(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
10 August 2023 (10.08.2023)

WIPO | PCT

(10) **International Publication Number**
WO 2023/149730 A1

(51) **International Patent Classification:**
H04B 7/0456 (2017.01) *H04B 7/0417* (2017.01)
H04B 7/06 (2006.01) *H04L 5/00* (2006.01)

(21) **International Application Number:**
PCT/KR2023/001540

(22) **International Filing Date:**
02 February 2023 (02.02.2023)

(25) **Filing Language:** English

(26) **Publication Language:** English

(30) **Priority Data:**

63/305,916	02 February 2022 (02.02.2022)	US
63/310,386	15 February 2022 (15.02.2022)	US
63/326,621	01 April 2022 (01.04.2022)	US
63/343,856	19 May 2022 (19.05.2022)	US
63/403,597	02 September 2022 (02.09.2022)	US
63/412,202	30 September 2022 (30.09.2022)	US
18/156,377	18 January 2023 (18.01.2023)	US

(71) **Applicant: SAMSUNG ELECTRONICS CO., LTD.** [KR/KR]; 129, Samsung-ro, Yeongtong-gu, Suwon-si, Gyeonggi-do 16677 (KR).

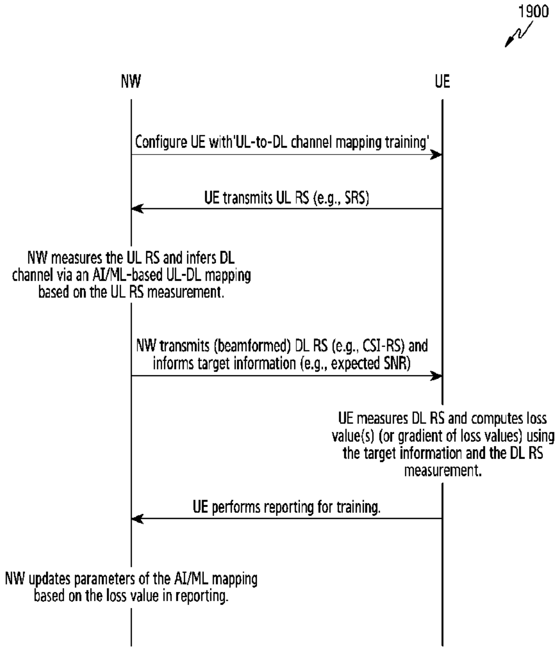
(72) **Inventors: LEE, Gilwon**; 665 Clyde Ave., Mountain View, California 94043 (US). **RAHMAN, Md. Saifur**; 665 Clyde Ave., Mountain View, California 94043 (US). **ONGGOSANUSI, Eko**; 665 Clyde Ave., Mountain View, California 94043 (US).

(74) **Agent: KWON, Hyuk-Rok** et al.; 11F, 19, Saemunan-ro 5-gil, Jongno-gu, Seoul 03173 (KR).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI,

(54) **Title:** METHOD AND APPARATUS FOR CSI CODEBOOK



$$K_1 \le \sum_{r=1}^{N}(2L_rM_v) \qquad \text{(I)}$$

(57) **Abstract:** The disclosure relates to a 5G or 6G communication system for supporting a higher data transmission rate. More particularly, the disclosure relates to apparatuses and methods for channel state information (CSI) codebook. A method for operating a user equipment (UE) includes receiving a configuration about a CSI report. The configuration includes information about N>1 groups of CSI reference signal (CSI- RS) ports and a codebook. The codebook includes a spatial-domain (SD) basis component, a frequency-domain (ED) basis component, and a coefficient component. The SD basis component includes Lr basis vectors for each group r=l,...,N. The ED basis component includes Mv basis vectors. The coefficient component includes coefficients associated with (SD, ED) basis vector pairs. The method further includes, based on the configuration, measuring the N groups of CSI-RS ports and determining the SD basis component, the ED basis component, and the coefficient component such that Ki coef ficients are non-zero and remaining coefficients are zero, where method further includes transmitting the CSI report including an indicator indicating locations of non-zero coefficients.

WO 2023/149730 A1

[Continued on next page]

SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

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

Description

Title of Invention: METHOD AND APPARATUS FOR CSI CODEBOOK

Technical Field

[1] The disclosure relates generally to wireless communication systems. More particularly, the disclosure relates to a channel state information (CSI) codebook.

Background Art

[2] 5G mobile communication technologies define broad frequency bands such that high transmission rates and new services are possible, and can be implemented not only in “Sub 6GHz” bands such as 3.5GHz, but also in “Above 6GHz” bands referred to as mmWave including 28GHz and 39GHz. In addition, it has been considered to implement 6G mobile communication technologies (referred to as Beyond 5G systems) in terahertz (THz) bands (for example, 95GHz to 3THz bands) in order to accomplish transmission rates fifty times faster than 5G mobile communication technologies and ultra-low latencies one-tenth of 5G mobile communication technologies.

[3] At the beginning of the development of 5G mobile communication technologies, in order to support services and to satisfy performance requirements in connection with enhanced Mobile BroadBand (eMBB), Ultra Reliable Low Latency Communications (URLLC), and massive Machine-Type Communications (mMTC), there has been ongoing standardization regarding beamforming and massive MIMO for mitigating radio-wave path loss and increasing radio-wave transmission distances in mmWave, supporting numerologies (for example, operating multiple subcarrier spacings) for efficiently utilizing mmWave resources and dynamic operation of slot formats, initial access technologies for supporting multi-beam transmission and broadbands, definition and operation of BWP (BandWidth Part), new channel coding methods such as a LDPC (Low Density Parity Check) code for large amount of data transmission and a polar code for highly reliable transmission of control information, L2 pre-processing, and network slicing for providing a dedicated network specialized to a specific service.

[4] Currently, there are ongoing discussions regarding improvement and performance enhancement of initial 5G mobile communication technologies in view of services to be supported by 5G mobile communication technologies, and there has been physical layer standardization regarding technologies such as V2X (Vehicle-to-everything) for aiding driving determination by autonomous vehicles based on information regarding positions and states of vehicles transmitted by the vehicles and for enhancing user convenience, NR-U (New Radio Unlicensed) aimed at system operations conforming to various regulation-related requirements in unlicensed bands, NR UE Power Saving,

Non-Terrestrial Network (NTN) which is UE-satellite direct communication for providing coverage in an area in which communication with terrestrial networks is unavailable, and positioning.

[5] Moreover, there has been ongoing standardization in air interface architecture/ protocol regarding technologies such as Industrial Internet of Things (IIoT) for supporting new services through interworking and convergence with other industries, IAB (Integrated Access and Backhaul) for providing a node for network service area expansion by supporting a wireless backhaul link and an access link in an integrated manner, mobility enhancement including conditional handover and DAPS (Dual Active Protocol Stack) handover, and two-step random access for simplifying random access procedures (2-step RACH for NR). There also has been ongoing standardization in system architecture/service regarding a 5G baseline architecture (for example, service based architecture or service based interface) for combining Network Functions Virtualization (NFV) and Software-Defined Networking (SDN) technologies, and Mobile Edge Computing (MEC) for receiving services based on UE positions.

[6] As 5G mobile communication systems are commercialized, connected devices that have been exponentially increasing will be connected to communication networks, and it is accordingly expected that enhanced functions and performances of 5G mobile communication systems and integrated operations of connected devices will be necessary. To this end, new research is scheduled in connection with eXtended Reality (XR) for efficiently supporting AR (Augmented Reality), VR (Virtual Reality), MR (Mixed Reality) and the like, 5G performance improvement and complexity reduction by utilizing Artificial Intelligence (AI) and Machine Learning (ML), AI service support, metaverse service support, and drone communication.

[7] Furthermore, such development of 5G mobile communication systems will serve as a basis for developing not only new waveforms for providing coverage in terahertz bands of 6G mobile communication technologies, multi-antenna transmission technologies such as Full Dimensional MIMO (FD-MIMO), array antennas and large-scale antennas, metamaterial-based lenses and antennas for improving coverage of terahertz band signals, high-dimensional space multiplexing technology using OAM (Orbital Angular Momentum), and RIS (Reconfigurable Intelligent Surface), but also full-duplex technology for increasing frequency efficiency of 6G mobile communication technologies and improving system networks, AI-based communication technology for implementing system optimization by utilizing satellites and AI (Artificial Intelligence) from the design stage and internalizing end-to-end AI support functions, and next-generation distributed computing technology for implementing services at levels of complexity exceeding the limit of UE operation capability by utilizing ultra-high-performance communication and computing resources.

Disclosure of Invention

Solution to Problem

[8] This disclosure relates to wireless communication networks, and more particularly to a terminal and a communication method thereof in a wireless communication system.

[9] In one embodiment, a user equipment (UE) is provided. The UE includes a transceiver configured to receive a configuration about a CSI report. The configuration includes information about (i) N>1 groups of CSI reference signal (CSI-RS) ports and (ii) a codebook. The codebook includes a spatial-domain (SD) basis component, a frequency-domain (FD) basis component, and a coefficient component. The SD basis component includes L_r basis vectors for each group r=1,...,N. The FD basis component includes M_v basis vectors. The coefficient component includes coefficients associated with (SD, FD) basis vector pairs. The UE further includes a processor operably coupled to the transceiver. The processor, based on the configuration, is configured to measure the N groups of CSI-RS ports and determine the SD basis component, the FD basis component, and the coefficient component such that K_1 coefficients are non-zero and remaining coefficients are zero, where $K_1 \leq \sum_{r=1}^{N}(2L_rM_v)$. The transceiver is further configured to transmit the CSI report including an indicator indicating locations of non-zero coefficients.

Advantageous Effects of Invention

[10] Aspects of the disclosure are to address at least the above-mentioned problems and/or disadvantages and to provide at least the advantages described below. Accordingly, an aspect of the disclosure is to provide efficient communication methods in a wireless communication system.

Brief Description of Drawings

[11] The above and other aspects, features, and advantages of certain embodiments of the disclosure will be more apparent from the following description taken in conjunction with the accompanying drawings, in which:

[12] FIGURE 1 illustrates an example wireless network according to embodiments of the disclosure;

[13] FIGURE 2 illustrates an example gNB according to embodiments of the disclosure;

[14] FIGURE 3 illustrates an example UE according to embodiments of the disclosure;

[15] FIGURES 4 and 5 illustrate example wireless transmit and receive paths according to embodiments of the disclosure;

[16] FIGURE 6 illustrates a transmitter block diagram for a physical downlink shared channel (PDSCH) in a subframe according to embodiments of the disclosure;

[17] FIGURE 7 illustrates a receiver block diagram for a PDSCH in a subframe according to embodiments of the disclosure;

[18] FIGURE 8 illustrates a transmitter block diagram for a physical uplink shared channel (PUSCH) in a subframe according to embodiments of the disclosure;

[19] FIGURE 9 illustrates a receiver block diagram for a PUSCH in a subframe according to embodiments of the disclosure;

[20] FIGURE 10 illustrates an example antenna blocks or arrays forming beams according to embodiments of the disclosure;

[21] FIGURE 11 illustrates an example distributed multiple-input multiple-output (D-MIMO) system according to embodiments of the disclosure;

[22] FIGURE 12 illustrates an example D-MIMO system according to embodiments of the disclosure;

[23] FIGURE 13 illustrates an example antenna port layout according to embodiments of the disclosure;

[24] FIGURE 14 illustrates a three-dimensional (3D) grid of oversampled discrete Fourier transform (DFT) beams according to embodiments of the disclosure;

[25] FIGURE 15 illustrates two new codebooks according to embodiments of the disclosure;

[26] FIGURE 16 illustrates an example D-MIMO where each transmit/receive point (TRP) has a single antenna panel according to embodiments of the disclosure;

[27] FIGURE 17 illustrates an example D-MIMO where each TRP has multiple antenna panels according to embodiments of the disclosure;

[28] FIGURE 18 illustrates an example D-MIMO where each TRP can be a single panel (SP) or multiple panel (MP) according to embodiments of the disclosure;

[29] FIGURE 19 illustrates an example signal flow for uplink (UL)-to-downlink (DL) channel mapping training according to embodiments of the disclosure;

[30] FIGURE 20 illustrates an example block diagram where a UL channel to DL channel mapping is trained through over-the-air (OTA) signaling according to embodiments of the disclosure;

[31] FIGURE 21 illustrates various hardware components of a UE, according to the embodiments as disclosed herein; and

[32] FIGURE 22 illustrates various hardware components of a base station, BS, according to the embodiments as disclosed herein;

[33] Throughout the drawings, it should be noted that like reference numbers are used to depict the same or similar elements, features, and structures.

