-20, The Whole Document. cited by applicant

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## Background/Summary

### TECHNICAL FIELD

(1) The present disclosure relates to wireless communications including resource block (RB) and physical resource group (PRG) level precoder cycling based on virtual demodulation reference signal (DMRS) ports.

### DESCRIPTION OF THE RELATED TECHNOLOGY

(2) Wireless communication systems are widely deployed to provide various telecommunication services such as telephony, video, data, messaging, and broadcasts. Typical wireless communication systems may employ multiple-access technologies capable of supporting communication with multiple users by sharing available system resources. Examples of such multiple-access technologies include code division multiple access (CDMA) systems, time division multiple access (TDMA) systems, frequency division multiple access (FDMA) systems, orthogonal frequency division multiple access (OFDMA) systems, single-carrier frequency division multiple access (SC-FDMA) systems, and time division synchronous code division multiple access (TD-SCDMA) systems.

(3) These multiple access technologies have been adopted in various telecommunication standards to provide a common protocol that enables different wireless devices to communicate on a municipal, national, regional, and even global level. An example telecommunication standard is 5G New Radio (NR). 5G NR is part of a continuous mobile broadband evolution promulgated by Third Generation Partnership Project (3GPP) to meet new requirements associated with latency, reliability, security, scalability (such as with Internet of Things (IoT)), and other requirements. 5G NR includes services associated with enhanced mobile broadband (eMBB), massive machine type communications (mMTC), and ultra-reliable low latency communications (URLLC). Some aspects of 5G NR may be based on the 4G Long Term Evolution (LTE) standard.

### SUMMARY

(4) The systems, methods and devices of this disclosure each have several innovative aspects, no single one of which is solely responsible for the desirable attributes disclosed herein.

(5) In some aspects, the techniques described herein relate to an apparatus for wireless communication at a user equipment (UE), including: one or more memories storing computer-executable instructions; and one or more processors coupled with the one or more memories and configured to execute the computer-executable instructions, individually or in combination, to cause the apparatus to: receive a transmission having non-transparent precoder cycling applied to each frequency domain resource unit of a frequency domain resource group of K frequency domain resource units in which both a data signal and a demodulation reference signal (DMRS) are precoded with a precoding matrix including a number of sub-matrices equal to a number of antenna groups, wherein a first sub-matrix for a first antenna group is the same for each frequency domain resource unit and a phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal across the frequency domain resource units of the frequency domain resource group; estimate a channel of the transmission based on the precoding matrix; and demodulate the data signal based on the estimated channel.

(6) In some aspects, the techniques described herein relate to a method of wireless communication at a user equipment (UE), including: receiving a transmission having non-transparent precoder cycling applied to each frequency domain resource unit of a frequency domain resource group of K frequency domain resource units in which both a data signal and a demodulation reference signal (DMRS) are precoded with a precoding matrix including a number of sub-matrices equal to a number of antenna groups, wherein a first sub-matrix for a first antenna group is the same for each frequency domain resource unit and a phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal across the frequency domain resource units of the frequency domain resource group; estimating a channel of the transmission based on the precoding matrix; and demodulating the data signal based on the estimated channel.

(7) The present disclosure also provides an apparatus (e.g., a UE) including means for performing at least one of the above methods, and a non-transitory computer-readable medium storing computer-executable instructions for performing at least one of the above methods.

(8) In some aspects, the techniques described herein relate to an apparatus for wireless communication, including: one or more memories storing computer-executable instructions; and one or more processors coupled with the one or more memories and configured to execute the computer-executable instructions, individually or in combination, to cause the apparatus to: generate a precoding matrix including a number of sub-matrices equal to a number of antenna groups, wherein a first sub-matrix for a first antenna group is the same for each frequency domain resource unit of a frequency domain resource group of  $K$  frequency domain resource units, and wherein a phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal for each frequency domain resource unit of the frequency domain resource group; apply the precoding matrix to both a data signal and a demodulation reference signal (DMRS) of a transmission for each frequency domain resource unit of the frequency domain resource group for non-transparent precoder cycling; and transmit the precoded transmission via the antenna groups.

(9) In some aspects, the techniques described herein relate to a method of wireless communication at a network node, including: generating a precoding matrix including a number of sub-matrices equal to a number of antenna groups, wherein a first sub-matrix for a first antenna group is the same for each frequency domain resource unit of a frequency domain resource group of  $K$  frequency domain resource units, and wherein a phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal for each frequency domain resource unit of the frequency domain resource group; applying the precoding matrix to both a data signal and a demodulation reference signal (DMRS) of a transmission for each frequency domain resource unit of the frequency domain resource group for non-transparent precoder cycling; and transmitting the precoded transmission via the antenna groups.

(10) The present disclosure also provides an apparatus (e.g., a BS) including means for performing at least one of the above methods, and a non-transitory computer-readable medium storing computer-executable instructions for performing at least one of the above methods.

(11) Details of one or more implementations of the subject matter described in this disclosure are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages will become apparent from the description, the drawings and the claims. Note that the relative dimensions of the following figures may not be drawn to scale.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. 1 is a diagram illustrating an example of a wireless communications system including an access network.

(2) FIG. 2A is a diagram illustrating an example of a first frame.

(3) FIG. 2B is a diagram illustrating an example of DL channels within a subframe.

(4) FIG. 2C is a diagram illustrating an example of a second frame.

(5) FIG. 2D is a diagram illustrating an example of a subframe.

(6) FIG. 3 is a diagram illustrating an example of a base station (BS) and user equipment (UE) in an access network.

(7) FIG. 4 is a diagram illustrating an example disaggregated base station architecture.

(8) FIG. 5 is a message diagram illustrating various messages and actions for non-transparent precoder cycling.

(9) FIG. 6A is a diagram of a first set of precoding matrices for non-transparent precoder cycling for two antenna groups.

(10) FIG. 6B is a diagram of a second set of precoding matrices for non-transparent precoder cycling for two antenna groups with a frequency domain resource group size of 4.

(11) FIG. 6C is a diagram of a third set of precoding matrices for non-transparent precoder cycling for 4 antenna groups with a frequency domain resource group size of 4.

(12) FIG. 7 is a conceptual data flow diagram illustrating the data flow between different means/components in an example network node.

(13) FIG. 8 is a conceptual data flow diagram illustrating the data flow between different means/components in an example UE.

(14) FIG. 9 is a flowchart of an example method for a UE to receive a transmission with non-transparent precoder cycling.

(15) FIG. 10 is a flowchart of an example method for a network node (e.g., a BS or gNB) to transmit data with non-transparent precoder cycling.

(16) Like reference numbers and designations in the various drawings indicate like elements.

### DETAILED DESCRIPTION

(17) The following description is directed to certain implementations for the purposes of describing the innovative aspects of this disclosure. However, a person having ordinary skill in the art will readily recognize that the teachings herein can be applied in a multitude of different ways. Some of the examples in this disclosure are based on wireless and wired local area network (LAN) communication according to the Institute of Electrical and Electronics Engineers (IEEE) 802.11 wireless standards, the IEEE 802.3 Ethernet standards, and the IEEE 1901 Powerline communication (PLC) standards. However, the described implementations may be implemented in any device, system or network that is capable of transmitting and receiving RF signals according to any of the wireless communication standards, including any of the IEEE 802.11 standards, the Bluetooth® standard, code division multiple access (CDMA), frequency division multiple access (FDMA), time division multiple access (TDMA), Global System for Mobile communications (GSM), GSM/General Packet Radio Service (GPRS), Enhanced Data GSM Environment (EDGE), Terrestrial Trunked Radio (TETRA), Wideband-CDMA (W-CDMA), Evolution Data Optimized (EV-DO), 1×EV-DO, EV-DO Rev A, EV-DO Rev B, High Speed Packet Access (HSPA), High Speed Downlink Packet Access (HSDPA), High Speed Uplink Packet Access (HSUPA), Evolved High Speed Packet Access (HSPA+), Long Term Evolution (LTE), AMPS, or other known signals that are used to communicate within a wireless, cellular or internet of things (IoT) network, such as a system utilizing 3G, 4G or 5G, or further implementations thereof, technology.

(18) In a wireless communications network such as a 5G NR network, a diversity scheme improves reliability of a message

signal by using two or more communication channels with different characteristics. The channels may be at least partly independent such that multiple versions of the same signal may be transmitted and/or received and combined in the receiver. Problems that affect one channel may be averaged out to improve reliability. In the case of multiple-input multiple-output (MIMO) using multiple antennas or groups of antennas, a precoder may achieve spatial diversity, which may be used with other types of diversity. In open-loop MIMO, feedback from a receiver may be unavailable to assist with precoder selection. Features of an efficient open loop diversity scheme include good performance, small demodulation reference signal (DMRS) overhead, and a transmission scheme consistent with DMRS transmission.

(19) A space-frequency block code (SFBC) is an example diversity scheme for 2-port MIMO using 2 DMRS ports. The two ports may apply to different pols, panels, or beams. SFBC transmission, however, may be inefficient due to the requirement of two antenna ports for a single layer transmission, which has lower spectral efficiency than multi-layer transmissions. Further, multiple transmission schemes for the same channel may complicate UE implementation and limit interference aware advanced reception techniques.

(20) An open-loop MIMO technique used in, for example, 5G NR networks is PRG level precoder cycling for a physical downlink shared channel. Resource blocks (RBs) may be bundled in groups of 2, 4, or wideband (i.e., all RBs). A different precoder may be applied to each PRG. A large bundling size requires a large number of RBs for cycling, while a small bundling size degrades channel estimation performance. Thus, there is a tradeoff between diversity gain and channel estimation performance.

(21) Other diversity schemes utilize cyclic delay diversity (CDD), where a different delay is introduced on each antenna port. Small delay CDD utilizes delays less than a cyclic prefix for a symbol. Small delay CDD may be equivalent to resource element (RE) level precoder cycling. Large delay CDD may utilize a DMRS port per rank (R). Each R-port DMRS resource may be precoded by a precoder per sub-array(S). DMRS bundling can be applied at an PRG level while non-transparent precoding is applied at an RE or RB level. This scheme allows high resolution RE or RB level precoding cycling for greater diversity while allowing DMRS bundling size to be kept at PRG level for greater channel estimation performance. However, this scheme uses  $S \times R$  DMRS ports and the data transmission scheme is not consistent with DMRS transmission, resulting in greater complexity.

(22) In an aspect, the present disclosure provides a diversity scheme using non-transparent RB or PRG level precoder cycling based on virtual DMRS ports. A frequency domain resource unit may refer to a level at which precoder cycling is applied. For example, the frequency domain resource unit may be a RB or a PRG. A frequency domain resource group may refer to a number of frequency domain resource units over which the precoder cycling occurs. In an example where the frequency domain resource unit is an RB, the frequency domain resource group may be a PRG with a bundling size of 2 or 4. In another example, where the frequency domain resource group is a PRG, the frequency domain resource group may be a group of PRGs with a bundling size of 2 or 4. A virtual DMRS port may refer to a port corresponding to an antenna group. For example, one virtual DMRS port may provide an R-port DMRS by applying a  $1 \times R$  sub-matrix corresponding to the antenna group to the DMRS sequence.