Best Mode for Carrying out the Invention

[34] Aspects of the disclosure are to address at least the above-mentioned problems and/or disadvantages and to provide at least the advantages described below. Accordingly, an aspect of the disclosure is to provide a terminal and a communication method thereof

in a wireless communication system.

[35] This disclosure relates to apparatuses and methods for CSI codebook.

[36] In one embodiment, a user equipment (UE) is provided. The UE includes a transceiver configured to receive a configuration about a CSI report. The configuration includes information about (i) N>1 groups of CSI reference signal (CSI-RS) ports and (ii) a codebook. The codebook includes a spatial-domain (SD) basis component, a frequency-domain (FD) basis component, and a coefficient component. The SD basis component includes L_r basis vectors for each group r=1,...,N. The FD basis component includes M_v basis vectors. The coefficient component includes coefficients associated with (SD, FD) basis vector pairs. The UE further includes a processor operably coupled to the transceiver. The processor, based on the configuration, is configured to measure the N groups of CSI-RS ports and determine the SD basis component, the FD basis component, and the coefficient component such that K_1 coefficients are non-zero and remaining coefficients are zero, where $K_1 \leq \sum_{r=1}^{N}(2L_rM_v)$. The transceiver is further configured to transmit the CSI report including an indicator indicating locations of non-zero coefficients.

[37] In another embodiment, a base station (BS) is provided. The BS includes a processor configured to generate a configuration about a CSI report. The configuration including information about (i) N>1 groups of CSI-RS ports and (ii) a codebook. The codebook includes a SD basis component, a FD basis component, and a coefficient component. The SD basis component includes L_r basis vectors for each group r=1,...,N. The FD basis component includes M_v basis vectors. The coefficient component includes coefficients associated with (SD, FD) basis vector pairs. The BS further includes a transceiver operably coupled to the processor. The transceiver is configured to transmit the configuration; transmit on the N groups of CSI-RS ports; and receive the CSI report including an indicator indicating locations of non-zero coefficients from among the SD basis component, the FD basis component, and the coefficient component that are based on the N groups of CSI-RS ports. K_1 coefficients are non-zero and remaining coefficients are zero, where $K_1 \leq \sum_{r=1}^{N}(2L_rM_v)$.

[38] In yet another embodiment, a method for operating a UE is provided. The method includes receiving a configuration about a CSI report. The configuration includes information about (i) N>1 groups of CSI-RS ports and (ii) a codebook. The codebook includes a SD basis component, a FD basis component, and a coefficient component. The SD basis component includes L_r basis vectors for each group r=1,...,N. The FD basis component includes M_v basis vectors. The coefficient component includes coefficients associated with (SD, FD) basis vector pairs. The method further includes, based on the configuration, measuring the N groups of CSI-RS ports and determining

the SD basis component, the FD basis component, and the coefficient component such that K_1 coefficients are non-zero and remaining coefficients are zero, where $K_1 \leq \sum_{r=1}^{N}(2L_r M_v)$. The method further includes transmitting the CSI report including an indicator indicating locations of non-zero coefficients.

[39] Other technical features may be readily apparent to one skilled in the art from the following figures, descriptions, and claims.

[40] Before undertaking the DETAILED DESCRIPTION below, it may be advantageous to set forth definitions of certain words and phrases used throughout this patent document. The term “couple” and its derivatives refer to any direct or indirect communication between two or more elements, whether or not those elements are in physical contact with one another. The terms “transmit,” “receive,” and “communicate,” as well as derivatives thereof, encompass both direct and indirect communication. The terms “include” and “comprise,” as well as derivatives thereof, mean inclusion without limitation. The term “or” is inclusive, meaning and/or. The phrase “associated with,” as well as derivatives thereof, means to include, be included within, interconnect with, contain, be contained within, connect to or with, couple to or with, be communicable with, cooperate with, interleave, juxtapose, be proximate to, be bound to or with, have, have a property of, have a relationship to or with, or the like. The term “controller” means any device, system or part thereof that controls at least one operation. Such a controller may be implemented in hardware or a combination of hardware and software and/or firmware. The functionality associated with any particular controller may be centralized or distributed, whether locally or remotely. The phrase “at least one of,” when used with a list of items, means that different combinations of one or more of the listed items may be used, and only one item in the list may be needed. For example, “at least one of: A, B, and C” includes any of the following combinations: A, B, C, A and B, A and C, B and C, and A and B and C.

[41] Moreover, various functions described below can be implemented or supported by one or more computer programs, each of which is formed from computer readable program code and embodied in a computer readable medium. The terms “application” and “program” refer to one or more computer programs, software components, sets of instructions, procedures, functions, objects, classes, instances, related data, or a portion thereof adapted for implementation in a suitable computer readable program code. The phrase “computer readable program code” includes any type of computer code, including source code, object code, and executable code. The phrase “computer readable medium” includes any type of medium capable of being accessed by a computer, such as read only memory (ROM), random access memory (RAM), a hard disk drive, a compact disc (CD), a digital video disc (DVD), or any other type of

memory. A “non-transitory” computer readable medium excludes wired, wireless, optical, or other communication links that transport transitory electrical or other signals. A non-transitory computer readable medium includes media where data can be permanently stored and media where data can be stored and later overwritten, such as a rewritable optical disc or an erasable memory device.

[42] Definitions for other certain words and phrases are provided throughout this patent document. Those of ordinary skill in the art should understand that in many if not most instances, such definitions apply to prior as well as future uses of such defined words and phrases.

[43] This application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 63/305,916 filed on February 2, 2022; U.S. Provisional Patent Application No. 63/310,386 filed on February 15, 2022; U.S. Provisional Patent Application No. 63/326,621 filed on April 1, 2022; U.S. Provisional Patent Application No. 63/343,856 filed on May 19, 2022; U.S. Provisional Patent Application No. 63/403,597 filed on September 2, 2022; and U.S. Provisional Patent Application No. 63/412,202 filed on September 30, 2022. The above-identified provisional patent applications are hereby incorporated by reference in their entirety.

[44] The following description with reference to the accompanying drawings is provided to assist in a comprehensive understanding of various embodiments of the disclosure as defined by the claims and their equivalents. It includes various specific details to assist in that understanding but these are to be regarded as merely exemplary. Accordingly, those of ordinary skill in the art will recognize that various changes and modifications of the various embodiments described herein can be made without departing from the scope and spirit of the disclosure. In addition, descriptions of well-known functions and constructions may be omitted for clarity and conciseness.

[45] The terms and words used in the following description and claims are not limited to their bibliographical meanings, but, are merely used by the inventor to enable a clear and consistent understanding of the disclosure. Accordingly, it should be apparent to those skilled in the art that the following description of various embodiments of the disclosure is provided for illustration purpose only and not for the purpose of limiting the disclosure as defined by the appended claims and their equivalents.

[46] It is to be understood that the singular forms “a,” “an,” and “the” include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to “a component surface” includes reference to one or more of such surfaces.

[47] Before undertaking the DETAILED DESCRIPTION below, it can be advantageous to set forth definitions of certain words and phrases used throughout this patent document. The term “couple” and its derivatives refer to any direct or indirect communication between two or more elements, whether or not those elements are in physical

contact with one another. The terms “transmit,” “receive,” and “communicate,” as well as derivatives thereof, encompass both direct and indirect communication. The terms “include” and “comprise,” as well as derivatives thereof, mean inclusion without limitation. The term “or” is inclusive, meaning and/or. The phrase “associated with,” as well as derivatives thereof, means to include, be included within, connect to, interconnect with, contain, be contained within, connect to or with, couple to or with, be communicable with, cooperate with, interleave, juxtapose, be proximate to, be bound to or with, have, have a property of, have a relationship to or with, or the like. The term “controller” means any device, system or part thereof that controls at least one operation. Such a controller can be implemented in hardware or a combination of hardware and software and/or firmware. The functionality associated with any particular controller can be centralized or distributed, whether locally or remotely. The phrase “at least one of,” when used with a list of items, means that different combinations of one or more of the listed items can be used, and only one item in the list can be needed. For example, “at least one of: A, B, and C” includes any of the following combinations: A, B, C, A and B, A and C, B and C, and A and B and C. For example, “at least one of: A, B, or C” includes any of the following combinations: A, B, C, A and B, A and C, B and C, and A, B and C.

[48] Moreover, various functions described below can be implemented or supported by one or more computer programs, each of which is formed from computer-readable program code and embodied in a computer-readable medium. The terms “application” and “program” refer to one or more computer programs, software components, sets of instructions, procedures, functions, objects, classes, instances, related data, or a portion thereof adapted for implementation in a suitable computer-readable program code. The phrase “computer-readable program code” includes any type of computer code, including source code, object code, and executable code. The phrase “computer-readable medium” includes any type of medium capable of being accessed by a computer, such as Read-Only Memory (ROM), Random Access Memory (RAM), a hard disk drive, a Compact Disc (CD), a Digital Video Disc (DVD), or any other type of memory. A “non-transitory” computer-readable medium excludes wired, wireless, optical, or other communication links that transport transitory electrical or other signals. A non-transitory computer-readable medium includes media where data can be permanently stored and media where data can be stored and later overwritten, such as a rewritable optical disc or an erasable memory device.

[49] Terms used herein to describe the embodiments of the disclosure are not intended to limit and/or define the scope of the disclosure. For example, unless otherwise defined, the technical terms or scientific terms used in the disclosure shall have the ordinary meaning understood by those with ordinary skills in the art to which the disclosure

belongs.

[50] It should be understood that “first”, “second” and similar words used in the disclosure do not express any order, quantity or importance, but are only used to distinguish different components.

[51] As used herein, any reference to “an example” or “example”, “an implementation” or “implementation”, “an embodiment” or “embodiment” means that particular elements, features, structures or characteristics described in connection with the embodiment is included in at least one embodiment. The phrases “in one embodiment” or “in one example” appearing in different places in the specification do not necessarily refer to the same embodiment.

[52] As used herein, “a portion of” something means “at least some of” the thing, and as such may mean less than all of, or all of, the thing. As such, “a portion of” a thing includes the entire thing as a special case, i.e., the entire thing is an example of a portion of the thing.

[53] As used herein, the term “set” means one or more. Accordingly, a set of items can be a single item or a collection of two or more items.

[54] In this disclosure, to determine whether a specific condition is satisfied or fulfilled, expressions, such as “greater than” or “less than” are used by way of example and expressions, such as “greater than or equal to” or “less than or equal to” are also applicable and not excluded. For example, a condition defined with “greater than or equal to” may be replaced by “greater than” (or vice-versa), a condition defined with “less than or equal to” may be replaced by “less than” (or vice-versa), etc.

[55] It will be further understood that similar words such as the term “include” or “comprise” mean that elements or objects appearing before the word encompass the listed elements or objects appearing after the word and their equivalents, but other elements or objects are not excluded. Similar words such as “connect” or “connected” are not limited to physical or mechanical connection, but can include electrical connection, whether direct or indirect. “Upper”, “lower”, “left” and “right” are only used to express a relative positional relationship, and when an absolute position of the described object changes, the relative positional relationship may change accordingly.

Mode for the Invention

[56] FIGURES 1 through 22, discussed below, and the various embodiments used to describe the principles of the disclosure in this patent document are by way of illustration only and should not be construed in any way to limit the scope of the disclosure. Those skilled in the art will understand that the principles of the disclosure may be implemented in any suitably-arranged system or device.

[57] The following documents and standards descriptions are hereby incorporated by

reference into the disclosure as if fully set forth herein: 3GPP TS 36.211 v17.0.0, “E UTRA, Physical channels and modulation” (herein “REF 1”); 3GPP TS 36.212 v17.0.0, “E UTRA, Multiplexing and Channel coding” (herein “REF 2”); 3GPP TS 36.213 v17.0.0, “E UTRA, Physical Layer Procedures” (herein “REF 3”); 3GPP TS 36.321 v17.0.0, “E-UTRA, Medium Access Control (MAC) protocol specification” (herein “REF 4”); 3GPP TS 36.331 v17.0.0, “E UTRA, Radio Resource Control (RRC) protocol specification” (herein “REF 5”); 3GPP TS 38.211 v17.0.0, “NR, Physical Channels and Modulation” (herein “REF 6”); 3GPP TS 38.212 v17.0.0, “NR, Multiplexing and channel coding” (herein “REF 7”); 3GPP TS 38.213 v17.0.0, “NR, Physical Layer Procedures for Control” (herein “REF 8”); 3GPP TS 38.214 v17.0.0; “NR, Physical Layer Procedures for Data” (herein “REF 9”); 3GPP TS 38.215 v17.0.0; “NR, Physical Layer Measurements” (herein “REF 10”); 3GPP TS 38.321 v17.0.0; “NR, Medium Access Control (MAC) Protocol Specification” (herein “REF 11”); 3GPP TS 38.331 v17.0.0; “NR, Radio Resource Control (RRC) Protocol Specification” (herein “REF 12”); and RP-213599 “Study on Artificial Intelligence (AI)/Machine Learning (ML) for NR Air Interface” (herein “REF 13”).