(23) The diversity scheme utilizes a precoding matrix that is applied to both the data and the DMRS. The precoding matrix includes a number of sub-matrices equal to a number of antenna groups. The precoding matrix is a  $N_{\text{sub.t}} \times R$  precoding matrix, where  $N_{\text{sub.t}}$  is the total number of transmit antennas. The first sub-matrix (e.g.,  $W_{\text{sub}.0}$ ) for a first antenna group is the same for each frequency domain unit. The phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal across the frequency domain resource units of the frequency domain resource group. For each frequency domain resource unit, the actual R-port DMRS to data signal mapping is the identity matrix ( $I_{\text{sub}.R}$ ). For each frequency domain resource group, non-transparent precoding matrix

$$(24) \begin{bmatrix} I_R \\ e^{j2\pi \frac{\text{Math.}[k]_K}{K}} I_R \end{bmatrix}$$

is applied on 2R-port virtual DMRS.

(25) At a receiving device (e.g., a UE), two different DMRS channel estimation and demodulation options are available. In a first option, the DMRS channel estimation is performed per frequency domain resource unit without assuming precoder bundling at a frequency domain resource group level. For interference channel estimation, the same frequency domain resource unit level DMRS estimation is performed. In the second option, a virtual DMRS channel at the frequency domain resource group level may be used for DMRS channel estimation. A per frequency domain resource unit level channel may be calculated based on the non-transparent precoding matrix and the virtual DMRS channel. The data signal may be estimated from the per frequency domain resource unit level channel.

(26) In an aspect, the non-transparent precoder cycling described herein provides a diversity scheme suitable for open-loop MIMO transmissions. As used herein, non-transparent precoder cycling refers to the transmitting device applying different precoders to frequency domain resources units of a transmission in a cycle that is known to the receiving device (i.e., non-transparent). The number of actual DMRS ports is not increased, while non-transparent precoder cycling is applied to provide diversity. From the perspective of a UE, virtual DMRS ports allow wideband (PRG level or group of PRG level) DMRS channel estimation to be performed. At the RB or PRG-level, the transmission scheme is consistent with DMRS ports, reducing complexity. Further, there are multiple receiver implementation options available for non-transparent precoder cycling.

(27) Several aspects of telecommunication systems will now be presented with reference to various apparatus and methods. These apparatus and methods will be described in the following detailed description and illustrated in the accompanying drawings by various blocks, components, circuits, processes, algorithms, etc. (collectively referred to as “elements”). These elements may be implemented using electronic hardware, computer software, or any combination thereof. Whether such elements are implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system.

(28) By way of example, an element, or any portion of an element, or any combination of elements may be implemented as a “processing system” that includes one or more processors. Examples of processors include microprocessors, microcontrollers,

graphics processing units (GPUs), central processing units (CPUs), application processors, digital signal processors (DSPs), reduced instruction set computing (RISC) processors, systems on a chip (SoC), baseband processors, field programmable gate arrays (FPGAs), programmable logic devices (PLDs), state machines, gated logic, discrete hardware circuits, and other suitable hardware configured to perform the various functionality described throughout this disclosure. The processor may include an interface or be coupled to an interface that can obtain or output signals. The processor may obtain signals via the interface and output signals via the interface. In some implementations, the interface may be a printed circuit board (PCB) transmission line. In some other implementations, the interface may include a wireless transmitter, a wireless transceiver, or a combination thereof. For example, the interface may include a radio frequency (RF) transceiver which can be implemented to receive or transmit signals, or both. One or more processors in the processing system may execute software. Software shall be construed broadly to mean instructions, instruction sets, code, code segments, program code, programs, subprograms, software components, applications, software applications, software packages, routines, subroutines, objects, executables, threads of execution, procedures, functions, etc., whether referred to as software, firmware, middleware, microcode, hardware description language, or otherwise.

(29) Accordingly, in one or more example implementations, the functions described may be implemented in hardware, software, or any combination thereof. If implemented in software, the functions may be stored on or encoded as one or more instructions or code on a computer-readable medium. Computer-readable media includes computer storage media, which may be referred to as non-transitory computer-readable media. Non-transitory computer-readable media may exclude transitory signals. Storage media may be any available media that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can include a random-access memory (RAM), a read-only memory (ROM), an electrically erasable programmable ROM (EEPROM), optical disk storage, magnetic disk storage, other magnetic storage devices, combinations of the aforementioned types of computer-readable media, or any other medium that can be used to store computer executable code in the form of instructions or data structures that can be accessed by a computer.

(30) FIG. 1 is a diagram illustrating an example of a wireless communications system and an access network **100**. The wireless communications system (also referred to as a wireless wide area network (WWAN)) includes base stations **102**, UEs **104**, an Evolved Packet Core (EPC) **160**, and another core network **190** (such as a 5G Core (5GC)). The base stations **102** may include macrocells (high power cellular base station) or small cells (low power cellular base station). The macrocells include base stations. The small cells include femtocells, picocells, and microcells. The small cells include femtocells, picocells, and microcells. The base stations **102** can be configured in a Disaggregated RAN (D-RAN) or Open RAN (O-RAN) architecture, where functionality is split between multiple units such as a central unit (CU), one or more distributed units (DUs), or a radio unit (RU). Such architectures may be configured to utilize a protocol stack that is logically split between one or more units (such as one or more CUs and one or more DUs). In some aspects, the CUs may be implemented within an edge RAN node, and in some aspects, one or more DUs may be co-located with a CU, or may be geographically distributed throughout one or multiple RAN nodes. The DUs may be implemented to communicate with one or more RUs.

(31) In some implementations, one or more of the UEs **104** includes a Rx precoder cycling component **140** configured to receive open loop MIMO transmissions with non-transparent precoder cycling. The Rx precoder cycling component **140** includes a precoder selection component **142**, a reception component **144**, a channel estimation component **146**, and a demodulation component **148**. The precoder selection component **142** is configured to select a precoding matrix comprising a number of sub-matrices equal to a number of antenna groups. A first sub-matrix for a first antenna group is the same for each frequency domain resource unit and a phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal across the frequency domain resource units of the frequency domain resource group. The reception component **144** is configured to receive a transmission having non-transparent precoder cycling applied to each frequency domain resource unit of a frequency domain resource group of K frequency domain resource units in which both a data signal and a demodulation reference signal (DMRS) are precoded with the precoding matrix. The channel estimation component **146** is configured to estimate a channel of the transmission based on the precoding matrix. The demodulation component **148** is configured to demodulate the data signal based on the estimated channel.

(32) In some implementations, one or more of the base stations **102** includes a Tx precoder cycling component **120** configured to transmit open loop MIMO transmissions with non-transparent precoder cycling. The Tx precoder cycling component **120** includes a matrix generation component **122**, a precoding component **124**, and a transmission component **126**. The Tx precoder cycling component **120** may optionally include a cyclic delay diversity (CDD) component **128**. The matrix generation component **122** is configured to generate a precoding matrix including a number of sub-matrices equal to a number of antenna groups. A first sub-matrix for a first antenna group is the same for each frequency domain resource unit of a frequency domain resource group of K frequency domain resource units, and a phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal for each frequency domain resource unit of the frequency domain resource group. The precoding component **124** is configured to apply the precoding matrix to both a data signal and a demodulation reference signal (DMRS) of a transmission for each frequency domain resource unit of the frequency domain resource group for non-transparent precoder cycling. The transmission component **126** is configured to transmit the precoded transmission via the antenna groups. The CDD component **128** is configured to precode the data signal with small delay cyclic delay diversity prior to precoding at a PRG-level with the precoding matrix.

(33) The base stations **102** configured for 4G LTE (collectively referred to as Evolved Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (E-UTRAN)) may interface with the EPC **160** through first backhaul links **132** (such as S1 interface), which may be wired or wireless. The base stations **102** configured for 5G NR (collectively referred to as Next Generation RAN (NG-RAN)) may interface with core network **190** through second backhaul links **184**, which may be wired or wireless. In addition to other functions, the base stations **102** may perform one or more of the following functions: transfer of user data, radio channel ciphering and deciphering, integrity protection, header compression, mobility control functions (such as handover, dual connectivity), inter-cell interference coordination, connection setup and release, load

balancing, for non-access stratum (NAS) messages, NAS node selection, radio access network (RAN) sharing, multimedia broadcast multicast service (MBMS), subscriber and equipment trace, RAN information management (RIM), paging, positioning, and delivery of warning messages. The base stations **102** may communicate directly or indirectly (such as through the EPC **160** or core network **190**) with each other over third backhaul links **134** (such as X2 interface). The third backhaul links **134** may be wired or wireless.

(34) The base stations **102** may wirelessly communicate with the UEs **104**. Each of the base stations **102** may provide communication coverage for a respective geographic coverage area **110**. There may be overlapping geographic coverage areas **110**. For example, the small cell **102'** may have a coverage area **110'** that overlaps the coverage area **110** of one or more macro base stations **102**. A network that includes both small cell and macrocells may be known as a heterogeneous network. A heterogeneous network also may include Home Evolved Node Bs (eNBs) (HeNBs), which may provide service to a restricted group known as a closed subscriber group (CSG). The communication links **112** between the base stations **102** and the UEs **104** may include UL (also referred to as reverse link) transmissions from a UE **104** to a base station **102** or DL (also referred to as forward link) transmissions from a base station **102** to a UE **104**. The communication links **112** may use multiple-input and multiple-output (MIMO) antenna technology, including spatial multiplexing, beamforming, or transmit diversity. The communication links may be through one or more carriers. The base stations **102**/UEs **104** may use spectrum up to Y MHz (such as 5, 10, 15, 20, 100, 400, etc. MHz) bandwidth per carrier allocated in a carrier aggregation of up to a total of Yx MHz (x component carriers) used for transmission in each direction. The carriers may or may not be adjacent to each other. Allocation of carriers may be asymmetric with respect to DL and UL (such as more or fewer carriers may be allocated for DL than for UL). The component carriers may include a primary component carrier and one or more secondary component carriers. A primary component carrier may be referred to as a primary cell (PCell) and a secondary component carrier may be referred to as a secondary cell (SCell).

(35) Certain UEs **104** may communicate with each other using device-to-device (D2D) communication link **158**. The D2D communication link **158** may use the DL/UL WWAN spectrum. The D2D communication link **158** may use one or more sidelink channels, such as a physical sidelink broadcast channel (PSBCH), a physical sidelink discovery channel (PSDCH), a physical sidelink shared channel (PSSCH), and a physical sidelink control channel (PSCCH). D2D communication may be through a variety of wireless D2D communications systems, such as for example, FlashLinQ, WiMedia, Bluetooth, ZigBee, Wi-Fi based on the IEEE 802.11 standard, LTE, or NR.

(36) The wireless communications system may further include a Wi-Fi access point (AP) **150** in communication with Wi-Fi stations (STAs) **152** via communication links **154** in a 5 GHz unlicensed frequency spectrum. When communicating in an unlicensed frequency spectrum, the STAs **152**/AP **150** may perform a clear channel assessment (CCA) prior to communicating in order to determine whether the channel is available.

(37) The small cell **102'** may operate in a licensed or an unlicensed frequency spectrum. When operating in an unlicensed frequency spectrum, the small cell **102'** may employ NR and use the same 5 GHz unlicensed frequency spectrum as used by the Wi-Fi AP **150**. The small cell **102'**, employing NR in an unlicensed frequency spectrum, may boost coverage to or increase capacity of the access network.

(38) A base station **102**, whether a small cell **102'** or a large cell (such as macro base station), may include an eNB, gNodeB (gNB), or other type of base station. Some base stations, such as gNB **180** may operate in one or more frequency bands within the electromagnetic spectrum.