[58] Wireless communication has been one of the most successful innovations in modern history. Recently, the number of subscribers to wireless communication services exceeded five billion and continues to grow quickly. The demand of wireless data traffic is rapidly increasing due to the growing popularity among consumers and businesses of smart phones and other mobile data devices, such as tablets, “note pad” computers, net books, eBook readers, and machine type of devices. In order to meet the high growth in mobile data traffic and support new applications and deployments, improvements in radio interface efficiency and coverage are of paramount importance.

[59] To meet the demand for wireless data traffic having increased since deployment of 4G communication systems and to enable various vertical applications, 5G/NR communication systems have been developed and are currently being deployed. The 5G/NR communication system is considered to be implemented in higher frequency (mmWave) bands, e.g., 28 GHz or 60GHz bands, so as to accomplish higher data rates or in lower frequency bands, such as 6 GHz, to enable robust coverage and mobility support. To decrease propagation loss of the radio waves and increase the transmission distance, the beamforming, massive multiple-input multiple-output (MIMO), full dimensional MIMO (FD-MIMO), array antenna, an analog beam forming, large scale antenna techniques are discussed in 5G/NR communication systems.

[60] In addition, in 5G/NR communication systems, development for system network improvement is under way based on advanced small cells, cloud radio access networks (RANs), ultra-dense networks, device-to-device (D2D) communication, wireless backhaul, moving network, cooperative communication, coordinated multi-points

(CoMP), reception-end interference cancelation and the like.

[61] The discussion of 5G systems and frequency bands associated therewith is for reference as certain embodiments of the disclosure may be implemented in 5G systems. However, the disclosure is not limited to 5G systems, or the frequency bands associated therewith, and embodiments of the disclosure may be utilized in connection with any frequency band. For example, aspects of the disclosure may also be applied to deployment of 5G communication systems, 6G or even later releases which may use terahertz (THz) bands.

[62] FIGURES 1-3 below describe various embodiments implemented in wireless communications systems and with the use of orthogonal frequency division multiplexing (OFDM) or orthogonal frequency division multiple access (OFDMA) communication techniques. The descriptions of FIGURES 1-3 are not meant to imply physical or architectural limitations to the manner in which different embodiments may be implemented. Different embodiments of the disclosure may be implemented in any suitably arranged communications system.

[63] FIGURE 1 illustrates an example wireless network according to embodiments of the disclosure. The embodiment of the wireless network shown in FIGURE 1 is for illustration only. Other embodiments of the wireless network 100 could be used without departing from the scope of this disclosure.

[64] As shown in FIGURE 1, the wireless network includes a gNB 101 (e.g., base station, BS), a gNB 102, and a gNB 103. The gNB 101 communicates with the gNB 102 and the gNB 103. The gNB 101 also communicates with at least one network 130, such as the Internet, a proprietary Internet Protocol (IP) network, or other data network.

[65] The gNB 102 provides wireless broadband access to the network 130 for a first plurality of user equipments (UEs) within a coverage area 120 of the gNB 102. The first plurality of UEs includes a UE 111, which may be located in a small business; a UE 112, which may be located in an enterprise; a UE 113, which may be a WiFi hotspot; a UE 114, which may be located in a first residence; a UE 115, which may be located in a second residence; and a UE 116, which may be a mobile device, such as a cell phone, a wireless laptop, a wireless PDA, or the like. The gNB 103 provides wireless broadband access to the network 130 for a second plurality of UEs within a coverage area 125 of the gNB 103. The second plurality of UEs includes the UE 115 and the UE 116. In some embodiments, one or more of the gNBs 101-103 may communicate with each other and with the UEs 111-116 using 5G/NR, long term evolution (LTE), long term evolution-advanced (LTE-A), WiMAX, WiFi, or other wireless communication techniques.

[66] Depending on the network type, the term “base station” or “BS” can refer to any component (or collection of components) configured to provide wireless access to a

network, such as transmit point (TP), transmit-receive point (TRP), an enhanced base station (eNodeB or eNB), a 5G/NR base station (gNB), a macrocell, a femtocell, a WiFi access point (AP), or other wirelessly enabled devices. Base stations may provide wireless access in accordance with one or more wireless communication protocols, e.g., 5G/NR 3rd generation partnership project (3GPP) NR, long term evolution (LTE), LTE advanced (LTE-A), high speed packet access (HSPA), Wi-Fi 802.11a/b/g/n/ac, etc. For the sake of convenience, the terms “BS” and “TRP” are used interchangeably in this patent document to refer to network infrastructure components that provide wireless access to remote terminals. Also, depending on the network type, the term “user equipment” or “UE” can refer to any component such as “mobile station,” “subscriber station,” “remote terminal,” “wireless terminal,” “receive point,” or “user device.” For the sake of convenience, the terms “user equipment” and “UE” are used in this patent document to refer to remote wireless equipment that wirelessly accesses a BS, whether the UE is a mobile device (such as a mobile telephone or smartphone) or is normally considered a stationary device (such as a desktop computer or vending machine).

[67] Dotted lines show the approximate extents of the coverage areas 120 and 125, which are shown as approximately circular for the purposes of illustration and explanation only. It should be clearly understood that the coverage areas associated with gNBs, such as the coverage areas 120 and 125, may have other shapes, including irregular shapes, depending upon the configuration of the gNBs and variations in the radio environment associated with natural and man-made obstructions.

[68] As described in more detail below, one or more of the UEs 111-116 include circuitry, programing, or a combination thereof for CSI codebook. In certain embodiments, one or more of the BSs 101-103 include circuitry, programing, or a combination thereof for CSI codebook.

[69] Although FIGURE 1 illustrates one example of a wireless network, various changes may be made to FIGURE 1. For example, the wireless network could include any number of gNBs and any number of UEs in any suitable arrangement. Also, the gNB 101 could communicate directly with any number of UEs and provide those UEs with wireless broadband access to the network 130. Similarly, each gNB 102-103 could communicate directly with the network 130 and provide UEs with direct wireless broadband access to the network 130. Further, the gNBs 101, 102, and/or 103 could provide access to other or additional external networks, such as external telephone networks or other types of data networks.

[70] FIGURE 2 illustrates an example gNB 102 according to embodiments of the disclosure. The embodiment of the gNB 102 illustrated in FIGURE 2 is for illustration only, and the gNBs 101 and 103 of FIGURE 1 could have the same or similar con-

figuration. However, gNBs come in a wide variety of configurations, and FIGURE 2 does not limit the scope of this disclosure to any particular implementation of a gNB.

[71] As shown in FIGURE 2, the gNB 102 includes multiple antennas 205a-205n, multiple transceivers 210a-210n, a controller/processor 225, a memory 230, and a backhaul or network interface 235. However, the components of the gNB 102 are not limited thereto. For example, the gNB 102 may include more or fewer components than those described above. In addition, the gNB 102 corresponds to the base station of the FIG. 21.

[72] The transceivers 210a-210n receive, from the antennas 205a-205n, incoming RF signals, such as signals transmitted by UEs in the network 100. The transceivers 210a-210n down-convert the incoming RF signals to generate IF or baseband signals. The IF or baseband signals are processed by receive (RX) processing circuitry in the transceivers 210a-210n and/or controller/processor 225, which generates processed baseband signals by filtering, decoding, and/or digitizing the baseband or IF signals. The controller/processor 225 may further process the baseband signals.

[73] Transmit (TX) processing circuitry in the transceivers 210a-210n and/or controller/processor 225 receives analog or digital data (such as voice data, web data, e-mail, or interactive video game data) from the controller/processor 225. The TX processing circuitry encodes, multiplexes, and/or digitizes the outgoing baseband data to generate processed baseband or IF signals. The transceivers 210a-210n up-converts the baseband or IF signals to RF signals that are transmitted via the antennas 205a-205n.

[74] The controller/processor 225 can include one or more processors or other processing devices that control the overall operation of the gNB 102. For example, the controller/processor 225 could control the reception of UL channel signals and the transmission of DL channel signals by the transceivers 210a-210n in accordance with well-known principles. The controller/processor 225 could support additional functions as well, such as more advanced wireless communication functions. For instance, the controller/processor 225 could support beam forming or directional routing operations in which outgoing/incoming signals from/to multiple antennas 205a-205n are weighted differently to effectively steer the outgoing signals in a desired direction. As another example, the controller/processor 225 could support methods for uplink transmission in full duplex systems. Any of a wide variety of other functions could be supported in the gNB 102 by the controller/processor 225.

[75] The controller/processor 225 is also capable of executing programs and other processes resident in the memory 230, such as an OS. The controller/processor 225 can move data into or out of the memory 230 as required by an executing process.

[76] The controller/processor 225 is also coupled to the backhaul or network interface 235. The backhaul or network interface 235 allows the gNB 102 to communicate with

other devices or systems over a backhaul connection or over a network. The interface 235 could support communications over any suitable wired or wireless connection(s). For example, when the gNB 102 is implemented as part of a cellular communication system (such as one supporting 5G/NR, LTE, or LTE-A), the interface 235 could allow the gNB 102 to communicate with other gNBs over a wired or wireless backhaul connection. When the gNB 102 is implemented as an access point, the interface 235 could allow the gNB 102 to communicate over a wired or wireless local area network or over a wired or wireless connection to a larger network (such as the Internet). The interface 235 includes any suitable structure supporting communications over a wired or wireless connection, such as an Ethernet or transceiver.

[77] The memory 230 is coupled to the controller/processor 225. Part of the memory 230 could include a RAM, and another part of the memory 230 could include a Flash memory or other ROM.

[78] Although FIGURE 2 illustrates one example of gNB 102, various changes may be made to FIGURE 2. For example, the gNB 102 could include any number of each component shown in FIGURE 2. Also, various components in FIGURE 2 could be combined, further subdivided, or omitted and additional components could be added according to particular needs.

[79] FIGURE 3 illustrates an example UE 116 according to embodiments of the disclosure. The embodiment of the UE 116 illustrated in FIGURE 3 is for illustration only, and the UEs 111-115 of FIGURE 1 could have the same or similar configuration. However, UEs come in a wide variety of configurations, and FIGURE 3 does not limit the scope of this disclosure to any particular implementation of a UE.

[80] As shown in FIGURE 3, the UE 116 includes antenna(s) 305, a transceiver(s) 310, and a microphone 320. The UE 116 also includes a speaker 330, a processor 340, an input/output (I/O) interface (IF) 345, an input 350, a display 355, and a memory 360. The memory 360 includes an operating system (OS) 361 and one or more applications 362. However, the components of the UE 116 are not limited thereto. For example, the UE 116 may include more or fewer components than those described above. In addition, the UE 116 corresponds to the UE of the FIG. 22.

[81] The transceiver(s) 310 receives, from the antenna 305, an incoming RF signal transmitted by a gNB of the network 100. The transceiver(s) 310 down-converts the incoming RF signal to generate an intermediate frequency (IF) or baseband signal. The IF or baseband signal is processed by RX processing circuitry in the transceiver(s) 310 and/or processor 340, which generates a processed baseband signal by filtering, decoding, and/or digitizing the baseband or IF signal. The RX processing circuitry sends the processed baseband signal to the speaker 330 (such as for voice data) or is processed by the processor 340 (such as for web browsing data).

[82] TX processing circuitry in the transceiver(s) 310 and/or processor 340 receives analog or digital voice data from the microphone 320 or other outgoing baseband data (such as web data, e-mail, or interactive video game data) from the processor 340. The TX processing circuitry encodes, multiplexes, and/or digitizes the outgoing baseband data to generate a processed baseband or IF signal. The transceiver(s) 310 up-converts the baseband or IF signal to an RF signal that is transmitted via the antenna(s) 305.