(39) The electromagnetic spectrum is often subdivided, based on frequency/wavelength, into various classes, bands, channels, etc. In 5G NR two initial operating bands have been identified as frequency range designations FR1 (410 MHz-7.125 GHz) and FR2 (24.25 GHz-52.6 GHz). The frequencies between FR1 and FR2 are often referred to as mid-band frequencies. Although a portion of FR1 is greater than 6 GHz, FR1 is often referred to (interchangeably) as a "Sub-6 GHz" band in various documents and articles. A similar nomenclature issue sometimes occurs with regard to FR2, which is often referred to (interchangeably) as a "millimeter wave" (mmW) band in documents and articles, despite being different from the extremely high frequency (EHF) band (30 GHz-300 GHz) which is identified by the International Telecommunications Union (ITU) as a "millimeter wave" band.

(40) With the above aspects in mind, unless specifically stated otherwise, it should be understood that the term "sub-6 GHz" or the like if used herein may broadly represent frequencies that may be less than 6 GHz, may be within FR1, or may include mid-band frequencies. Further, unless specifically stated otherwise, it should be understood that the term "millimeter wave" or the like if used herein may broadly represent frequencies that may include mid-band frequencies, may be within FR2, or may be within the EHF band. Communications using the mmW radio frequency band have extremely high path loss and a short range. The mmW base station **180** may utilize beamforming **182** with the UE **104** to compensate for the path loss and short range.

(41) The EPC **160** may include a Mobility Management Entity (MME) **162**, other MMEs **164**, a Serving Gateway **166**, a Multimedia Broadcast Multicast Service (MBMS) Gateway **168**, a Broadcast Multicast Service Center (BM-SC) **170**, and a Packet Data Network (PDN) Gateway **172**. The MME **162** may be in communication with a Home Subscriber Server (HSS) **174**. The MME **162** is the control node that processes the signaling between the UEs **104** and the EPC **160**. Generally, the MME **162** provides bearer and connection management. All user Internet protocol (IP) packets are transferred through the Serving Gateway **166**, which itself is connected to the PDN Gateway **172**. The PDN Gateway **172** provides UE IP address allocation as well as other functions. The PDN Gateway **172** and the BM-SC **170** are connected to the IP Services **176**. The IP Services **176** may include the Internet, an intranet, an IP Multimedia Subsystem (IMS), a PS Streaming Service, or other IP services. The BM-SC **170** may provide functions for MBMS user service provisioning and delivery. The BM-SC **170** may serve as an entry point for content provider MBMS transmission, may be used to authorize and initiate MBMS Bearer Services within a public land mobile network (PLMN), and may be used to schedule MBMS transmissions. The MBMS Gateway **168** may be used to distribute MBMS traffic to the base stations **102** belonging to a Multicast Broadcast Single Frequency Network (MBSFN) area broadcasting a particular service, and may be responsible for session management (start/stop) and for collecting eMBMS related

charging information.

(42) The core network **190** may include an Access and Mobility Management Function (AMF) **192**, other AMFs **193**, a Session Management Function (SMF) **194**, and a User Plane Function (UPF) **195**. The AMF **192** may be in communication with a Unified Data Management (UDM) **196**. The AMF **192** is the control node that processes the signaling between the UEs **104** and the core network **190**. Generally, the AMF **192** provides QoS flow and session management. All user Internet protocol (IP) packets are transferred through the UPF **195**. The UPF **195** provides UE IP address allocation as well as other functions. The UPF **195** is connected to the IP Services **197**. The IP Services **197** may include the Internet, an intranet, an IP Multimedia Subsystem (IMS), a PS Streaming Service, or other IP services.

(43) The base station may include or be referred to as a gNB, Node B, eNB, an access point, a base transceiver station, a radio base station, a radio transceiver, a transceiver function, a basic service set (BSS), an extended service set (ESS), a transmit reception point (TRP), or some other suitable terminology. The base station **102** provides an access point to the EPC **160** or core network **190** for a UE **104**. Examples of UEs **104** include a cellular phone, a smart phone, a session initiation protocol (SIP) phone, a laptop, a personal digital assistant (PDA), a satellite radio, a global positioning system, a multimedia device, a video device, a digital audio player (such as a MP3 player), a camera, a game console, a tablet, a smart device, a wearable device, a vehicle, an electric meter, a gas pump, a large or small kitchen appliance, a healthcare device, an implant, a sensor/actuator, a display, or any other similar functioning device. Some of the UEs **104** may be referred to as IoT devices (such as a parking meter, gas pump, toaster, vehicles, heart monitor, etc.). The UE **104** also may be referred to as a station, a mobile station, a subscriber station, a mobile unit, a subscriber unit, a wireless unit, a remote unit, a mobile device, a wireless device, a wireless communications device, a remote device, a mobile subscriber station, an access terminal, a mobile terminal, a wireless terminal, a remote terminal, a handset, a user agent, a mobile client, a client, or some other suitable terminology.

(44) Although the following description may be focused on 5G NR, the concepts described herein may be applicable to other similar areas, such as LTE, LTE-A, CDMA, GSM, and other wireless technologies including future 6G technologies.

(45) FIG. 2A is a diagram **200** illustrating an example of a first frame. FIG. 2B is a diagram **230** illustrating an example of DL channels within a subframe. FIG. 2C is a diagram **250** illustrating an example of a second frame. FIG. 2D is a diagram **280** illustrating an example of a subframe. The 5G NR frame structure may be FDD in which for a particular set of subcarriers (carrier system bandwidth), subframes within the set of subcarriers are dedicated for either DL or UL, or may be TDD in which for a particular set of subcarriers (carrier system bandwidth), subframes within the set of subcarriers are dedicated for both DL and UL. A subset of the total cell bandwidth of a cell is referred to as a Bandwidth Part (BWP) and bandwidth adaptation is achieved by configuring the UE with BWP(s) and telling the UE which of the configured BWPs is currently the active one. In an aspect, a narrow bandwidth part (NBWP) refers to a BWP having a bandwidth less than or equal to a maximum configurable bandwidth of a BWP. The bandwidth of the NBWP is less than the carrier system bandwidth.

(46) In the examples provided by FIGS. 2A, 2C, the 5G NR frame structure is assumed to be TDD, with subframe **4** being configured with slot format **28** (with mostly DL), where D is DL, U is UL, and X is flexible for use between DL/UL, and subframe **3** being configured with slot format **34** (with mostly UL). While subframes **3**, **4** are shown with slot formats **34**, **28**, respectively, any particular subframe may be configured with any of the various available slot formats 0-61. Slot formats **0**, **1** are all DL, UL, respectively. Other slot formats 2-61 include a mix of DL, UL, and flexible symbols. UEs are configured with the slot format (dynamically through DL control information (DCI), or semi-statically/statically through radio resource control (RRC) signaling) through a received slot format indicator (SFI). Note that the description infra applies also to a 5G NR frame structure that is TDD.

(47) Other wireless communication technologies may have a different frame structure or different channels. A frame (10 milliseconds (ms)) may be divided into 10 equally sized subframes (1 ms). Each subframe may include one or more time slots. Subframes also may include mini-slots, which may include 7, 4, or 2 symbols. Each slot may include 7 or 14 symbols, depending on the slot configuration. For slot configuration 0, each slot may include 14 symbols, and for slot configuration 1, each slot may include 7 symbols. The symbols on DL may be cyclic prefix (CP) OFDM (CP-OFDM) symbols. The symbols on UL may be CP-OFDM symbols (for high throughput scenarios) or discrete Fourier transform (DFT) spread OFDM (DFT-s-OFDM) symbols (also referred to as single carrier frequency-division multiple access (SC-FDMA) symbols) (for power limited scenarios; limited to a single stream transmission). The number of slots within a subframe is based on the slot configuration and the numerology. For slot configuration 0, different numerologies  $\mu$  0 to 5 allow for 1, 2, 4, 8, 16, and 32 slots, respectively, per subframe. For slot configuration 1, different numerologies 0 to 2 allow for 2, 4, and 8 slots, respectively, per subframe. Accordingly, for slot configuration 0 and numerology  $u$ , there are 14 symbols/slot and 24 slots/subframe. The subcarrier spacing and symbol length/duration are a function of the numerology. The subcarrier spacing may be equal to  $2^{\text{sup.}\mu} \times 15$  kHz, where  $u$  is the numerology 0 to 5. As such, the numerology  $\mu=0$  has a subcarrier spacing of 15 kHz and the numerology  $\mu=5$  has a subcarrier spacing of 480 kHz. The symbol length/duration is inversely related to the subcarrier spacing. FIGS. 2A-2D provide an example of slot configuration 0 with 14 symbols per slot and numerology  $\mu=2$  with 4 slots per subframe. The slot duration is 0.25 ms, the subcarrier spacing is 60 kHz, and the symbol duration is approximately 16.67 microseconds ( $\mu\text{s}$ ).

(48) A resource grid may be used to represent the frame structure. Each time slot includes a resource block (RB) (also referred to as physical RBs (PRBs)) that extends **12** consecutive subcarriers. The resource grid is divided into multiple resource elements (REs). The number of bits carried by each RE depends on the modulation scheme.

(49) As illustrated in FIG. 2A, some of the REs carry reference (pilot) signals (RS) for the UE. The RS may include demodulation RS (DMRS) (indicated as Rx for one particular configuration, where **100x** is the port number, but other DM-RS configurations are possible) and channel state information reference signals (CSI-RS) for channel estimation at the UE. The RS also may include beam measurement RS (BRS), beam refinement RS (BRRS), and phase tracking RS (PT-RS).

(50) FIG. 2B illustrates an example of various DL channels within a subframe of a frame. The physical downlink control channel (PDCCH) carries DCI within one or more control channel elements (CCEs), each CCE including nine RE groups (REGs), each REG including four consecutive REs in an OFDM symbol. A primary synchronization signal (PSS) may be within

symbol **2** of particular subframes of a frame. The PSS is used by a UE **104** to determine subframe/symbol timing and a L1 identity. A secondary synchronization signal (SSS) may be within symbol **4** of particular subframes of a frame. The SSS is used by a UE to determine a L1 cell identity group number and radio frame timing. Based on the L1 identity and the L1 cell identity group number, the UE can determine a physical cell identifier (PCI). Based on the PCI, the UE can determine the locations of the aforementioned DMRS. The physical broadcast channel (PBCH), which carries a master information block (MIB), may be logically grouped with the PSS and SSS to form a synchronization signal (SS)/PBCH block (SSB). The MIB provides a number of RBs in the system bandwidth and a system frame number (SFN). The physical downlink shared channel (PDSCH) carries user data, broadcast system information not transmitted through the PBCH such as system information blocks (SIBs), and paging messages.

(51) As illustrated in FIG. 2C, some of the REs carry DM-RS (indicated as R for one particular configuration, but other DM-RS configurations are possible) for channel estimation at the base station. The UE may transmit DM-RS for the physical uplink control channel (PUCCH) and DM-RS for the physical uplink shared channel (PUSCH). The PUSCH DM-RS may be transmitted in the first one or two symbols of the PUSCH. The PUCCH DM-RS may be transmitted in different configurations depending on whether short or long PUCCHs are transmitted and depending on the particular PUCCH format used. The UE may transmit sounding reference signals (SRS). The SRS may be transmitted in the last symbol of a subframe. The SRS may have a comb structure, and a UE may transmit SRS on one of the combs. The SRS may be used by a base station for channel quality estimation to enable frequency-dependent scheduling on the UL.

(52) FIG. 2D illustrates an example of various UL channels within a subframe of a frame. The PUCCH may be located as indicated in one configuration. The PUCCH carries uplink control information (UCI), such as scheduling requests, a channel quality indicator (CQI), a precoding matrix indicator (PMI), a rank indicator (RI), and HARQ ACK/NACK feedback. The PUSCH carries data, and may additionally be used to carry a buffer status report (BSR), a power headroom report (PHR), or UCI.