[83] The processor 340 can include one or more processors or other processing devices and execute the OS 361 stored in the memory 360 in order to control the overall operation of the UE 116. For example, the processor 340 could control the reception of DL channel signals and the transmission of UL channel signals by the transceiver(s) 310 in accordance with well-known principles. In some embodiments, the processor 340 includes at least one microprocessor or microcontroller.

[84] The processor 340 is also capable of executing other processes and programs resident in the memory 360. The processor 340 can move data into or out of the memory 360 as required by an executing process. In some embodiments, the processor 340 is configured to execute the applications 362 based on the OS 361 or in response to signals received from gNBs or an operator. The processor 340 is also coupled to the I/O interface 345, which provides the UE 116 with the ability to connect to other devices, such as laptop computers and handheld computers. The I/O interface 345 is the communication path between these accessories and the processor 340.

[85] The processor 340 is also coupled to the input 350, which includes for example, a touchscreen, keypad, etc., and the display 355. The operator of the UE 116 can use the input 350 to enter data into the UE 116. The display 355 may be a liquid crystal display, light emitting diode display, or other display capable of rendering text and/or at least limited graphics, such as from web sites.

[86] The memory 360 is coupled to the processor 340. Part of the memory 360 could include a random-access memory (RAM), and another part of the memory 360 could include a Flash memory or other read-only memory (ROM).

[87] Although FIGURE 3 illustrates one example of UE 116, various changes may be made to FIGURE 3. For example, various components in FIGURE 3 could be combined, further subdivided, or omitted and additional components could be added according to particular needs. As a particular example, the processor 340 could be divided into multiple processors, such as one or more central processing units (CPUs) and one or more graphics processing units (GPUs). In another example, the transceiver(s) 310 may include any number of transceivers and signal processing chains and may be connected to any number of antennas. Also, while FIGURE 3 illustrates the UE 116 configured as a mobile telephone or smartphone, UEs could be configured to operate as other types of mobile or stationary devices.

[88] FIGURE 4 and FIGURE 5 illustrate example wireless transmit and receive paths according to this disclosure. In the following description, a transmit path 400, of FIGURE 4, may be described as being implemented in a BS (such as the BS 102), while a receive path 500, of FIGURE 5, may be described as being implemented in a UE (such as a UE 116). However, it may be understood that the receive path 500 can be implemented in a BS and that the transmit path 400 can be implemented in a UE. In some embodiments, the receive path 500 is configured to support CSI codebook as described in embodiments of the disclosure.

[89] The transmit path 400 as illustrated in FIGURE 4 includes a channel coding and modulation block 405, a serial-to-parallel (S-to-P) block 410, a size N inverse fast Fourier transform (IFFT) block 415, a parallel-to-serial (P-to-S) block 420, an add cyclic prefix block 425, and an up-converter (UC) 430. The receive path 500 as illustrated in FIGURE 5 includes a down-converter (DC) 555, a remove cyclic prefix block 560, a serial-to-parallel (S-to-P) block 565, a size N fast Fourier transform (FFT) block 570, a parallel-to-serial (P-to-S) block 575, and a channel decoding and demodulation block 580.

[90] As illustrated in FIGURE 4, the channel coding and modulation block 405 receives a set of information bits, applies coding (such as a low-density parity check (LDPC) coding), and modulates the input bits (such as with quadrature phase shift keying (QPSK) or quadrature amplitude modulation (QAM)) to generate a sequence of frequency-domain modulation symbols. The serial-to-parallel block 410 converts (such as de-multiplexes) the serial modulated symbols to parallel data in order to generate N parallel symbol streams, where N is the IFFT/FFT size used in the BS 102 and the UE 116. The size N IFFT block 415 performs an IFFT operation on the N parallel symbol streams to generate time-domain output signals. The parallel-to-serial block 420 converts (such as multiplexes) the parallel time-domain output symbols from the size N IFFT block 415 in order to generate a serial time-domain signal. The add cyclic prefix block 425 inserts a cyclic prefix to the time-domain signal. The up-converter 430 modulates (such as up-converts) the output of the add cyclic prefix block 425 to an RF frequency for transmission via a wireless channel. The signal may also be filtered at baseband before conversion to the RF frequency.

[91] A transmitted RF signal from the BS 102 arrives at the UE 116 after passing through the wireless channel, and reverse operations to those at the BS 102 are performed at the UE 116.

[92] As illustrated in FIGURE 5, the down-converter 555 down-converts the received signal to a baseband frequency, and the remove cyclic prefix block 560 removes the cyclic prefix to generate a serial time-domain baseband signal. The serial-to-parallel block 565 converts the time-domain baseband signal to parallel time domain signals.

The size N FFT block 570 performs an FFT algorithm to generate N parallel frequency-domain signals. The parallel-to-serial block 575 converts the parallel frequency-domain signals to a sequence of modulated data symbols. The channel decoding and demodulation block 580 demodulates and decodes the modulated symbols to recover the original input data stream.

[93] Each of the BSs 101-103 may implement a transmit path 400 as illustrated in FIGURE 4 that is analogous to transmitting in the downlink to UEs 111-116 and may implement a receive path 500 as illustrated in FIGURE 5 that is analogous to receiving in the uplink from UEs 111-116. Similarly, each of UEs 111-116 may implement the transmit path 400 for transmitting in the uplink to the BSs 101-103 and may implement the receive path 500 for receiving in the downlink from the BSs 101-103.

[94] Each of the components in FIGURE 4 and FIGURE 5 can be implemented using hardware or using a combination of hardware and software/firmware. As a particular example, at least some of the components in FIGURES 4 and FIGURE 5 may be implemented in software, while other components may be implemented by configurable hardware or a mixture of software and configurable hardware. For instance, the FFT block 570 and the IFFT block 515 may be implemented as configurable software algorithms, where the value of size N may be modified according to the implementation.

[95] Furthermore, although described as using FFT and IFFT, this is by way of illustration only and may not be construed to limit the scope of this disclosure. Other types of transforms, such as discrete Fourier transform (DFT) and inverse discrete Fourier transform (IDFT) functions, can be used. It may be appreciated that the value of the variable N may be any integer number (such as 1, 2, 3, 4, or the like) for DFT and IDFT functions, while the value of the variable N may be any integer number that is a power of two (such as 1, 2, 4, 8, 16, or the like) for FFT and IFFT functions.

[96] Although FIGURE 4 and FIGURE 5 illustrate examples of wireless transmit and receive paths, various changes may be made to FIGURE 4 and FIGURE 5. For example, various components in FIGURE 4 and FIGURE 5 can be combined, further subdivided, or omitted and additional components can be added according to particular needs. Also, FIGURE 4 and FIGURE 5 are meant to illustrate examples of the types of transmit and receive paths that can be used in a wireless network. Any other suitable architectures can be used to support wireless communications in a wireless network.

[97] A communication system includes a downlink (DL) that conveys signals from transmission points such as base stations (BSs) or NodeBs to user equipments (UEs) and an Uplink (UL) that conveys signals from UEs to reception points such as NodeBs. A UE, also commonly referred to as a terminal or a mobile station, may be fixed or mobile and may be a cellular phone, a personal computer device, or an automated device. An eNodeB, which is generally a fixed station, may also be referred to as an

access point or other equivalent terminology. For LTE systems, a NodeB is often referred as an eNodeB.

[98] In a communication system, such as LTE system, DL signals can include data signals conveying information content, control signals conveying DL control information (DCI), and reference signals (RS) that are also known as pilot signals. An eNodeB transmits data information through a physical DL shared channel (PDSCH). An eNodeB transmits DCI through a physical DL control channel (PDCCH) or an Enhanced PDCCH (EPDCCH) - see also REF 3. An eNodeB transmits acknowledgement information in response to data transport block (TB) transmission from a UE in a physical hybrid ARQ indicator channel (PHICH). An eNodeB transmits one or more of multiple types of RS including a UE-common RS (CRS), a channel state information RS (CSI-RS), or a demodulation RS (DMRS). A CRS is transmitted over a DL system bandwidth (BW) and can be used by UEs to obtain a channel estimate to demodulate data or control information or to perform measurements. To reduce CRS overhead, an eNodeB may transmit a CSI-RS with a smaller density in the time and/or frequency domain than a CRS. DMRS can be transmitted only in the BW of a respective PDSCH or EPDCCH and a UE can use the DMRS to demodulate data or control information in a PDSCH or an EPDCCH, respectively. A transmission time interval for DL channels is referred to as a subframe and can have, for example, duration of 1 millisecond.

[99] DL signals also include transmission of a logical channel that carries system control information. A BCCH is mapped to either a transport channel referred to as a broadcast channel (BCH) when the DL signals convey a master information block (MIB) or to a DL shared channel (DL-SCH) when the DL signals convey a System Information Block (SIB). Most system information is included in different SIBs that are transmitted using DL-SCH. A presence of system information on a DL-SCH in a subframe can be indicated by a transmission of a corresponding PDCCH conveying a codeword with a cyclic redundancy check (CRC) scrambled with system information RNTI (SI-RNTI). Alternatively, scheduling information for a SIB transmission can be provided in an earlier SIB and scheduling information for the first SIB (SIB-1) can be provided by the MIB.

[100] DL resource allocation is performed in a unit of subframe and a group of physical resource blocks (PRBs). A transmission BW includes frequency resource units referred to as resource blocks (RBs). Each RB includes $N_{\mathrm{sc}}^{\mathrm{RB}}$ sub-carriers, or resource elements (REs), such as 12 REs. A unit of one RB over one subframe is referred to as a PRB. A UE can be allocated M_{PDSCH} RBs for a total of $M_{sc}^{PDSCH} = M_{PDSCH} \cdot N_{sc}^{RB}$ REs for the PDSCH transmission BW.

[101] UL signals can include data signals conveying data information, control signals conveying UL control information (UCI), and UL RS. UL RS includes DMRS and Sounding RS (SRS). A UE transmits DMRS only in a BW of a respective PUSCH or PUCCH. An eNodeB can use a DMRS to demodulate data signals or UCI signals. A UE transmits SRS to provide an eNodeB with an UL CSI. A UE transmits data information or UCI through a respective physical UL shared channel (PUSCH) or a Physical UL control channel (PUCCH). If a UE needs to transmit data information and UCI in a same UL subframe, the UE may multiplex both in a PUSCH. UCI includes Hybrid Automatic Repeat request acknowledgement (HARQ-ACK) information, indicating correct (ACK) or incorrect (NACK) detection for a data TB in a PDSCH or absence of a PDCCH detection (DTX), scheduling request (SR) indicating whether a UE has data in the UE's buffer, rank indicator (RI), and channel state information (CSI) enabling an eNodeB to perform link adaptation for PDSCH transmissions to a UE. HARQ-ACK information is also transmitted by a UE in response to a detection of a PDCCH/EPDCCH indicating a release of semi-persistently scheduled PDSCH (see also REF 3).

[102] An UL subframe includes two slots. Each slot includes $N_{\mathrm{symb}}^{\mathrm{UL}}$ symbols for transmitting data information, UCI, DMRS, or SRS. A frequency resource unit of an UL system BW is an RB. A UE is allocated N_{RB} RBs for a total of $N_{\mathrm{RB}} \cdot N_{\mathrm{sc}}^{\mathrm{RB}}$ REs for a transmission BW. For a PUCCH, N_{RB} =1. A last subframe symbol can be used to multiplex SRS transmissions from one or more UEs. A number of subframe symbols that are available for data/UCI/DMRS transmission is $N_{\mathrm{symb}} = 2 \cdot (N_{\mathrm{symb}}^{\mathrm{UL}} - 1) - N_{\mathrm{SRS}}$, where $N_{\mathrm{SRS}} = 1$ if a last subframe symbol is used to transmit SRS and N_{SRS} =0 otherwise.

[103] FIGURE 6 illustrates a transmitter block diagram 600 for a PDSCH in a subframe according to embodiments of the disclosure. The embodiment of the transmitter block diagram 600 illustrated in FIGURE 6 is for illustration only. One or more of the components illustrated in FIGURE 6 can be implemented in specialized circuitry configured to perform the noted functions or one or more of the components can be implemented by one or more processors executing instructions to perform the noted functions. FIGURE 6 does not limit the scope of this disclosure to any particular implementation of the transmitter block diagram 600.