(53) FIG. 3 is a diagram of an example of a base station **310** and a UE **350** in an access network. In the DL, IP packets from the EPC **160** may be provided to a controller/processor **375**. The controller/processor **375** implements layer **3** and layer **2** functionality. Layer **3** includes a radio resource control (RRC) layer, and layer **2** includes a service data adaptation protocol (SDAP) layer, a packet data convergence protocol (PDCP) layer, a radio link control (RLC) layer, and a medium access control (MAC) layer. The controller/processor **375** provides RRC layer functionality associated with broadcasting of system information (such as MIB, SIBs), RRC connection control (such as RRC connection paging, RRC connection establishment, RRC connection modification, and RRC connection release), inter radio access technology (RAT) mobility, and measurement configuration for UE measurement reporting; PDCP layer functionality associated with header compression/decompression, security (ciphering, deciphering, integrity protection, integrity verification), and handover support functions; RLC layer functionality associated with the transfer of upper layer packet data units (PDUs), error correction through ARQ, concatenation, segmentation, and reassembly of RLC service data units (SDUs), re-segmentation of RLC data PDUs, and reordering of RLC data PDUs; and MAC layer functionality associated with mapping between logical channels and transport channels, multiplexing of MAC SDUs onto transport blocks (TBs), demultiplexing of MAC SDUs from TBs, scheduling information reporting, error correction through HARQ, priority handling, and logical channel prioritization.

(54) The transmit (TX) processor **316** and the receive (RX) processor **370** implement layer **1** functionality associated with various signal processing functions. Layer **1**, which includes a physical (PHY) layer, may include error detection on the transport channels, forward error correction (FEC) coding/decoding of the transport channels, interleaving, rate matching, mapping onto physical channels, modulation/demodulation of physical channels, and MIMO antenna processing. The TX processor **316** handles mapping to signal constellations based on various modulation schemes (such as binary phase-shift keying (BPSK), quadrature phase-shift keying (QPSK), M-phase-shift keying (M-PSK), M-quadrature amplitude modulation (M-QAM)). The coded and modulated symbols may be split into parallel streams. Each stream may be mapped to an OFDM subcarrier, multiplexed with a reference signal (such as a pilot) in the time or frequency domain, and combined together using an Inverse Fast Fourier Transform (IFFT) to produce a physical channel carrying a time domain OFDM symbol stream. The OFDM stream is spatially precoded to produce multiple spatial streams. Channel estimates from a channel estimator **374** may be used to determine the coding and modulation scheme, as well as for spatial processing. The channel estimate may be derived from a reference signal or channel condition feedback transmitted by the UE **350**. Each spatial stream may be provided to a different antenna **320** via a separate transmitter **318TX**. Each transmitter **318TX** may modulate an RF carrier with a respective spatial stream for transmission.

(55) At the UE **350**, each receiver **354RX** receives a signal through its respective antenna **352**. Each receiver **354RX** recovers information modulated onto an RF carrier and provides the information to the receive (RX) processor **356**. The TX processor **368** and the RX processor **356** implement layer **1** functionality associated with various signal processing functions. The RX processor **356** may perform spatial processing on the information to recover any spatial streams destined for the UE **350**. If multiple spatial streams are destined for the UE **350**, they may be combined by the RX processor **356** into a single OFDM symbol stream. The RX processor **356** converts the OFDM symbol stream from the time-domain to the frequency domain using a Fast Fourier Transform (FFT). The frequency domain signal includes a separate OFDM symbol stream for each subcarrier of the OFDM signal. The symbols on each subcarrier, and the reference signal, are recovered and demodulated by determining the most likely signal constellation points transmitted by the base station **310**. These soft decisions may be based on channel estimates computed by the channel estimator **358**. The soft decisions are decoded and deinterleaved to recover the data and control signals that were originally transmitted by the base station **310** on the physical channel. The data and control signals are provided to the controller/processor **359**, which implements layer **3** and layer **2** functionality.

(56) The controller/processor **359** can be associated with a memory **360** that stores program codes and data. The memory **360** may be referred to as a computer-readable medium and may be any of the types of computer-readable mediums discussed herein (e.g., RAM, ROM, EEPROM, optical disk storage, magnetic disk storage, other magnetic storage devices, combinations of the



aforementioned types of computer-readable media, or any other medium that can be used to store computer executable code in the form of instructions or data structures that can be accessed by a computer). In the UL, the controller/processor 359 provides demultiplexing between transport and logical channels, packet reassembly, deciphering, header decompression, and control signal processing to recover IP packets from the EPC 160. The controller/processor 359 is also responsible for error detection using an ACK or NACK protocol to support HARQ operations.

(57) Similar to the functionality described in connection with the DL transmission by the base station 310, the controller/processor 359 provides RRC layer functionality associated with system information (such as MIB, SIBs) acquisition, RRC connections, and measurement reporting; PDCP layer functionality associated with header compression/decompression, and security (ciphering, deciphering, integrity protection, integrity verification); RLC layer functionality associated with the transfer of upper layer PDUs, error correction through ARQ, concatenation, segmentation, and reassembly of RLC SDUs, re-segmentation of RLC data PDUs, and reordering of RLC data PDUs; and MAC layer functionality associated with mapping between logical channels and transport channels, multiplexing of MAC SDUs onto TBs, demultiplexing of MAC SDUs from TBs, scheduling information reporting, error correction through HARQ, priority handling, and logical channel prioritization.

(58) Channel estimates derived by a channel estimator 358 from a reference signal or feedback transmitted by the base station 310 may be used by the TX processor 368 to select the appropriate coding and modulation schemes, and to facilitate spatial processing. The spatial streams generated by the TX processor 368 may be provided to different antenna 352 via separate transmitters 354TX. Each transmitter 354TX may modulate an RF carrier with a respective spatial stream for transmission.

(59) The UL transmission is processed at the base station 310 in a manner similar to that described in connection with the receiver function at the UE 350. Each receiver 318RX receives a signal through its respective antenna 320. Each receiver 318RX recovers information modulated onto an RF carrier and provides the information to a RX processor 370.

(60) The controller/processor 375 can be associated with a memory 376 that stores program codes and data. The memory 376 may be referred to as a computer-readable medium and may be any of the types of computer-readable mediums discussed herein (e.g., RAM, ROM, EEPROM, optical disk storage, magnetic disk storage, other magnetic storage devices, combinations of the aforementioned types of computer-readable media, or any other medium that can be used to store computer executable code in the form of instructions or data structures that can be accessed by a computer). In the UL, the controller/processor 375 provides demultiplexing between transport and logical channels, packet reassembly, deciphering, header decompression, control signal processing to recover IP packets from the UE 350. IP packets from the controller/processor 375 may be provided to the EPC 160. The controller/processor 375 is also responsible for error detection using an ACK or NACK protocol to support HARQ operations.

(61) At least one of the TX processor 368, the RX processor 356, and the controller/processor 359 may be configured to perform aspects in connection with the Rx precoder cycling component 140 of FIG. 1. For example, the memory 360 may include executable instructions defining the Rx precoder cycling component 140. The TX processor 368, the RX processor 356, and/or the controller/processor 359 may be configured to execute the Rx precoder cycling component 140.

(62) At least one of the TX processor 316, the RX processor 370, and the controller/processor 375 may be configured to perform aspects in connection with the Tx precoder cycling component 120 of FIG. 1. For example, the memory 376 may include executable instructions defining the Tx precoder cycling component 120. The TX processor 316, the RX processor 370, and/or the controller/processor 375 may be configured to execute the Tx precoder cycling component 120.

(63) FIG. 4 is a diagram illustrating an example disaggregated base station 400 architecture. The disaggregated base station 400 architecture may include one or more central units (CUs) 410 that can communicate directly with a core network 420 via a backhaul link, or indirectly with the core network 420 through one or more disaggregated base station units (such as a Near-Real Time (Near-RT) RAN Intelligent Controller (RIC) 425 via an E2 link, or a Non-Real Time (Non-RT) RIC 415 associated with a Service Management and Orchestration (SMO) Framework 405, or both). A CU 410 may communicate with one or more distributed units (DUs) 430 via respective midhaul links, such as an F1 interface. The DUs 430 may communicate with one or more radio units (RUs) 440 via respective fronthaul links. The RUs 440 may communicate with respective UEs 104 via one or more radio frequency (RF) access links. In some implementations, the UE 104 may be simultaneously served by multiple RUs 440.

(64) Each of the units, i.e., the CUS 410, the DUs 430, the RUs 440, as well as the Near-RT RICs 425, the Non-RT RICs 415 and the SMO Framework 405, may include one or more interfaces or be coupled to one or more interfaces configured to receive or transmit signals, data, or information (collectively, signals) via a wired or wireless transmission medium. Each of the units, or an associated processor or controller providing instructions to the communication interfaces of the units, can be configured to communicate with one or more of the other units via the transmission medium. For example, the units can include a wired interface configured to receive or transmit signals over a wired transmission medium to one or more of the other units. Additionally, the units can include a wireless interface, which may include a receiver, a transmitter or transceiver (such as a radio frequency (RF) transceiver), configured to receive or transmit signals, or both, over a wireless transmission medium to one or more of the other units.

(65) In some aspects, the CU 410 may host one or more higher layer control functions. Such control functions can include radio resource control (RRC), packet data convergence protocol (PDCP), service data adaptation protocol (SDAP), or the like. Each control function can be implemented with an interface configured to communicate signals with other control functions hosted by the CU 410. The CU 410 may be configured to handle user plane functionality (i.e., Central Unit-User Plane (CU-UP)), control plane functionality (i.e., Central Unit-Control Plane (CU-CP)), or a combination thereof. In some implementations, the CU 410 can be logically split into one or more CU-UP units and one or more CU-CP units. The CU-UP unit can communicate bidirectionally with the CU-CP unit via an interface, such as the E1 interface when implemented in an O-RAN configuration. The CU 410 can be implemented to communicate with the DU 430, as necessary, for network control and signaling.

(66) The DU 430 may correspond to a logical unit that includes one or more base station functions to control the operation of one or more RUs 440. In some aspects, the DU 430 may host one or more of a radio link control (RLC) layer, a medium access

control (MAC) layer, and one or more high physical (PHY) layers (such as modules for forward error correction (FEC) encoding and decoding, scrambling, modulation and demodulation, or the like) depending, at least in part, on a functional split, such as those defined by the 3rd Generation Partnership Project (3GPP). In some aspects, the DU **430** may further host one or more low PHY layers. Each layer (or module) can be implemented with an interface configured to communicate signals with other layers (and modules) hosted by the DU **430**, or with the control functions hosted by the CU **410**.

(67) Lower-layer functionality can be implemented by one or more RUs **440**. In some deployments, an RU **440**, controlled by a DU **430**, may correspond to a logical node that hosts RF processing functions, or low-PHY layer functions (such as performing fast Fourier transform (FFT), inverse FFT (iFFT), digital beamforming, physical random access channel (PRACH) extraction and filtering, or the like), or both, based at least in part on the functional split, such as a lower layer functional split. In such an architecture, the RU(s) **440** can be implemented to handle over the air (OTA) communication with one or more UEs **104**. In some implementations, real-time and non-real-time aspects of control and user plane communication with the RU(s) **440** can be controlled by the corresponding DU **430**. In some scenarios, this configuration can enable the DU(s) **430** and the CU **410** to be implemented in a cloud-based RAN architecture, such as a vRAN architecture.