[104] As shown in FIGURE 6, information bits 610 are encoded by encoder 620, such as a turbo encoder, and modulated by modulator 630, for example using quadrature phase shift keying (QPSK) modulation. A serial to parallel (S/P) converter 640 generates M modulation symbols that are subsequently provided to a mapper 650 to be mapped to

REs selected by a transmission BW selection unit 655 for an assigned PDSCH transmission BW, unit 660 applies an Inverse fast Fourier transform (IFFT), the output is then serialized by a parallel to serial (P/S) converter 670 to create a time domain signal, filtering is applied by filter 680, and a signal transmitted 690. Additional functionalities, such as data scrambling, cyclic prefix insertion, time windowing, interleaving, and others are well known in the art and are not shown for brevity.

[105] FIGURE 7 illustrates a receiver block diagram 700 for a PDSCH in a subframe according to embodiments of the disclosure. The embodiment of the diagram 700 illustrated in FIGURE 7 is for illustration only. One or more of the components illustrated in FIGURE 7 can be implemented in specialized circuitry configured to perform the noted functions or one or more of the components can be implemented by one or more processors executing instructions to perform the noted functions. FIGURE 7 does not limit the scope of this disclosure to any particular implementation of the diagram 700.

[106] As shown in FIGURE 7, a received signal 710 is filtered by filter 720, REs 730 for an assigned reception BW are selected by BW selector 735, unit 740 applies a fast Fourier transform (FFT), and an output is serialized by a parallel-to-serial converter 750. Subsequently, a demodulator 760 coherently demodulates data symbols by applying a channel estimate obtained from a DMRS or a CRS (not shown), and a decoder 770, such as a turbo decoder, decodes the demodulated data to provide an estimate of the information data bits 780. Additional functionalities such as time-windowing, cyclic prefix removal, de-scrambling, channel estimation, and de-interleaving are not shown for brevity.

[107] FIGURE 8 illustrates a transmitter block diagram 800 for a PUSCH in a subframe according to embodiments of the disclosure. The embodiment of the block diagram 800 illustrated in FIGURE 8 is for illustration only. One or more of the components illustrated in FIGURE 6 can be implemented in specialized circuitry configured to perform the noted functions or one or more of the components can be implemented by one or more processors executing instructions to perform the noted functions. FIGURE 8 does not limit the scope of this disclosure to any particular implementation of the block diagram 800.

[108] As shown in FIGURE 8, information data bits 810 are encoded by encoder 820, such as a turbo encoder, and modulated by modulator 830. A discrete Fourier transform (DFT) unit 840 applies a DFT on the modulated data bits, REs 850 corresponding to an assigned PUSCH transmission BW are selected by transmission BW selection unit 855, unit 860 applies an IFFT and, after a cyclic prefix insertion (not shown), filtering is applied by filter 870 and a signal transmitted 880.

[109] FIGURE 9 illustrates a receiver block diagram 900 for a PUSCH in a subframe

according to embodiments of the disclosure. The embodiment of the block diagram 900 illustrated in FIGURE 9 is for illustration only. One or more of the components illustrated in FIGURE 9 can be implemented in specialized circuitry configured to perform the noted functions or one or more of the components can be implemented by one or more processors executing instructions to perform the noted functions. FIGURE 9 does not limit the scope of this disclosure to any particular implementation of the block diagram 900.

[110] As shown in FIGURE 9, a received signal 910 is filtered by filter 920. Subsequently, after a cyclic prefix is removed (not shown), unit 930 applies an FFT, REs 940 corresponding to an assigned PUSCH reception BW are selected by a reception BW selector 945, unit 950 applies an inverse DFT (IDFT), a demodulator 960 coherently demodulates data symbols by applying a channel estimate obtained from a DMRS (not shown), a decoder 970, such as a turbo decoder, decodes the demodulated data to provide an estimate of the information data bits 980.

[111] In next generation cellular systems, various use cases are envisioned beyond the capabilities of LTE system. Termed 5G or the fifth-generation cellular system, a system capable of operating at sub-6GHz and above-6 GHz (for example, in mmWave regime) becomes one of the requirements. In 3GPP TR 22.891, 74 5G use cases have been identified and described; those use cases can be roughly categorized into three different groups. A first group is termed “enhanced mobile broadband (eMBB),” targeted to high data rate services with less stringent latency and reliability requirements. A second group is termed “ultra-reliable and low latency (URLL)” targeted for applications with less stringent data rate requirements, but less tolerant to latency. A third group is termed “massive MTC (mMTC)” targeted for large number of low-power device connections such as 1 million per km2 with less stringent the reliability, data rate, and latency requirements.

[112] The 3GPP NR specification supports up to 32 CSI-RS antenna ports which enable a gNB to be equipped with a large number of antenna elements (such as 64 or 128). In this case, a plurality of antenna elements is mapped onto one CSI-RS port. For next generation cellular systems such as 5G, the maximum number of CSI-RS ports can either remain the same or increase.

[113] FIGURE 10 illustrates an example antenna blocks or arrays 1000 according to embodiments of the disclosure. The embodiment of the antenna blocks or arrays 1000 illustrated in FIGURE 10 is for illustration only. FIGURE 10 does not limit the scope of this disclosure to any particular implementation of the antenna blocks or arrays.

[114] For mmWave bands, although the number of antenna elements can be larger for a given form factor, the number of CSI-RS ports -which can correspond to the number of digitally precoded ports - tends to be limited due to hardware constraints (such as the

feasibility to install a large number of ADCs/DACs at mmWave frequencies) as illustrated in FIGURE 10. In this case, one CSI-RS port is mapped onto a large number of antenna elements which can be controlled by a bank of analog phase shifters 1001. One CSI-RS port can then correspond to one sub-array which produces a narrow analog beam through analog beamforming 1005. This analog beam can be configured to sweep across a wider range of angles 1020 by varying the phase shifter bank across symbols or subframes. The number of sub-arrays (equal to the number of RF chains) is the same as the number of CSI-RS ports NCSI-PORT. A digital beamforming unit 1010 performs a linear combination across NCSI-PORT analog beams to further increase precoding gain. While analog beams are wideband (hence not frequency-selective), digital precoding can be varied across frequency sub-bands or resource blocks. Receiver operation can be conceived analogously.

[115] Since the above system utilizes multiple analog beams for transmission and reception (wherein one or a small number of analog beams are selected out of a large number, for instance, after a training duration - to be performed from time to time), the term “multi-beam operation” is used to refer to the overall system aspect. This includes, for the purpose of illustration, indicating the assigned DL or UL transmit (TX) beam (also termed “beam indication”), measuring at least one reference signal for calculating and performing beam reporting (also termed “beam measurement” and “beam reporting”, respectively), and receiving a DL or UL transmission via a selection of a corresponding receive (RX) beam.

[116] The above system is also applicable to higher frequency bands such as >52.6GHz (also termed the FR4). In this case, the system can employ only analog beams. Due to the O2 absorption loss around 60GHz frequency (~10dB additional loss @100m distance), larger number of and sharper analog beams (hence larger number of radiators in the array) will be needed to compensate for the additional path loss.

[117] At lower frequency bands such as FR1 or particularly sub-1 GHz band, on the other hand, the number of antenna elements cannot be increased in a given form factor due to large wavelength. As an example, for the case of the wavelength size (λ) of the center frequency 600 MHz (which is 50 cm), it requires 4 m for uniform-linear-array (ULA) antenna panel of 16 antenna elements with the half-wavelength distance between two adjacent antenna elements. Considering a plurality of antenna elements is mapped to one digital port in practical cases, the required size for antenna panels at gNB to support a large number of antenna ports, e.g., 32 CSI-RS ports, becomes very large in such low frequency bands, and it leads to the difficulty of deploying 2-D antenna arrays within the size of a conventional form factor. This can result in a limited number of physical antenna elements and, subsequently CSI-RS ports, that can be supported at a single site and limit the spectral efficiency of such systems.

[118] FIGURE 11 illustrates an example system for D-MIMO 1100 according to embodiments of the disclosure. The embodiment of the example system for D-MIMO 1100 illustrated in FIGURE 11 is for illustration only. FIGURE 112 does not limit the scope of this disclosure to any particular implementation of the example system for D-MIMO.

[119] As illustrated in FIGURE 11, one approach to resolving the issue described above is to form multiple TRPs (multi-TRP) or RRHs with a small number of antenna ports instead of integrating all of the antenna ports in a single panel (or at a single site) and to distribute the multiple panels in multiple locations/sites (or TRPs, RRHs). This approach, the concept of distributed MIMO (D-MIMO), is shown in FIGURE 11.

[120] FIGURE 12 illustrates an example system for D-MIMO 1200 according to embodiments of the disclosure. The embodiment of the example system for D-MIMO 1200 illustrated in FIGURE 12 is for illustration only. FIGURE 12 does not limit the scope of this disclosure to any particular implementation of the example system for D-MIMO.

[121] As illustrated in FIGURE 12, the multiple TRPs at multiple locations can still be connected to a single base unit, and thus the signal transmitted/received via multiple distributed TRPs can be processed in a centralized manner through the single base unit.

[122] Note that although low frequency band systems (sub-1GHz band) have been mentioned as a motivation for distributed MIMO (or mTRP), the distributed MIMO technology is frequency-band-agnostic and can be useful in mid- (sub-6GHz) and high-band (above-6GHz) systems in addition to low-band (sub-1GHz) systems.

[123] The terminology “distributed MIMO” is used as an illustrative purpose, it can be considered under another terminology such as multi-TRP, mTRP, cell-free network, and so on.

[124] All the following components and embodiments are applicable for UL transmission with CP-OFDM (cyclic prefix OFDM) waveform as well as DFT-SOFDM (DFT-spread OFDM) and SC-FDMA (single-carrier FDMA) waveforms. Furthermore, all the following components and embodiments are applicable for UL transmission when the scheduling unit in time is either one subframe (which can consist of one or multiple slots) or one slot.

[125] In the disclosure, the frequency resolution (reporting granularity) and span (reporting bandwidth) of CSI or calibration coefficient reporting can be defined in terms of frequency “subbands” and “CSI reporting band” (CRB), respectively.

[126] A subband for CSI or calibration coefficient reporting is defined as a set of contiguous PRBs which represents the smallest frequency unit for CSI or calibration coefficient reporting. The number of PRBs in a subband can be fixed for a given value of DL system bandwidth, configured either semi-statically via higher-layer/RRC

signaling, or dynamically via L1 DL control signaling or MAC control element (MAC CE). The number of PRBs in a subband can be included in CSI or calibration coefficient reporting setting.

[127] "CSI or calibration coefficient reporting band" is defined as a set/collection of subbands, either contiguous or non-contiguous, wherein CSI or calibration coefficient reporting is performed. For example, CSI or calibration coefficient reporting band can include all the subbands within the DL system bandwidth. This can also be termed "full-band". Alternatively, CSI or calibration coefficient reporting band can include only a collection of subbands within the DL system bandwidth. This can also be termed "partial band".

[128] The term "CSI or calibration coefficient reporting band" is used only as an example for representing a function. Other terms such as "CSI or calibration coefficient reporting subband set" or "CSI or calibration coefficient reporting bandwidth" can also be used.

[129] In terms of UE configuration, a UE can be configured with at least one CSI or calibration coefficient reporting band. This configuration can be semi-static (via higher-layer signaling or RRC) or dynamic (via MAC CE or L1 DL control signaling). When configured with multiple (N) CSI or calibration coefficient reporting bands (e.g., via RRC signaling), a UE can report CSI associated with $n \leq N$ CSI reporting bands. For instance, >6GHz, large system bandwidth may require multiple CSI or calibration coefficient reporting bands. The value of n can either be configured semi-statically (via higher-layer signaling or RRC) or dynamically (via MAC CE or L1 DL control signaling). Alternatively, the UE can report a recommended value of n via an UL channel.

[130] Therefore, CSI parameter frequency granularity can be defined per CSI reporting band as follows. A CSI parameter is configured with "single" reporting for the CSI reporting band with Mn subbands when one CSI parameter for all the Mn subbands within the CSI reporting band. A CSI parameter is configured with "subband" for the CSI reporting band with Mn subbands when one CSI parameter is reported for each of the Mn subbands within the CSI reporting band.

[131] FIGURE 13 illustrates an example antenna port layout 1300 according to embodiments of the disclosure. The embodiment of the antenna port layout 1300 illustrated in FIGURE 13 is for illustration only. FIGURE 13 does not limit the scope of this disclosure to any particular implementation of the antenna port layout.