(68) The SMO Framework **405** may be configured to support RAN deployment and provisioning of non-virtualized and virtualized network elements. For non-virtualized network elements, the SMO Framework **405** may be configured to support the deployment of dedicated physical resources for RAN coverage requirements which may be managed via an operations and maintenance interface (such as an O1 interface). For virtualized network elements, the SMO Framework **405** may be configured to interact with a cloud computing platform (such as an open cloud (O-Cloud) **490**) to perform network element life cycle management (such as to instantiate virtualized network elements) via a cloud computing platform interface (such as an O2 interface). Such virtualized network elements can include, but are not limited to, CUs **410**, DUs **430**, RUs **440** and Near-RT RICs **425**. In some implementations, the SMO Framework **405** can communicate with a hardware aspect of a 4G RAN, such as an open eNB (O-eNB) **411**, via an O1 interface. Additionally, in some implementations, the SMO Framework **405** can communicate directly with one or more RUs **440** via an O1 interface. The SMO Framework **405** also may include a Non-RT RIC **415** configured to support functionality of the SMO Framework **405**.

(69) The Non-RT RIC **415** may be configured to include a logical function that enables non-real-time control and optimization of RAN elements and resources, Artificial Intelligence/Machine Learning (AI/ML) workflows including model training and updates, or policy-based guidance of applications/features in the Near-RT RIC **425**. The Non-RT RIC **415** may be coupled to or communicate with (such as via an A1 interface) the Near-RT RIC **425**. The Near-RT RIC **425** may be configured to include a logical function that enables near-real-time control and optimization of RAN elements and resources via data collection and actions over an interface (such as via an E2 interface) connecting one or more CUs **410**, one or more DUs **430**, or both, as well as an O-eNB, with the Near-RT RIC **425**.

(70) In some implementations, to generate AI/ML models to be deployed in the Near-RT RIC **425**, the Non-RT RIC **415** may receive parameters or external enrichment information from external servers. Such information may be utilized by the Near-RT RIC **425** and may be received at the SMO Framework **405** or the Non-RT RIC **415** from non-network data sources or from network functions. In some examples, the Non-RT RIC **415** or the Near-RT RIC **425** may be configured to tune RAN behavior or performance. For example, the Non-RT RIC **415** may monitor long-term trends and patterns for performance and employ AI/ML models to perform corrective actions through the SMO Framework **405** (such as reconfiguration via O1) or via creation of RAN management policies (such as A1 policies).

(71) FIG. 5 is a message diagram **500** illustrating various messages for open loop MIMO with precoder cycling. The UE **104** may be in communication with one or more base stations **502**. The base station **502** may provide a primary cell and/or secondary cells.

(72) In an aspect, open loop MIMO may be used for broadcast data and control channels, and for communications before an RRC connection is established or as fallback in case of unreliable channel state information feedback. Accordingly, open loop MIMO may operate with minimal signaling.

(73) A base station **502** may transmit a synchronization signal block (SSB) **505**. The SSB **505** may include a primary synchronization signal (PSS), a secondary synchronization signal (SSS), and a physical broadcast channel (PBCH). The PBCH may carry some information for the cell provided by the base station **502**. For example, the PBCH may indicate a location for system information **510**. The base station **502** may transmit the system information **510**. The system information **510** may include parameters for open loop MIMO transmissions. For example, the system information **510** may indicate a number of antenna groups and a number of layers for various channels.

(74) In some implementations, the UE **104** may transmit a capability message **515** that indicates a capability of the UE with respect to precoder cycling. For example, the capability message **515** may indicate a capability for RB level or PRG level precoder cycling.

(75) In some implementations, the base station **502** may transmit an RRC configuration **520**. The RRC configuration **520** may indicate non-transparent precoder cycling parameters such as a frequency domain resource unit size or a frequency domain resource group size (K). The RRC configuration **520** may also configure a number of antenna groups.

(76) The base station **502** may perform precoding **530** using non-transparent precoder cycling. For example, the base station **502** may generate a precoding matrix and apply the precoding matrix to both a data signal and a DMRS of a transmission **540**. For instance, the transmission **540** may be one of a broadcast data transmission, a control channel, a transmission prior to radio resource control connection establishment, or a fallback transmission. The base station **502** transmits the precoded transmission **540** (e.g., PDSCH) via the antenna groups.

(77) The UE **104** receives the transmission **540** and performs channel estimation **550** based on the precoding matrix. For example, the channel estimation may be per frequency domain resource unit or per virtual DMRS channel. The UE **104** performs demodulation **560** of the transmission **540** based on the channel estimates.

(78) FIG. 6A is a diagram of a first set **600** of precoding matrices **602** (e.g., **602a** and **602b**) for non-transparent precoder cycling

for two antenna groups, where the size of each precoding matrix is  $N_{\text{sub.t}} \times R$  and  $N_{\text{sub.t}}$  is the number of transmit antennas of the base station **502**. Each precoding matrix **602** in the first set **600** includes two sub-matrices corresponding to two antenna groups. A first sub-matrix ( $W_{\text{sub.0}}$ ) for a first antenna group is the same for each frequency domain resource unit (e.g., **RB0** and **RB1**) of a frequency domain resource group of  $K$  (e.g.,  $K=2$ ) frequency domain resource units. That is, each precoding matrix **602** includes a same first sub-matrix  $W_{\text{sub.0}}$ . A phase of each subsequent

$$(79) (e.g., \text{by } e^{j2 \frac{\text{Math.}[k]_K}{K}})$$

(80) sub-matrix ( $W_{\text{sub.1}}$ ) for each subsequent antenna group is shifted to be orthogonal for each frequency domain resource unit of the frequency domain resource group. The term  $k$  is an index of a frequency domain resource unit and  $[k]_{\text{sub.K}}$  is an index of the frequency domain resource unit within the frequency domain resource group (e.g.,  $k \bmod K$ ). Each sub-matrix  $W_{\text{sub.i}}$  may be a  $(N_{\text{sub.t}}/2) \times R$  matrix.

(81) FIG. **6B** is a diagram of a second set **610** of precoding matrices **612** (e.g., **612a**, **612b**, **612c**, **612d**) for non-transparent precoder cycling for two antenna groups with a frequency domain resource group size of 4. Each precoding matrix **612** in the second set **610** includes two sub-matrices corresponding to two antenna groups. A first sub-matrix ( $W_{\text{sub.0}}$ ) for a first antenna group is the same for each frequency domain resource unit (e.g., **RB**) of a frequency domain resource group of  $K$  (e.g.,  $K=4$ ) frequency domain resource units. A phase of each subsequent sub-matrix ( $W_{\text{sub.1}}$ ) for each subsequent antenna group is shifted

$$(82) (e.g., \text{by } e^{j2 \frac{\text{Math.}[k]_K}{K}})$$

to be orthogonal for each frequency domain resource unit of the frequency domain resource group. The term  $k$  is an index of a frequency domain resource unit and  $[k]$  is an index of the frequency domain resource unit within the frequency domain resource group (e.g.,  $k \bmod K$ ).

(83) FIG. **6C** is a diagram of a third set **620** of precoding matrices **622** (e.g., **622a**, **622b**, **622c**, and **622d**) for non-transparent precoder cycling for 4 antenna groups with a frequency domain resource group size of 4. Each precoding matrix **622** in the third set **620** includes four sub-matrices corresponding to the four antenna groups. A first sub-matrix ( $W_{\text{sub.0}}$ ) for a first antenna group is the same for each frequency domain resource unit (e.g., **RB**) of a frequency domain resource group of  $K$  (e.g.,  $K=4$ ) frequency domain resource units. A phase of each subsequent sub-matrix ( $W_{\text{sub.1}}$ ,  $W_{\text{sub.2}}$ ,  $W_{\text{sub.3}}$ ) for each subsequent antenna group is shifted (e.g., by a factor of

$$(84) (e.g., \text{by } e^{j2 \frac{\text{Math.}[k]_K}{K}})$$

to be orthogonal for each frequency domain resource unit of the frequency domain resource group. For the first frequency domain resource unit (**RB0**),  $k$  is 0, so the sub-matrix  $W_{\text{sub.1}}$  is not shifted. For the other resource blocks, each subsequent sub-matrix is shifted by another factor of

$$(85) e^{j2 \frac{[k]_K}{K}}.$$

For instance, for the third frequency domain resource unit (**RB2**) where  $k=2$ , the phase of the third subsequent sub-matrix  $W_{\text{sub.3}}$  is shifted by a factor of

$$(86) e^{j2 \frac{\text{Math.2.Math.3}}{K}} = e^{j2 \frac{\text{Math.6}}{K}}.$$

(87) The defined non-transparent precoder cycling allows the receiving device (e.g., UE **104**) to perform channel estimation for either the frequency domain resource unit or the frequency domain resource group based on the precoding matrix and/or the virtual DMRS port. That is, the phase shift values applied to the precoding matrix are known to the UE **104**. The UE may perform channel estimation based on the phase shift values. In some cases, the DMRS to data signal mapping is the identity matrix, simplifying the channel estimation.

(88) FIG. **7** is a conceptual data flow diagram **700** illustrating the data flow between different means/components in an example base station **102**, which may be an example of the base station **102** (FIG. **1**) including the Tx precoder cycling component **120**. The Tx precoder cycling component **120** may be implemented by the memory **376** and the TX processor **316**, the RX processor **370**, and/or the controller/processor **375** of FIG. **3**. For example, the memory **376** may store executable instructions defining the Tx precoder cycling component **120** and the TX processor **316**, the RX processor **370**, and/or the controller/processor **375** may execute the instructions.

(89) The base station **102** may include a receiver component **770**, which may include, for example, a radio frequency (RF) receiver for receiving the signals described herein. The base station **102** may include a transmitter component **772**, which may include, for example, an RF transmitter for transmitting the signals described herein. The transmitter component **772** may output RF signals to a plurality of antenna groups **774**. In an aspect, the receiver component **770** and the transmitter component **772** may be co-located in a transceiver such as illustrated by the TX/RX **318** in FIG. **3**.

(90) As discussed with respect to FIG. **1**, the Tx precoder cycling component **120** may include the matrix generation component **122**, the precoding component **124**, and the transmission component **126**. In some implementations, the Tx precoder cycling component **120** may optionally include the CDD component **128**.

(91) The receiver component **770** may receive UL signals from the UE **104** such as the capability message **515**. The receiver component **770** may output the capability message **515** to the matrix generation component **122**.

(92) The matrix generation component **122** is configured to generate a precoding matrix comprising a number of sub-matrices equal to a number of antenna groups. In some implementations, the precoding matrix is an  $N_{\text{sub.t}} \times R$  matrix, where  $R$  is a rank of the transmission. With such a precoding matrix, an  $R$ -port DMRS to data signal mapping is an identity matrix of size  $R$ . The precoding matrix may be one of the example precoding matrices discussed above with respect to FIGS. **6A-6C**. A first sub-matrix for a first antenna group is the same for each frequency domain resource unit of a frequency domain resource group of  $K$  frequency domain resource units. A phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal for each frequency domain resource unit of the frequency domain resource group. The matrix generation component **122** outputs the sets **600**, **610**, **620** of precoding matrices **602**, **612**, **622** to the precoding component **124**.

(93) The precoding component **124** is configured to apply a respective precoding matrix **602**, **612**, **622** to both a data signal **722**

and a DMRS 732 of a transmission for each frequency domain resource unit of the frequency domain resource group for non-transparent precoder cycling. For example, the precoding component 124 may apply the precoding matrix for each frequency domain resource unit to the respective frequency domain resource unit within the frequency domain resource group. The pattern for the precoding matrix may be repeated for each frequency domain resource group.

(94) In some implementations, the CDD component 128 is configured to precode the data signal with small delay cyclic delay diversity prior to precoding at a PRG-level with the precoding matrix. For example, the data signal may be based on data symbols 720. The CDD component 128 may apply small delay values  $\delta_{\text{sub.0.sup.cyc}}, \dots, \delta_{\text{sub.3.sup.cyc}}$  that are configured to the UE. For example, the small delay values may be configured via the system information 510, the RRC configuration 520, or may be published in a standard or regulation. The CDD component 128 may apply the delay values when the precoding matrix is applied at the PRG level (i.e., the frequency domain resource unit is a PRG). The CDD component 128 outputs the CDD precoded data signal 722 to the precoding component 124.

(95) In an aspect, a port mapping may be defined between DMRS 732 (applying the same precoding to a DMRS sequence 730 as the data signal 722) and a virtual or physical RS (XRS) used to define the CDD transmission. For example, the port mapping in case of two antenna groups may be written as:

$$(96) \quad \begin{matrix} a_{\text{DMRS}}^{(\tilde{p}_0)}(m) \\ \text{DMRS} [ a_{\text{DMRS}}^{(\tilde{p}_0)}(m) ] = \\ \text{Math.} \\ a_{\text{DMRS}}^{(\tilde{p}_R)}(m) \end{matrix} = \begin{matrix} \text{XRS} [U_{2 \times R}]^H [ \begin{matrix} 1 & 0 \\ 0 & e^{j2 \frac{I L}{L}} \end{matrix} ] [ \begin{matrix} e^{j2 \frac{I L}{L}} & 0 \\ 0 & e^{j2 \frac{I L}{L}} \end{matrix} ] [ \begin{matrix} a_{\text{XRS}}^{(p_0)}(m) \\ a_{\text{XRS}}^{(p_1)}(m) \end{matrix} ] \end{matrix}$$

where m is the RE index, I is the PRG index, and L is the number of PRGs in the frequency domain resource group (i.e., a group of PRGs).

(97) As another example, the port mapping in case of four antenna groups may be written as:

$$(98) \quad \begin{matrix} a_{\text{DMRS}}^{(\tilde{p}_0)}(m) \\ \text{DMRS} [ a_{\text{DMRS}}^{(\tilde{p}_0)}(m) ] = \\ \text{Math.} \\ a_{\text{DMRS}}^{(\tilde{p}_R)}(m) \end{matrix} = \begin{matrix} \text{XRS} [U_{4 \times R}]^H \text{diag}[1, e^{j2 \frac{I L}{L}}, e^{j4 \frac{I L}{L}}, e^{j6 \frac{I L}{L}}] \text{Math.} \text{diag}[e^{j2 \frac{I L}{L}}, e^{j2 \frac{I L}{L}}, e^{j2 \frac{I L}{L}}, e^{j2 \frac{I L}{L}}] [ \begin{matrix} a_{\text{XRS}}^{(p_0)}(m) \\ a_{\text{XRS}}^{(p_1)}(m) \\ a_{\text{XRS}}^{(p_2)}(m) \\ a_{\text{XRS}}^{(p_3)}(m) \end{matrix} ] \end{matrix}$$

where  $U_{\text{sub.N} \times R}$  is an  $N_{\text{sub.t}} \times R$  unitary matrix.

(99) In an aspect, the combination of small delay CDD and PRG-level non-transparent precoder cycling provides a high delay diversity performance. Due to additional orthogonal cover codes to separate DMRS ports, the XRS ports can be separately estimated to provide wideband channel estimation. Further, each PRG went through separate precoder cycling for frequency domain diversity. This transmission scheme is consistent with DMRS transmission, which simplifies interference estimation.

(100) The transmission component 126 is configured to transmit the precoded transmission via the antenna groups. For example, the transmission component 126 may provide the precoded transmission for each antenna group to the appropriate transceiver (e.g., RX/TX) 354 of the transmitter component 772.

(101) FIG. 8 is a conceptual data flow diagram 800 illustrating the data flow between different means/components in an example UE 104, which may be an example of the UE 104 (FIG. 1) and include the Rx precoder cycling component 140. The Rx precoder cycling component 140 may be implemented by the memory 360 and the TX processor 368, the RX processor 356, and/or the controller/processor 359. For example, the memory 360 may store executable instructions defining the Rx precoder cycling component 140 and the TX processor 368, the RX processor 356, and/or the controller/processor 359 may execute the instructions.

(102) The UE 104 may include a receiver component 870, which may include, for example, a RF receiver for receiving the signals described herein. The UE 104 may include a transmitter component 872, which may include, for example, an RF transmitter for transmitting the signals described herein. In an aspect, the receiver component 870 and the transmitter component 872 may co-located in a transceiver such as the TX/RX 352 in FIG. 3.

(103) As discussed with respect to FIG. 1, the Rx precoder cycling component 140 includes the precoder selection component 142, the reception component 144, the channel estimation component 146, and the demodulation component 148.

(104) The receiver component 870 may receive DL signals described herein such as the SSB 505, system information 510, RRC configuration 520, and transmission 540. The receiver component 870 may output the SSB 505, system information 510, or RRC configuration 520 to the precoder selection component 142 as control signaling. The receiver component 870 may output the control signaling to the precoder selection component 142. The receiver component 870 may output the transmission 540 to the reception component 144.

(105) The precoder selection component 142 is configured to select or identify a precoding matrix to be used for reception. The precoder selection component 142 may receive control signaling (e.g., system information 510 and/or RRC configuration 520) indicating parameters of the precoding matrix. The precoding matrix may include a number of sub-matrices equal to a number of antenna groups. A first sub-matrix for a first antenna group is the same for each frequency domain resource unit and a phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal across the frequency domain resource units of the frequency domain resource group. The precoder selection component 142 may provide a set 600, 610, 620 of precoding matrices 602, 612, 622 to the channel estimation component 146.

(106) The reception component 144 is configured to receive a transmission having non-transparent precoder cycling applied to

each frequency domain resource unit of a frequency domain resource group of K frequency domain resource units in which both a data signal and a DMRS are precoded with a precoding matrix. The precoding matrix is the precoding matrix selected by the precoder selection component **142**. The reception component **144** may provide the DMRS to the channel estimation component **146**. The reception component **144** may provide the data signal to the demodulation component **148**.

(107) The channel estimation component **146** is configured to estimate a channel of the transmission based on the precoding matrix. In some implementations, the channel estimation component **146** may have two options for channel estimation for the non-transparent precoder cycling. The channel estimation component **146** may be configured to perform one or both options. The channel estimation component **146** may output the channel estimates to the demodulation component **148**.

(108) For example, the channel estimation component **146** may include a per RB estimator **810** configured to perform DMRS channel estimation for each RB based on the precoding matrix for the RB. For instance, the per RB estimator **810** may determine any phase shifts applied by the precoding and estimate the channel based on the known DMRS sequence. The per RB estimator **810** may also perform interference channel estimation using the same RB level DMRS estimation.

(109) As another example, the channel estimation component **146** may include a per PRG estimator **820** and a per RB channel calculator **822**. The per PRG estimator **820** may acquire a virtual DMRS channel per antenna group (e.g., H.sub.0W.sub.0 and H.sub.1W.sub.1) after performing DMRS channel estimation for a PRG unit. The per RB channel calculator **822** may calculate a per-RB channel based on the virtual DMRS channel and the phase-shift for each RB as defined by the precoding matrix (e.g., H.sub.0W.sub.0 and

$$(110) e^{\frac{j^2 \cdot \text{Math.}[k]_k}{K}} H_1 W_1) .$$

(111) The demodulation component **148** is configured to demodulate the data signal based on the estimated channel. For example, the demodulation component **148** may apply the channel estimate to each RB of the received data signal to determine the modulation symbol for each RE.

(112) FIG. **9** is a flowchart of an example method **900** for a UE to receive a transmission with non-transparent precoder cycling. The method **900** may be performed by a UE (such as the UE **104**, which may include the memory **360** and which may be the entire UE **104** or a component of the UE **104** such as the Rx precoder cycling component **140**, TX processor **368**, the RX processor **356**, or the controller/processor **359**). The method **900** may be performed by the Rx precoder cycling component **140** in communication with the Tx precoder cycling component **120** of the base station **102**. Optional blocks are shown with dashed lines.

(113) At block **910**, the method **900** includes receiving a transmission having non-transparent precoder cycling applied to each frequency domain resource unit of a frequency domain resource group of K frequency domain resource units in which both a data signal and a DMRS are precoded with a precoding matrix comprising a number of sub-matrices equal to a number of antenna groups. In some implementations, for example, the UE **104**, the RX processor **356** or the controller/processor **359** may execute the Rx precoder cycling component **140** or the reception component **144** to receive the **540** having non-transparent precoder cycling applied to each frequency domain resource unit (e.g., RB or PRG) of a frequency domain resource group of K frequency domain resource units in which both a data signal **542** and a DMRS **544** are precoded with a precoding matrix **602**, **612**, **622** comprising a number of sub-matrices equal to a number of antenna groups. A first sub-matrix for a first antenna group is the same for each frequency domain resource unit and a phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal across the frequency domain resource units of the frequency domain resource group. In some implementations, the frequency domain resource unit is a RB and the frequency domain resource group is a PRG of K RBs. In some implementations, the frequency domain resource unit is a PRG and the frequency domain resource group is a group of PRGs. In some implementations, the precoding matrix is an N.sub.t×R matrix, where R is a rank of the transmission, and wherein an R-port DMRS to data signal mapping is an identity matrix of size R. Accordingly, the UE **104**, the RX processor **356**, or the controller/processor **359** executing the Rx precoder cycling component **140** or precoder selection component **142** may provide means for receiving a transmission having non-transparent precoder cycling applied to each frequency domain resource unit of a frequency domain resource group of K frequency domain resource units in which both a data signal and a DMRS are precoded with a precoding matrix comprising a number of sub-matrices equal to a number of antenna groups.

(114) At block **920**, the method **900** includes estimating a channel of the transmission based on the precoding matrix. In some implementations, for example, the UE **104**, the RX processor **356** or the controller/processor **359** may execute the Rx precoder cycling component **140** or the channel estimation component **146** to estimate a channel (H) of the transmission based on the precoding matrix.

(115) In some implementations where frequency domain resource unit is a RB, the block **920** may optionally include, at sub-block **922**, performing DMRS channel estimation for each RB based on the precoding matrix for the RB. In some implementations where frequency domain resource unit is a RB, the block **920** may optionally include, at sub-block **924**, acquiring a virtual DMRS channel for each antenna group by performing DMRS channel estimation for a PRG. At sub-block **926**, the block **920** may further optionally include calculating a per RB channel based on the virtual DMRS channel and a phase-shift for each RB.

(116) In some implementations, where the frequency domain resource unit is a PRG, the block **920** may optionally include, at sub-block **928**, performing DMRS channel estimation for each PRG. In some implementations, where the frequency domain resource unit is a PRG, the block **920** may optionally include, at sub-block **930** acquiring a virtual DMRS channel for each antenna group by combining per-PRG DMRS channel estimates. At sub-block **932**, the block **920** may further optionally include calculating a per RB channel based on the virtual channel and the shift for each RB.

(117) In view of the above, the UE **104**, the RX processor **356**, or the controller/processor **359** executing the Rx precoder cycling component **140** or the reception component **144** may provide means for estimating a channel of the transmission based on the precoding matrix.