[132] As illustrated in FIGURE 13, N1 and N2 are the number of antenna ports with the same polarization in the first and second dimensions, respectively. For 2D antenna port layouts, $N1 > 1$, $N2 > 1$, and for 1D antenna port layouts $N1 > 1$ and $N2 = 1$. Therefore, for a dual-polarized antenna port layout, the total number of antenna ports is

2N1N2 when each antenna maps to an antenna port. An illustration is shown in FIGURE 13 where “X” represents two antenna polarizations. In this disclosure, the term “polarization” refers to a group of antenna ports. For example, antenna ports $j = X + 0, X + 1, \ldots, X + \frac{P_{CSIRS}}{2} - 1$ comprise a first antenna polarization, and antenna ports $j = X + \frac{P_{CSIRS}}{2}, X + \frac{P_{CSIRS}}{2} + 1, \ldots, X + P_{CSIRS} - 1$ comprise a second antenna polarization, where P_{CSIRS} is a number of CSI-RS antenna ports and X is a starting antenna port number (e.g., X=3000, then antenna ports are 3000, 3001, 3002, …). Let N_g be a number of antenna panels at the gNB. When there are multiple antenna panels (N_g>1), we assume that each panel is dual-polarized antenna ports with N_1 and N_2 ports in two dimensions. This is illustrated in FIGURE 13. Note that the antenna port layouts may or may not be the same in different antenna panels.

[133] In the disclosure CSI codebook designs to support distributed MIMO or multi-TRP (mTRP) operations are provided

[134] Various embodiments for CSI codebook designs and reporting for distributed MIMO or multi-TRP operations in wireless networks are described herein.

[135] CSI enhancement described in Rel-18 MIMO considers Rel-16/17 Type-II CSI codebook refinements to support mTRP coherent joint transmission (C-JT) operations by considering performance-and-overhead trade-off. The Rel-16/17 Type-II CSI codebook has three components W_1, W_2, and W_f. Among them, W_2 is the component that could induce large CSI feedback overhead especially in mTRP C-JT operations. In the disclosure, several embodiments relating to W_2 in addition to W_1 and W_f are provided to alleviate amount of CSI reporting overhead to have good performance-and-overhead trade-off for C-JT operations.

[136] In one example, the antenna architecture of a D-MIMO or CJT system is structured. For example, the antenna structure at each RRH (or TRP) is dual-polarized (single or multi-panel as shown in FIGURE 13. The antenna structure at each RRH/TRP can be the same. Alternatively, the antenna structure at an RRH/TRP can be different from another RRH/TRP. Likewise, the number of ports at each RRH/TRP can be the same. Alternatively, the number of ports at one RRH/TRP can be different from another RRH/TRP. In one example, N_g=N_{RRH}, a number of RRHs/TRPs in the D-MIMO transmission.

[137] In another example, the antenna architecture of a D-MIMO or CJT system is unstructured. For example, the antenna structure at one RRH/TRP can be different from another RRH/TRP.

[138] A structured antenna architecture is assumed in the rest of the disclosure. For simplicity, it is assumed that each RRH/TRP is equivalent to a panel, although, an

RRH/TRP can have multiple panels in practice. The disclosure however is not restrictive to a single panel assumption at each RRH/TRP, and can easily be extended (covers) the case when an RRH/TRP has multiple antenna panels.

[139] In one embodiment, an RRH constitutes (or corresponds to or is equivalent to) at least one of the following:

[140] ● In one example, an RRH corresponds to a TRP.

[141] ● In one example, an RRH or TRP corresponds to a CSI-RS resource. A UE is configured with $K=N_{RRH}>1$ non-zero-power (NZP) CSI-RS resources, and a CSI reporting is configured to be across multiple CSI-RS resources. This is similar to Class B, K > 1 configuration in Rel. 14 LTE. The K NZP CSI-RS resources can belong to a CSI-RS resource set or multiple CSI-RS resource sets (e.g., K resource sets each comprising one CSI-RS resource). The details are as explained earlier in this disclosure.

[142] ● In one example, an RRH or TRP corresponds to a CSI-RS resource group, where a group comprises one or multiple NZP CSI-RS resources. A UE is configured with $K\geq N_{RRH}>1$ non-zero-power (NZP) CSI-RS resources, and a CSI reporting is configured to be across multiple CSI-RS resources from resource groups. This is similar to Class B, K > 1 configuration in Rel. 14 LTE. The K NZP CSI-RS resources can belong to a CSI-RS resource set or multiple CSI-RS resource sets (e.g., K resource sets each comprising one CSI-RS resource). The details are as explained earlier in this disclosure. In particular, the K CSI-RS resources can be partitioned into N_{RRH} resource groups. The information about the resource grouping can be provided together with the CSI-RS resource setting/configuration, or with the CSI reporting setting/configuration, or with the CSI-RS resource configuration.

[143] ● In one example, an RRH or TRP corresponds to a subset (or a group) of CSI-RS ports. A UE is configured with at least one NZP CSI-RS resource comprising (or associated with) CSI-RS ports that can be grouped (or partitioned) multiple subsets/groups/parts of antenna ports, each corresponding to (or constituting) an RRH/TRP. The information about the subsets of ports or grouping of ports can be provided together with the CSI-RS resource setting/configuration, or with the CSI reporting setting/configuration, or with the CSI-RS resource configuration.

[144] ● In one example, an RRH or TRP corresponds to one or more examples described herein depending on a configuration. For example, this configuration can be explicit via a parameter (e.g., an RRC parameter). Alternatively, it can be implicit.

[145] a. In one example, when implicit, it could be based on the value of K. For example, when K>1 CSI-RS resources, an RRH corresponds to one or more examples described above, and when K=1 CSI-RS resource, an RRH corresponds to one or more examples described above.

[146] b. In another example, the configuration could be based on the configured codebook. For example, an RRH corresponds to a CSI-RS resource or resource group when the codebook corresponds to a decoupled codebook (modular or separate codebook for each RRH), and an RRH corresponds to a subset (or a group) of CSI-RS ports when codebook corresponds to a coupled (joint or coherent) codebook (one joint codebook across TRPs/RRHs).

[147] In one example, when RRH or TRP maps (or corresponds to) a CSI-RS resource or resource group, and a UE can select a subset of RRHs (resources or resource groups) and report the CSI for the selected RRHs (resources or resource groups), the selected RRHs can be reported via an indicator. For example, the indicator can be a CRI or a PMI (component) or a new indicator.

[148] In one example, when RRH or TRP maps (or corresponds to) a CSI-RS port group, and a UE can select a subset of RRHs (port groups) and report the CSI for the selected RRHs (port groups), the selected RRHs can be reported via an indicator. For example, the indicator can be a CRI or a PMI (component) or a new indicator.

[149] In one example, when multiple (K>1) CSI-RS resources are configured for N_{RRH} RRHs, a decoupled (modular) codebook is used/configured, and when a single (K=1) CSI-RS resource for N_{RRH} RRHs, a joint codebook is used/configured.

[150] As described in U.S. Patent No. 10,659,118, issued May 19, 2020, and titled "Method and Apparatus for Explicit CSI Reporting in Advanced Wireless Communication Systems," which is incorporated herein by reference in its entirety, a UE is configured with high-resolution (e.g., Type II) CSI reporting in which the linear combination-based Type II CSI reporting framework is extended to include a frequency dimension in addition to the first and second antenna port dimensions.

[151] FIGURE 14 illustrates a 3D grid of oversampled DFT beams 1400 according to embodiments of the disclosure. The embodiment of the 3D grid of oversampled DFT beams 1400 illustrated in FIGURE 14 is for illustration only. FIGURE 14 does not limit the scope of this disclosure to any particular implementation of the 3D grid of oversampled DFT beams.

[152] As illustrated, FIGURE 14 shows a 3D grid 1400 of the oversampled DFT beams (1st port dim., 2nd port dim., freq. dim.) in which

[153] ● 1st dimension is associated with the 1st port dimension,

[154] ● 2nd dimension is associated with the 2nd port dimension, and

[155] ● 3rd dimension is associated with the frequency dimension.

[156] The basis sets for 1^{st} and 2^{nd} port domain representation are oversampled DFT codebooks of length-N1 and length-N 2, respectively, and with oversampling factors O1 and O2, respectively. Likewise, the basis set for frequency domain representation (i.e., 3rd dimension) is an oversampled DFT codebook of length-N3 and with over-

sampling factor O3. In one example, O1 = O2 = O3 = 4. In one example, O1 = O2 = 4 and O3 = 1. In another example, the oversampling factors Oi belongs to {2, 4, 8}. In yet another example, at least one of O1, O2 , and O3 is higher layer configured (via RRC signaling).

[157] As explained in Section 5.2.2.2.6 of REF8, a UE is configured with higher layer parameter codebookType set to ' typeII-PortSelection-r16 ' for an enhanced Type II CSI reporting in which the pre-coders for all SBs and for a given layer l=1,..,v, where v is the associated RI value, is given by either

$$\boldsymbol{W}^{l} = \boldsymbol{A}\boldsymbol{C}_{l}\boldsymbol{B}^{H} = [\boldsymbol{a}_0\ \boldsymbol{a}_1 \dots \boldsymbol{a}_{L-1}]\begin{bmatrix} c_{l,0,0} & c_{l,0,1} & \cdots & c_{l,0,M-1} \\ c_{l,1,0} & c_{l,1,1} & \cdots & c_{l,1,M-1} \\ \vdots & \vdots & \vdots & \vdots \\ c_{l,L-1,0} & c_{l,L-1,1} & \cdots & c_{l,L-1,M-1} \end{bmatrix}[\boldsymbol{b}_0\ \boldsymbol{b}_1 \dots \boldsymbol{b}_{M-1}]^{H} =$$

$$\sum_{f=0}^{M-1}\sum_{i=0}^{L-1} c_{l,i,f}\left(\boldsymbol{a}_i\boldsymbol{b}_f^{H}\right) = \sum_{i=0}^{L-1}\sum_{f=0}^{M-1} c_{l,i,f}\left(\boldsymbol{a}_i\boldsymbol{b}_f^{H}\right), \text{(Eq. 1)}$$

or

$$\boldsymbol{W}^{l} = \begin{bmatrix} \boldsymbol{A} & 0 \\ 0 & \boldsymbol{A} \end{bmatrix}\boldsymbol{C}_{l}\boldsymbol{B}^{H} =$$

$$\begin{bmatrix} \boldsymbol{a}_0\ \boldsymbol{a}_1 \dots \boldsymbol{a}_{L-1} & 0 \\ 0 & \boldsymbol{a}_0\ \boldsymbol{a}_1 \dots \boldsymbol{a}_{L-1} \end{bmatrix}\begin{bmatrix} c_{l,0,0} & c_{l,0,1} & \cdots & c_{l,0,M-1} \\ c_{l,1,0} & c_{l,1,1} & \cdots & c_{l,1,M-1} \\ \vdots & \vdots & \vdots & \vdots \\ c_{l,L-1,0} & c_{l,L-1,1} & \cdots & c_{l,L-1,M-1} \end{bmatrix}[\boldsymbol{b}_0\ \boldsymbol{b}_1 \dots \boldsymbol{b}_{M-1}]^{H} =$$

$$\begin{bmatrix} \sum_{f=0}^{M-1}\sum_{i=0}^{L-1} c_{l,i,f}\left(\boldsymbol{a}_i\boldsymbol{b}_f^{H}\right) \\ \sum_{f=0}^{M-1}\sum_{i=0}^{L-1} c_{l,i+L,f}\left(\boldsymbol{a}_i\boldsymbol{b}_f^{H}\right) \end{bmatrix}, \text{(Eq. 2)}$$

where

[158] ● N_1 is a number of antenna ports in a first antenna port dimension (having the same antenna polarization),

[159] ● N_2 is a number of antenna ports in a second antenna port dimension (having the same antenna polarization),

[160] ● $P_{CSI\text{-}RS}$ is a number of CSI-RS ports configured to the UE,

[161] ● N_3 is a number of SBs for PMI reporting or number of FD units or number of FD components (that comprise the CSI reporting band) or a total number of precoding matrices indicated by the PMI (one for each FD unit/component),

[162] ● a_i is a $2N_1N_2 \times 1$ (Eq. 1) or $N_1N_2 \times 1$ (Eq. 2) column vector, or a_i is a $P_{CSIRS} \times 1$ (Eq. 1) or $\frac{P_{CSIRS}}{2} \times 1$ port selection column vector, where a port selection vector is a defined as a vector which contains a value of 1 in one element and zeros elsewhere

[163] ● b_f is a $N_3{\times}1$ column vector,

[164] ● $c_{l,i,f}$ is a complex coefficient.