(118) At block **940**, the method **900** includes demodulating the data signal based on the estimated channel. In some

implementations, for example, the UE **104**, the RX processor **356** or the controller/processor **359** may execute the Rx precoder cycling component **140** or the demodulation component **148** to demodulate the data signal based on the estimated channel. (119) Accordingly, the UE **104**, the RX processor **356**, or the controller/processor **359** executing the Rx precoder cycling component **140** or precoder selection component **142** may provide means for receiving a transmission having non-transparent precoder cycling applied to each frequency domain resource unit of a frequency domain resource group of K frequency domain resource units in which both a data signal and a DMRS are precoded with a precoding matrix comprising a number of sub-matrices equal to a number of antenna groups.

(120) FIG. **10** is a flowchart of an example method **1000** for a network node (e.g., a base station or gNB) to transmit data with non-transparent precoder cycling. For example, the method **1000** may be used for open-loop MIMO transmissions. The method **1000** may be performed by a network node (such as the base station **102**, which may include the memory **376** and which may be the entire base station **102** or a component of the base station **102** such as the Tx precoder cycling component **120**, the TX processor **316**, the RX processor **370**, or the controller/processor **375**). The method **1000** may be performed by the Tx precoder cycling component **120** in communication with the Rx precoder cycling component **140** of the UE **104**.

(121) At block **1010**, the method **1000** includes generating a precoding matrix comprising a number of sub-matrices equal to a number of antenna groups. In some implementations, for example, the base station **102**, the TX processor **316**, or the controller/processor **375** may execute the Tx precoder cycling component **120** or the matrix generation component **122** to generate the precoding matrix **602**, **612**, **622** comprising a number of sub-matrices equal to a number of antenna groups. In the precoding matrix, a first sub-matrix for a first antenna group is the same for each frequency domain resource unit of a frequency domain resource group of K frequency domain resource units. Additionally, a phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal for each frequency domain resource unit of the frequency domain resource group. In some implementations, the precoding matrix is an  $N_{\text{sub}} \times R$  matrix, where R is a rank of the transmission, and wherein an R-port DMRS to data signal mapping is an identity matrix of size R. Accordingly, the base station **102**, the TX processor **316**, or the controller/processor **375** executing the Tx precoder cycling component **120** or the matrix generation component **122** may provide means for generating a precoding matrix comprising a number of sub-matrices equal to a number of antenna groups.

(122) At block **1020**, the method **1000** may optionally include precoding the data signal with small delay cyclic delay diversity prior to precoding at a PRG-level with the precoding matrix. In some implementations, for example, the base station **102**, the TX processor **316**, or the controller/processor **375** may execute the Tx precoder cycling component **120** or the CDD component **128** to precode the data signal with small delay cyclic delay diversity prior to precoding at a PRG-level with the precoding matrix. Accordingly, the base station **102**, the TX processor **316**, or the controller/processor **375** executing the Tx precoder cycling component **120** or the CDD component **128** may provide means for precoding the data signal with small delay cyclic delay diversity prior to precoding at a PRG-level with the precoding matrix.

(123) At block **1030**, the method **1000** includes applying the precoding matrix to both a data signal and a DMRS of a transmission for each frequency domain resource unit of the frequency domain resource group for non-transparent precoder cycling. In some implementations, for example, the base station **102**, the TX processor **316**, or the controller/processor **375** may execute the Tx precoder cycling component **120** or the precoding component **124** to apply the precoding matrix to both a data signal and a DMRS of a transmission for each frequency domain resource unit of the frequency domain resource group for non-transparent precoder cycling. Accordingly, the base station **102**, the TX processor **316**, or the controller/processor **375** executing the Tx precoder cycling component **120** or the precoding component **124** may provide means for applying the precoding matrix to both a data signal and a DMRS of a transmission for each frequency domain resource unit of the frequency domain resource group for non-transparent precoder cycling.

(124) At block **1040**, the method **1000** includes transmitting the precoded transmission via the antenna groups. In some implementations, for example, the base station **102**, the TX processor **316**, or the controller/processor **375** may execute the Tx precoder cycling component **120**, the transmission component **126**, and/or the transmitter component **772** to transmit the precoded transmission via the antenna groups **774**. Accordingly, the base station **102**, the TX processor **316**, or the controller/processor **375** executing Tx precoder cycling component **120**, the transmission component **126**, and/or the transmitter component **772** may provide means for transmitting the precoded transmission via the antenna groups.

(125) The following numbered clauses provide an overview of aspects of the present disclosure:

(126) Clause 1. An apparatus for wireless communication at a user equipment (UE), comprising: one or more memories storing computer-executable instructions; and one or more processors coupled with the one or more memories and configured to execute the computer-executable instructions, individually or in combination, to cause the apparatus to: receive a transmission having non-transparent precoder cycling applied to each frequency domain resource unit of a frequency domain resource group of K frequency domain resource units in which both a data signal and a demodulation reference signal (DMRS) are precoded with a precoding matrix comprising a number of sub-matrices equal to a number of antenna groups, wherein a first sub-matrix for a first antenna group is the same for each frequency domain resource unit and a phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal across the frequency domain resource units of the frequency domain resource group; estimate a channel of the transmission based on the precoding matrix; and demodulate the data signal based on the estimated channel.

(127) Clause 2. The apparatus of clause 1, wherein the frequency domain resource unit is a resource block (RB) and the frequency domain resource group is a physical resource group (PRG) of K RBs.

(128) Clause 3. The apparatus of clause 2, wherein to estimate the channel of the transmission based on the precoding matrix the one or more processors, individually or in combination, are configured to perform DMRS channel estimation for each RB based on the precoding matrix for the RB.

(129) Clause 4. The apparatus of clause 2, wherein to estimate the channel of the transmission based on the precoding matrix the one or more processors, individually or in combination, are configured to: acquire a virtual DMRS channel for each antenna

group by performing DMRS channel estimation for a PRG; and calculate a per RB channel based on the virtual DMRS channel and a phase-shift for each RB.

(130) Clause 5. The apparatus of clause 1, wherein the frequency domain resource unit is a physical resource group (PRG) and the frequency domain resource group is a group of PRGs.

(131) Clause 6. The apparatus of clause 5, wherein to estimate the channel of the transmission based on the precoding matrix the one or more processors, individually or in combination, are configured to perform DMRS channel estimation for each PRG.

(132) Clause 7. The apparatus of clause 5, to estimate the channel of the transmission based on the precoding matrix the one or more processors, individually or in combination, are configured to: acquire a virtual DMRS channel for each antenna group by combining per-PRG DMRS channel estimates; and calculate a per RB channel based on the virtual channel and the shift for each RB.

(133) Clause 8. The apparatus of clause 5, wherein the data signal is precoded with small delay cyclic delay diversity prior to precoding at a PRG-level with the precoding matrix.

(134) Clause 9. The apparatus of clause 1, wherein the precoding matrix is an  $N_{\text{sub},t} \times R$  matrix, where  $R$  is a rank of the transmission, and wherein an  $R$ -port DMRS to data signal mapping is an identity matrix of size  $R$ .

(135) Clause 10. An apparatus for wireless communication, comprising: one or more memories storing computer-executable instructions; and one or more processors coupled with the one or more memories and configured to execute the computer-executable instructions, individually or in combination, to cause the apparatus to: generate a precoding matrix comprising a number of sub-matrices equal to a number of antenna groups, wherein a first sub-matrix for a first antenna group is the same for each frequency domain resource unit of a frequency domain resource group of  $K$  frequency domain resource units, and wherein a phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal for each frequency domain resource unit of the frequency domain resource group; apply the precoding matrix to both a data signal and a demodulation reference signal (DMRS) of a transmission for each frequency domain resource unit of the frequency domain resource group for non-transparent precoder cycling; and transmit the precoded transmission via the antenna groups.

(136) Clause 11. The apparatus of clause 10, wherein the frequency domain resource unit is a resource block (RB) and the frequency domain resource group is a physical resource group (PRG) of  $K$  RBs.

(137) Clause 12. The apparatus of clause 10, wherein the frequency domain resource unit is a physical resource group (PRG) and the frequency domain resource group is a group of PRGs.

(138) Clause 13. The apparatus of clause 12, wherein the one or more processors, individually or in combination, are configured to precode the data signal with small delay cyclic delay diversity prior to precoding at a PRG-level with the precoding matrix.

(139) Clause 14. The apparatus of clause 10, wherein the precoding matrix is an  $N_{\text{sub},t} \times R$  matrix, where  $R$  is a rank of the transmission, and wherein an  $R$ -port DMRS to data signal mapping is an identity matrix of size  $R$ .

(140) Clause 15. The apparatus of clause 10, wherein the transmission is one of a broadcast data transmission, a control channel, a transmission prior to radio resource control connection establishment, or a fallback transmission.

(141) Clause 16. A method of wireless communication at a user equipment (UE), comprising: receiving a transmission having non-transparent precoder cycling applied to each frequency domain resource unit of a frequency domain resource group of  $K$  frequency domain resource units in which both a data signal and a demodulation reference signal (DMRS) are precoded with a precoding matrix comprising a number of sub-matrices equal to a number of antenna groups, wherein a first sub-matrix for a first antenna group is the same for each frequency domain resource unit and a phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal across the frequency domain resource units of the frequency domain resource group; estimating a channel of the transmission based on the precoding matrix; and demodulating the data signal based on the estimated channel.

(142) Clause 17. The method of clause 16, wherein the frequency domain resource unit is a resource block (RB) and the frequency domain resource group is a physical resource group (PRG) of  $K$  RBs.

(143) Clause 18. The method of clause 17, wherein estimating the channel of the transmission based on the precoding matrix comprises performing DMRS channel estimation for each RB based on the precoding matrix for the RB.

(144) Clause 19. The method of clause 17, wherein estimating a channel of the transmission based on the precoding matrix comprises: acquiring a virtual DMRS channel for each antenna group by performing DMRS channel estimation for a PRG; and calculating a per RB channel based on the virtual DMRS channel and a phase-shift for each RB.

(145) Clause 20. The method of clause 16, wherein the frequency domain resource unit is a physical resource group (PRG) and the frequency domain resource group is a group of PRGs.

(146) Clause 21. The method of clause 20, wherein estimating the channel of the transmission based on the precoding matrix comprises performing DMRS channel estimation for each PRG.

(147) Clause 22. The method of clause 20, wherein estimating a channel of the transmission comprises: acquiring a virtual DMRS channel for each antenna group by combining per-PRG DMRS channel estimates; and calculating a per RB channel based on the virtual channel and the shift for each RB.

(148) Clause 23. The method of clause 20, wherein the data signal is precoded with small delay cyclic delay diversity prior to precoding at a PRG-level with the precoding matrix.

(149) Clause 24. The method of clause 16, wherein the precoding matrix is an  $N_{\text{sub},t} \times R$  matrix, where  $R$  is a rank of the transmission, and wherein an  $R$ -port DMRS to data signal mapping is an identity matrix of size  $R$ .

(150) Clause 25. A method of wireless communication at a network node, comprising: generating a precoding matrix comprising a number of sub-matrices equal to a number of antenna groups, wherein a first sub-matrix for a first antenna group is the same for each frequency domain resource unit of a frequency domain resource group of  $K$  frequency domain resource units, and wherein a phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal for each frequency domain resource unit of the frequency domain resource group; applying the precoding matrix to both a data signal and a demodulation reference signal (DMRS) of a transmission for each frequency domain resource unit of the frequency domain

resource group for non-transparent precoder cycling; and transmitting the data signal via the antenna groups.