[165] In a variation, when the UE reports a subset K<2LM coefficients (where K is either fixed, configured by the gNB or reported by the UE), then the coefficient $c_{l,i,f}$ in precoder equations Eq. 1 or Eq. 2 is replaced with $x_{l,i,f} \times c_{l,i,f}$, where

[166] ● $x_{l,i,f}=1$ if the coefficient $c_{l,i,f}$ is reported by the UE according to some embodiments of this disclosure.

[167] ● $x_{l,i,f}=0$ otherwise (i.e., $c_{l,i,f}$ is not reported by the UE).

[168] The indication whether $x_{l,i,f}=1$ or 0 is according to some embodiments of this disclosure. For example, it can be via a bitmap.

[169] In a variation, the precoder equations Eq. 1 or Eq. 2 are respectively generalized to

$$\boldsymbol{W}^{l} = \sum_{i=0}^{L-1} \sum_{f=0}^{M_i-1} c_{l,i,f}\left(\boldsymbol{a}_i \boldsymbol{b}_{i,f}^{H}\right) \text{ (Eq. 3)}$$

and

$$\boldsymbol{W}^{l} = \begin{bmatrix} \sum_{i=0}^{L-1} \sum_{f=0}^{M_i-1} c_{l,i,f}\left(\boldsymbol{a}_i \boldsymbol{b}_{i,f}^{H}\right) \\ \sum_{i=0}^{L-1} \sum_{=0}^{M_i-1} c_{l,i+L,f}\left(\boldsymbol{a}_i \boldsymbol{b}_{i,f}^{H}\right) \end{bmatrix} \text{ (Eq. 4),}$$

where for a given i, the number of basis vectors is M_i and the corresponding basis vectors are $\{b_{i,f}\}$. Note that M_i is the number of coefficients $c_{l,i,f}$ reported by the UE for a given i, where $M_i \leq M$ (where $\{M_i\}$ or $\sum M_i$ is either fixed, configured by the gNB or reported by the UE).

[170] The columns of W^l are normalized to norm one. For rank R or R layers (v=R), the pre-coding matrix is given by $\boldsymbol{W}^{(R)} = \frac{1}{\sqrt{R}}\left[\boldsymbol{W}^{1} \quad \boldsymbol{W}^{2} \quad \cdots \quad \boldsymbol{W}^{R}\right]$. Eq. 2 is assumed in the rest of the disclosure. The embodiments of the disclosure, however, are general and are also application to Eq. 1, Eq. 3 and Eq. 4.

[171] Here $L \leq \frac{P_{CSI-RS}}{2}$ and $M \leq N_3$. If $L = \frac{P_{CSI-RS}}{2}$, then A is an identity matrix, and hence not reported. Likewise, if M = N3, then B is an identity matrix, and hence not reported. Assuming M < N3, in an example, to report columns of B, the oversampled DFT codebook is used. For instance, $b_f=w_f$, where the quantity w_f is given by:

$$\boldsymbol{w}_f = \begin{bmatrix} 1 & e^{j\frac{2\pi n_{3,l}^{(f)}}{O_3 N_3}} & e^{j\frac{2\pi . 2 n_{3,l}^{(f)}}{O_3 N_3}} & \cdots & e^{j\frac{2\pi .(N_3-1) n_{3,l}^{(f)}}{O_3 N_3}} \end{bmatrix}^{T}.$$

[172] When $O_3=1$, the FD basis vector for layer $l \in \{1,..,\upsilon\}$ (where υ is the RI or rank value)

$$\boldsymbol{w}_f = \left[y_{0,l}^{(f)} \quad y_{1,l}^{(f)} \quad \cdots \quad y_{N_3-1,l}^{(f)} \right]^T,$$

where $y_{t,l}^{(f)} = e^{j\frac{2\pi t n_{3,l}^{(f)}}{N_3}}$ and $n_{3,l} = \left[n_{3,l}^{(0)}, \dots, n_{3,l}^{(M-1)} \right]$ where $n_{3,l}^{(f)} \in \{0,1,\dots,N_3-1\}$.

[173] In another example, discrete cosine transform DCT basis is used to construct/report basis B for the 3rd dimension. The m-th column of the DCT compression matrix is simply given by:

$$\left[\mathbf{W}_f\right]_{nm} = \begin{cases} \frac{1}{\sqrt{K}}, \; n = 0 \\ \sqrt{\frac{2}{K}} \cos\frac{\pi(2m+1)n}{2K}, \; n = 1, \dots K-1 \end{cases}, \text{ and } K = N_3, \text{ and } m = 0, \dots, N_3 - 1.$$

[174] Since DCT is applied to real valued coefficients, the DCT is applied to the real and imaginary components (of the channel or channel eigenvectors) separately. Alternatively, the DCT is applied to the magnitude and phase components (of the channel or channel eigenvectors) separately. The use of DFT or DCT basis is for illustration purpose only. The disclosure is applicable to any other basis vectors to construct/report A and B.

[175] On a high level, a precoder W^l can be described as follows.

[176]
$$\boldsymbol{W} = \boldsymbol{A}_l \boldsymbol{C}_l \boldsymbol{B}_l^H = \boldsymbol{W}_1 \widetilde{\boldsymbol{W}}_2 \boldsymbol{W}_f^H, \qquad \text{(Eq. 5)}$$

[177] where $A=W_1$ corresponds to the Rel. 15 W_1 in Type II CSI codebook [REF8], and $B=W_f$.

[178] The $\boldsymbol{C}_l = \widetilde{\boldsymbol{W}}_2$ matrix consists of all the required linear combination coefficients (e.g., amplitude and phase or real or imaginary). Each reported coefficient ($c_{l,i,f}=p_{l,i,f}\varphi_{l,i,f}$) in $\widetilde{\mathbf{W}}_2$ is quantized as amplitude coefficient ($p_{l,i,f}$) and phase coefficient ($\varphi_{l,i,f}$). In one example, the amplitude coefficient ($p_{l,i,f}$) is reported using a A-bit amplitude codebook where A belongs to {2, 3, 4}. If multiple values for A are supported, then one value is configured via higher layer signaling. In another example, the amplitude coefficient ($p_{l,i,f}$) is reported as $p_{l,i,f} = p_{l,i,f}^{(1)} p_{l,i,f}^{(2)}$ where

[179] ● $p_{l,i,f}^{(1)}$ is a reference or first amplitude which is reported using an A1-bit amplitude codebook where A1 belongs to {2, 3, 4}, and

[180] ● $p_{l,i,f}^{(2)}$ is a differential or second amplitude which is reported using a A2-bit amplitude codebook where A2≤A1 belongs to {2, 3, 4}.

[181] For layer l, let us denote the linear combination (LC) coefficient associated with

spatial domain (SD) basis vector (or beam) i $\in\{0,1,\ldots,2L-1\}$ and frequency domain (FD) basis vector (or beam) f $\in\{0,1,\ldots,M-1\}$ as $c_{l,i,f}$, and the strongest coefficient as c_{l,i^*,f^*}. The strongest coefficient is reported out of the K_{NZ} non-zero (NZ) coefficients that is reported using a bitmap, where $K_{NZ} \leq K_0 = \lceil \beta \times 2LM \rceil < 2LM$ and β is higher layer configured. The remaining 2LM-K_{NZ} coefficients that are not reported by the UE are assumed to be zero. The following quantization scheme is used to quantize/report the K_{NZ} NZ coefficients.

[182] ● UE reports the following for the quantization of the NZ coefficients in $\tilde{W}_2$

[183] a. A X-bit indicator for the strongest coefficient index (i^*, f^*), where $X = \lceil \log_2 K_{NZ} \rceil$ or $\lceil \log_2 2L \rceil$.

[184] i. Strongest coefficient $c_{l,i^*,f^*}=1$ (hence its amplitude/phase are not reported)

[185] b. Two antenna polarization-specific reference amplitudes are used.

[186] i. For the polarization associated with the strongest coefficient $c_{l,i^*,f^*}=1$, since the reference amplitude $p^{(1)}_{l,i,f} = 1$, it is not reported

[187] ii. For the other polarization, reference amplitude $p^{(1)}_{l,i,f}$ is quantized to 4 bits

[188] 1. The 4-bit amplitude alphabet is $\left\{1, \left(\frac{1}{2}\right)^{\frac{1}{4}}, \left(\frac{1}{4}\right)^{\frac{1}{4}}, \left(\frac{1}{8}\right)^{\frac{1}{4}}, \ldots, \left(\frac{1}{2^{14}}\right)^{\frac{1}{4}}\right\}$.

[189] c. For $\{c_{l,i,f},\ (i,f) \neq (i^*,f^*)\}$:

[190] i. For each polarization, differential amplitudes $p^{(2)}_{l,i,f}$ i. of the coefficients calculated relative to the associated polarization-specific reference amplitude and quantized to 3 bits

[191] 1. The 3-bit amplitude alphabet is $\left\{1, \frac{1}{\sqrt{2}}, \frac{1}{2}, \frac{1}{2\sqrt{2}}, \frac{1}{4}, \frac{1}{4\sqrt{2}}, \frac{1}{8}, \frac{1}{8\sqrt{2}}\right\}$.

[192] 2. Note: The final quantized amplitude $p_{l,i,f}$ is given by $p^{(1)}_{l,i,f} \times p^{(2)}_{l,i,f}$

[193] ii. Each phase is quantized to either 8PSK ($N_{ph}=8$) or 16PSK ($N_{ph}=16$) (which is configurable).

[194] For the polarization $r^* \in \{0,1\}$ associated with the strongest coefficient c_{l,i^*,f^*}, we have $r^* = \left\lfloor \frac{i^*}{L} \right\rfloor$ and the reference amplitude $p^{(1)}_{l,i,f} = p^{(1)}_{l,r^*} = 1$. For the other polarization $r \in \{0,1\}$ and $r \neq r^*$, we have $r = \left(\left\lfloor \frac{i^*}{L} \right\rfloor + 1\right) \bmod 2$ and the reference amplitude $p^{(1)}_{l,i,f} = p^{(1)}_{l,r}$ is quantized (reported) using the 4-bit amplitude codebook mentioned

above.

[195] In Rel. 16 enhanced Type II and Type II port selection codebooks, a UE can be configured to report M FD basis vectors. In one example, $M = \left\lceil p \times \frac{N_3}{R} \right\rceil$, where R is higher-layer configured from {1,2} and p is higher-layer configured from $\left\{\frac{1}{4}, \frac{1}{2}\right\}$. In one example, the p value is higher-layer configured for rank 1-2 CSI reporting. For rank > 2 (e.g., rank 3-4), the p value (denoted by v_0) can be different. In one example, for rank 1-4, (p, v_0) is jointly configured from $\left\{\left(\frac{1}{2}, \frac{1}{4}\right), \left(\frac{1}{4}, \frac{1}{4}\right), \left(\frac{1}{4}, \frac{1}{8}\right)\right\}$, i.e., $M = \left\lceil p \times \frac{N_3}{R} \right\rceil$ for rank 1-2 and $M = \left\lceil v_0 \times \frac{N_3}{R} \right\rceil$ for rank 3-4. In one example, $N_3 = N_{SB} \times R$ where N_{SB} is the number of SBs for CQI reporting. In one example, M is replaced with M_υ to show its dependence on the rank value υ, hence p is replaced with $p_\upsilon, \upsilon \in \{1,2\}$ and v_0 is replaced with $p_\upsilon, \upsilon \in \{3,4\}$.

[196] A UE can be configured to report M_υ FD basis vectors in one-step from N_3 basis vectors freely (independently) for each layer $l \in \{1,..,\upsilon\}$ of a rank υ CSI reporting. Alternatively, a UE can be configured to report M_υ FD basis vectors in two-step as follows.

[197] ● In step 1, an intermediate set (InS) comprising $N'_3 < N_3$ basis vectors is selected/reported, wherein the InS is common for all layers.

[198] ● In step 2, for each layer $l \in \{1,..,\upsilon\}$ of a rank υ CSI reporting, M_υ FD basis vectors are selected/reported freely (independently) from N'_3 basis vectors in the InS.

[199] In one example, one-step method is used when $N_3 \le 19$ and two-step method is used when $N_3 > 19$. In one example, $N_3' = \lceil \alpha M_v \rceil$ where $\alpha > 1$ is either fixed (to 2 for example) or configurable.