(151) Clause 26. The method of clause 25, wherein the frequency domain resource unit is a resource block (RB) and the frequency domain resource group is a physical resource group (PRG) of K RBs.

(152) Clause 27. The method of clause 25, wherein the frequency domain resource unit is a physical resource group (PRG) and the frequency domain resource group is a group of PRGs.

(153) Clause 28. The method of clause 27, further comprising precoding the data signal with small delay cyclic delay diversity prior to precoding at a PRG-level with the precoding matrix.

(154) Clause 29. The method of clause 25, wherein the precoding matrix is an  $N_{\text{sub.t}} \times R$  matrix, where R is a rank of the transmission, and wherein an R-port DMRS to data signal mapping is an identity matrix of size R.

(155) Clause 30. The method of clause 25, wherein the transmission is one of a broadcast data transmission, a control channel, a transmission prior to radio resource control connection establishment, or a fallback transmission.

(156) As used herein, a phrase referring to “at least one of” a list of items refers to any combination of those items, including single members. As an example, “at least one of: a, b, or c” is intended to cover: a, b, c, a-b, a-c, b-c, and a-b-c.

(157) The various illustrative logics, logical blocks, modules, circuits and algorithm processes described in connection with the implementations disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. The interchangeability of hardware and software has been described generally, in terms of functionality, and illustrated in the various illustrative components, blocks, modules, circuits and processes described above. Whether such functionality is implemented in hardware or software depends upon the particular application and design constraints imposed on the overall system.

(158) The hardware and data processing apparatus used to implement the various illustrative logics, logical blocks, modules and circuits described in connection with the aspects disclosed herein may be implemented or performed with a general purpose single- or multi-chip 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, or any conventional processor, controller, microcontroller, or state machine. A processor also may be implemented as a combination of computing devices, such as 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. In some implementations, particular processes and methods may be performed by circuitry that is specific to a given function.

(159) In one or more aspects, the functions described may be implemented in hardware, digital electronic circuitry, computer software, firmware, including the structures disclosed in this specification and their structural equivalents thereof, or in any combination thereof. Implementations of the subject matter described in this specification also can be implemented as one or more computer programs, i.e., one or more modules of computer program instructions, encoded on a computer storage media for execution by, or to control the operation of, data processing apparatus.

(160) 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. The processes of a method or algorithm disclosed herein may be implemented in a processor-executable software module which may reside on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that can be enabled to transfer a computer program from one place to another. A storage media may be any available media that may be accessed by a computer. By way of example, and not limitation, such computer-readable media may include RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that may be used to store desired program code in the form of instructions or data structures and that may be accessed by a computer. Also, any connection can be properly termed a computer-readable 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. Additionally, the operations of a method or algorithm may reside as one or any combination or set of codes and instructions on a machine readable medium and computer-readable medium, which may be incorporated into a computer program product.

(161) Various modifications to the implementations described in this disclosure may be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other implementations without departing from the spirit or scope of this disclosure. Thus, the claims are not intended to be limited to the implementations shown herein, but are to be accorded the widest scope consistent with this disclosure, the principles and the novel features disclosed herein.

(162) Additionally, a person having ordinary skill in the art will readily appreciate, the terms “upper” and “lower” are sometimes used for ease of describing the figures, and indicate relative positions corresponding to the orientation of the figure on a properly oriented page, and may not reflect the proper orientation of any device as implemented.

(163) Certain features that are described in this specification in the context of separate implementations also can be implemented in combination in a single implementation. Conversely, various features that are described in the context of a single implementation also can be implemented in multiple implementations separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination.

(164) Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. Further, the drawings may schematically depict one more example processes in the form of a flow diagram. However, other operations that are not depicted can be incorporated in the example processes that are schematically illustrated. For example, one or more additional operations can be performed before, after, simultaneously, or between any of the illustrated operations. In certain circumstances, multitasking and parallel processing may be advantageous.



Moreover, the separation of various system components in the implementations described above should not be understood as requiring such separation in all implementations, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products. Additionally, other implementations are within the scope of the following claims. In some cases, the actions recited in the claims can be performed in a different order and still achieve desirable results.

## Claims

1. An apparatus for wireless communication at a user equipment (UE), comprising: one or more memories storing computer-executable instructions; and one or more processors coupled with the one or more memories and configured to execute the computer-executable instructions, individually or in combination, to cause the apparatus to: receive a transmission having non-transparent precoder cycling applied to each frequency domain resource unit of a frequency domain resource group of K frequency domain resource units in which both a data signal and a demodulation reference signal (DMRS) are precoded with a precoding matrix comprising a number of sub-matrices equal to a number of antenna groups, wherein a first sub-matrix for a first antenna group is the same for each frequency domain resource unit and a phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal across the frequency domain resource units of the frequency domain resource group; estimate a channel of the transmission based on the precoding matrix; and demodulate the data signal based on the estimated channel.
2. The apparatus of claim 1, wherein the frequency domain resource unit is a resource block (RB) and the frequency domain resource group is a physical resource group (PRG) of K RBs.
3. The apparatus of claim 2, wherein to estimate the channel of the transmission based on the precoding matrix the one or more processors, individually or in combination, are configured to perform DMRS channel estimation for each RB based on the precoding matrix for the RB.
4. The apparatus of claim 2, wherein to estimate the channel of the transmission based on the precoding matrix the one or more processors, individually or in combination, are configured to: acquire a virtual DMRS channel for each antenna group by performing DMRS channel estimation for a PRG; and calculate a per RB channel based on the virtual DMRS channel and a phase-shift for each RB.
5. The apparatus of claim 1, wherein the frequency domain resource unit is a physical resource group (PRG) and the frequency domain resource group is a group of PRGs.
6. The apparatus of claim 5, wherein to estimate the channel of the transmission based on the precoding matrix the one or more processors, individually or in combination, are configured to perform DMRS channel estimation for each PRG.
7. The apparatus of claim 5, to estimate the channel of the transmission based on the precoding matrix the one or more processors, individually or in combination, are configured to: acquire a virtual DMRS channel for each antenna group by combining per-PRG DMRS channel estimates; and calculate a per RB channel based on the virtual channel and the shift for each RB.
8. The apparatus of claim 5, wherein the data signal is precoded with small delay cyclic delay diversity prior to precoding at a PRG-level with the precoding matrix.
9. The apparatus of claim 1, wherein the precoding matrix is an  $N_{\text{sub}} \times R$  matrix, where R is a rank of the transmission, and wherein an R-port DMRS to data signal mapping is an identity matrix of size R.
10. An apparatus for wireless communication, comprising: one or more memories storing computer-executable instructions; and one or more processors coupled with the one or more memories and configured to execute the computer-executable instructions, individually or in combination, to cause the apparatus to: generate a precoding matrix comprising a number of sub-matrices equal to a number of antenna groups, wherein a first sub-matrix for a first antenna group is the same for each frequency domain resource unit of a frequency domain resource group of K frequency domain resource units, and wherein a phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal for each frequency domain resource unit of the frequency domain resource group; apply the precoding matrix to both a data signal and a demodulation reference signal (DMRS) of a transmission for each frequency domain resource unit of the frequency domain resource group for non-transparent precoder cycling; and transmit the precoded transmission via the antenna groups.
11. The apparatus of claim 10, wherein the frequency domain resource unit is a resource block (RB) and the frequency domain resource group is a physical resource group (PRG) of K RBs.
12. The apparatus of claim 10, wherein the frequency domain resource unit is a physical resource group (PRG) and the frequency domain resource group is a group of PRGs.
13. The apparatus of claim 12, wherein the one or more processors, individually or in combination, are configured to precode the data signal with small delay cyclic delay diversity prior to precoding at a PRG-level with the precoding matrix.
14. The apparatus of claim 10, wherein the precoding matrix is an  $N_{\text{sub}} \times R$  matrix, where R is a rank of the transmission, and wherein an R-port DMRS to data signal mapping is an identity matrix of size R.
15. The apparatus of claim 10, wherein the transmission is one of a broadcast data transmission, a control channel, a transmission prior to radio resource control connection establishment, or a fallback transmission.
16. A method of wireless communication at a user equipment (UE), comprising: receiving a transmission having non-transparent precoder cycling applied to each frequency domain resource unit of a frequency domain resource group of K frequency domain resource units in which both a data signal and a demodulation reference signal (DMRS) are precoded with a precoding matrix comprising a number of sub-matrices equal to a number of antenna groups, wherein a first sub-matrix for a first antenna group is the same for each frequency domain resource unit and a phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal across the frequency domain resource units of the frequency domain resource group; estimating a

channel of the transmission based on the precoding matrix; and demodulating the data signal based on the estimated channel.

17. The method of claim 16, wherein the frequency domain resource unit is a resource block (RB) and the frequency domain resource group is a physical resource group (PRG) of K RBs.

18. The method of claim 17, wherein estimating the channel of the transmission based on the precoding matrix comprises performing DMRS channel estimation for each RB based on the precoding matrix for the RB.

19. The method of claim 17, wherein estimating a channel of the transmission based on the precoding matrix comprises: acquiring a virtual DMRS channel for each antenna group by performing DMRS channel estimation for a PRG; and calculating a per RB channel based on the virtual DMRS channel and a phase-shift for each RB.

20. The method of claim 16, wherein the frequency domain resource unit is a physical resource group (PRG) and the frequency domain resource group is a group of PRGs.

21. The method of claim 20, wherein estimating the channel of the transmission based on the precoding matrix comprises performing DMRS channel estimation for each PRG.

22. The method of claim 20, wherein estimating a channel of the transmission comprises: acquiring a virtual DMRS channel for each antenna group by combining per-PRG DMRS channel estimates; and calculating a per RB channel based on the virtual channel and the shift for each RB.

23. The method of claim 20, wherein the data signal is precoded with small delay cyclic delay diversity prior to precoding at a PRG-level with the precoding matrix.

24. The method of claim 16, wherein the precoding matrix is an  $N_{\text{sub},t} \times R$  matrix, where R is a rank of the transmission, and wherein an R-port DMRS to data signal mapping is an identity matrix of size R.

25. A method of wireless communication at a network node, comprising: generating a precoding matrix comprising a number of sub-matrices equal to a number of antenna groups, wherein a first sub-matrix for a first antenna group is the same for each frequency domain resource unit of a frequency domain resource group of K frequency domain resource units, and wherein a phase of each subsequent sub-matrix for each subsequent antenna group is shifted to be orthogonal for each frequency domain resource unit of the frequency domain resource group; applying the precoding matrix to both a data signal and a demodulation reference signal (DMRS) of a transmission for each frequency domain resource unit of the frequency domain resource group for non-transparent precoder cycling; and transmitting the precoded transmission via the antenna groups.

26. The method of claim 25, wherein the frequency domain resource unit is a resource block (RB) and the frequency domain resource group is a physical resource group (PRG) of K RBs.

27. The method of claim 25, wherein the frequency domain resource unit is a physical resource group (PRG) and the frequency domain resource group is a group of PRGs.

28. The method of claim 27, further comprising precoding the data signal with small delay cyclic delay diversity prior to precoding at a PRG-level with the precoding matrix.

29. The method of claim 25, wherein the precoding matrix is an  $N_{\text{sub},t} \times R$  matrix, where R is a rank of the transmission, and wherein an R-port DMRS to data signal mapping is an identity matrix of size R.

30. The method of claim 25, wherein the transmission is one of a broadcast data transmission, a control channel, a transmission prior to radio resource control connection establishment, or a fallback transmission.

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