[200] The codebook parameters used in the DFT based frequency domain compression (Eq. 5) are $(L, p_v \text{ for } v \in \{1,2\}, p_v \text{ for } v \in \{3,4\}, \beta, \alpha, N_{ph})$. The set of values for these codebook parameters are as follows.

[201]

- L: the set of values is $\{2,4\}$ in general, except $L \in \{2,4,6\}$ for rank 1-2, 32 CSI-RS antenna ports, and $R = 1$.
- $(p_v$ for $v \in \{1,2\}, p_v$ for $v \in \{3,4\}) \in \left\{\left(\frac{1}{2},\frac{1}{4}\right),\left(\frac{1}{4},\frac{1}{4}\right),\left(\frac{1}{4},\frac{1}{8}\right)\right\}$.
- $\beta \in \left\{\frac{1}{4},\frac{1}{2},\frac{3}{4}\right\}$.
- $\alpha = 2$
- $N_{ph} = 16$.

The set of values for these codebook parameters are as in Table 1.

[202] [Table 1]

$paramCombination$	L	p_v		β
		$v \in \{1,2\}$	$v \in \{3,4\}$	
1	2	¼	1/8	¼
2	2	¼	1/8	½
3	4	¼	1/8	¼
4	4	¼	1/8	½
5	4	¼	¼	¾
6	4	½	¼	½
7	6	¼	-	½
8	6	¼	-	¾

[203] In Rel. 17 (further enhanced Type II port selecting codebook), $M \in \{1,2\}$, $L = \frac{K_1}{2}$ where $K_1 = \alpha \times P_{CSIRS}$, and codebook parameters (M,α,β) are configured from Table 2.

[204] [Table 2]

paramCombination -r17	*M*	*α*	*β*
1	1	¾	½
2	1	1	½
3	1	1	¾
4	1	1	1
5	2	½	½
6	2	¾	½
7	2	1	½
8	2	1	¾

[205] The above-mentioned framework (Eq. 5) represents the precoding-matrices for multiple (N_3) FD units using a linear combination (double sum) over 2L (or K_1) SD beams/ports and M_υ FD beams. This framework can also be used to rethe precoding-matrices in time domain (TD) by replacing the FD basis matrix W_f with a TD basis matrix W_t, wherein the columns of W_t comprises M_υ TD beams that resome form of delays or channel tap locations. Hence, a precoder W^1 can be described as follows.

[206]

$$\boldsymbol{W} = \boldsymbol{A}_l \boldsymbol{C}_l \boldsymbol{B}_l^H = \boldsymbol{W}_1 \widetilde{\boldsymbol{W}}_2 \boldsymbol{W}_t^H, \qquad \text{(Eq. 5A)}$$

[207] In one example, the M_υ TD beams (representing delays or channel tap locations) are selected from a set of N_3 TD beams, i.e., N_3 corresponds to the maximum number of TD units, where each TD unit corresponds to a delay or channel tap location. In one example, a TD beam corresponds to a single delay or channel tap location. In another example, a TD beam corresponds to multiple delays or channel tap locations. In another example, a TD beam corresponds to a combination of multiple delays or channel tap locations.

[208] FIGURE 15 illustrates an example of two new codebooks 1500 according to embodiments of the disclosure. The embodiment of the two new codebooks 1500 illustrated in FIGURE 15 is for illustration only. FIGURE 15 does not limit the scope of this disclosure to any particular implementation of the two new codebooks.

[209] In one example, the codebook for the CSI report is according to at least one of the following examples.

[210] In one example, the codebook can be a Rel. 15 Type I single-panel codebook (cf. 5.2.2.2.1, TS 38.214).

[211] In one example, the codebook can be a Rel. 15 Type I multi-panel codebook (cf.

5.2.2.2.2, TS 38.214).

[212] In one example, the codebook can be a Rel. 15 Type II codebook (cf. 5.2.2.2.3, TS 38.214).

[213] In one example, the codebook can be a Rel. 15 port selection Type II codebook (cf. 5.2.2.2.4, TS 38.214).

[214] In one example, the codebook can be a Rel. 16 enhanced Type II codebook (cf. 5.2.2.2.5, TS 38.214).

[215] In one example, the codebook can be a Rel. 16 enhanced port selection Type II codebook (cf. 5.2.2.2.6, TS 38.214).

[216] In one example, the codebook can be a Rel. 17 further enhanced port selection Type II codebook (cf. 5.2.2.2.7, TS 38.214).

[217] In one example, the codebook is a new codebook for C-JT CSI reporting.

[218] a. In one example, the new codebook is a decoupled codebook comprising the following components: (called 'CB1' hereafter)

[219] i. Intra-TRP: per TRP Rel. 16/17 Type II codebook components, i.e., SD basis vectors (W1), FD basis vectors (Wf), W2 components (e.g., SCI, indices of NZ coefficients, and amplitude/phase of NZ coefficients).

[220] ii. Inter-TRP: co-amplitude and co-phase for each TRP.

[221] b. In one example, the new codebook is a joint codebook (called 'CB2' hereafter) comprising following components

[222] i. Per TRP SD basis vectors (W1)

[223] ii. Single joint FD basis vectors (Wf)

[224] iii. Single joint W2 components (e.g., SCI, indices of NZ coefficients, and amplitude/phase of NZ coefficients)

[225] In the disclosure, when the codebook is a legacy codebook (e.g., one of Rel. 15/16/17 NR codebooks, according to one of the examples above), then the CSI reporting is based on a CSI resource set comprising one or multiple NZP CSI-RS resource(s), where each NZP CSI-RS resource comprises CSI-RS antenna ports for all TRPs/RRHs, i.e., $P = \sum_{r=1}^{N} P_r$, where P is the total number of antenna ports, and P_r is the number of antenna ports associated with r-th TRP. In this case, a TRP corresponds to (or maps to or is associated with) a group of antenna ports.

[226] In the disclosure, when the codebook is a new codebook (e.g., mTRP/CJT codebook), then the CSI reporting is based on a CSI resource set comprising one or multiple NZP CSI-RS resource(s).

[227] ● In one example, each NZP CSI-RS resource comprises CSI-RS antenna ports for all TRPs/RRHs. i.e., $P = \sum_{r=1}^{N} P_r$, where P is the total number of antenna ports, and P_r

is the number of antenna ports associated with r-th TRP. In this case, a TRP corresponds to (or maps to or is associated with) a group of antenna ports.

[228] ● In one example, each NZP CSI-RS resource corresponds to (or maps to or is associated with) a TRP/RRH.

[229] In one embodiment, a UE is configured with an mTRP (or D-MIMO) codebook, which is designed based on Rel-16/17 Type-II codebook. The mTRP codebook has a triple-stage structure which can be represented as $\boldsymbol{W} = \boldsymbol{W}_1\boldsymbol{W}_2\boldsymbol{W}_f^H$, where the component W_1 is used to report/indicate a spatial-domain (SD) basis matrix comprising SD basis vectors, the component W_f is used to report/indicate a frequency-domain (FD) basis matrix comprising FD basis vectors, and the component W_2 is used to report/indicate coefficients corresponding to SD and FD basis vectors.

[230] FIGURE 16 illustrates an example D-MIMO 1600 where each TRP has a single antenna panel according to embodiments of the disclosure. The embodiment of the example D-MIMO 1600 where each TRP has a single antenna panel illustrated in FIGURE 16 is for illustration only. FIGURE 16 does not limit the scope of this disclosure to any particular implementation of the example D-MIMO where each TRP has a single antenna panel.

[231] In one embodiment as illustrated in FIGURE 16, each TRP has a single antenna panel. The component W_1 has a block diagonal structure comprising X diagonal blocks, where 1 (co-pol) or 2 (dual-pol) diagonal blocks are associated with each TRP.

[232] In one example, $X=N_{TRP}$ assuming co-polarized (single polarized) antenna structure at each TRP. In one example, when $N_{TRP}=2$, the components W_1 is given by:

$$\boldsymbol{W}_1 = \begin{bmatrix} B_1 & 0 \\ 0 & B_2 \end{bmatrix}$$

where B_1 is a basis matrix for the 1st TRP, and B_2 is a basis matrix for the 2nd TRP. In one example, $\boldsymbol{B}_r = [\boldsymbol{b}_{r,0}, \boldsymbol{b}_{r,1}, \ldots, \boldsymbol{b}_{r,L_r-1}]$ comprises L_r columns or beams (or basis vectors) for r-th TRP. In one example, $L_r=L$ for all r values (TRP-common L value), for example, $L\in\{2,3,4,6\}$. In one example, L_r can be different across TRPs (TRP-specific L value), for example, L_r can take a value (fixed or configured) from $\{2,3,4,6\}$.

[233] In one example, $X=2N_{TRP}$ assuming dual-polarized (cross-polarized) antenna structure at each TRP.

[234] In one example, when $N_{TRP}=2$, the components W_1 is given by:

$$\boldsymbol{W}_1 = \begin{bmatrix} B_1 & 0 & 0 & 0 \\ 0 & B_1 & 0 & 0 \\ 0 & 0 & B_2 & 0 \\ 0 & 0 & 0 & B_2 \end{bmatrix}$$

where B_1 is a basis matrix for the 1st TRP and is common (the same) for the two polarizations, which correspond to the first and second diagonal blocks, and B_2 is a basis matrix for the 2nd TRP and is common (the same) for the two polarizations, which correspond to the third and fourth diagonal blocks. In general, (2r-1)-th and (2r)-th diagonal blocks correspond to the two antenna polarizations for the r-th TRP. In one example, $\boldsymbol{B}_r = [\boldsymbol{b}_{r,0}, \boldsymbol{b}_{r,1}, \dots, \boldsymbol{b}_{r,L_r-1}]$ comprises L_r columns or beams (or basis vectors) for r-th TRP. In one example, L_r=L for all r values (TRP-common L value), for example, L∈{2,3,4,6}. In one example, L_r can be different across TRPs (TRP-specific L value), for example, L_r can take a value (fixed or configured) from {2,3,4,6}.

[235] In one example, when N_{TRP}=2, the components W_1 is given by:

$$\boldsymbol{W}_1 = \begin{bmatrix} B_1 & 0 & 0 & 0 \\ 0 & B_2 & 0 & 0 \\ 0 & 0 & B_1 & 0 \\ 0 & 0 & 0 & B_2 \end{bmatrix}$$

where B_1 is a basis matrix for the 1st TRP and is common (the same) for the two polarizations, which correspond to the first and third diagonal blocks, and B_2 is a basis matrix for the 2nd TRP and is common (the same) for the two polarizations, which correspond to the second and fourth diagonal blocks. In general, r-th and (r+N_{TRP})-th diagonal blocks correspond to the two antenna polarizations for the r-th TRP. In one example, $\boldsymbol{B}_r = [\boldsymbol{b}_{r,0}, \boldsymbol{b}_{r,1}, \dots, \boldsymbol{b}_{r,L_r-1}]$ comprises L_r columns or beams (or basis vectors) for r-th TRP. In one example, L_r=L for all r values (TRP-common L value), for example, L∈{2,3,4,6}. In one example, L_r can be different across TRPs (TRP-specific L value), for example, L_r can take a value (fixed or configured) from {2,3,4,6}.

[236] In one example, when N_{TRP}=2, the components W_1 is given by:

$$\boldsymbol{W}_1 = \begin{bmatrix} B_{1,1} & 0 & 0 & 0 \\ 0 & B_{1,2} & 0 & 0 \\ 0 & 0 & B_{2,1} & 0 \\ 0 & 0 & 0 & B_{2,2} \end{bmatrix}$$

where $B_{1,1}$ and $B_{1,2}$ are basis matrices for the first and second antenna polarizations of the 1st TRP, which correspond to the first and second diagonal blocks, and $B_{2,1}$ and $B_{2,2}$ are basis matrices for the first and second antenna polarizations of the 2nd TRP, which correspond to the third and fourth diagonal blocks. In general, (2r-1)-th and (2r)-th diagonal blocks correspond to the two antenna polarizations for the r-th TRP. In one example, $\boldsymbol{B}_{r,p} = [\boldsymbol{b}_{r,p,0}, \boldsymbol{b}_{r,p,1}, \dots, \boldsymbol{b}_{r,p,L_{r,p}-1}]$ comprises $L_{r,p}$ columns or beams (or basis vectors) for p-th polarization of r-th TRP. In one example, $L_{r,p}$=L for all r and p values (TRP-common and polarization-common L value), for example L∈{2,3,4,6}. In one example, $L_{r,p}=L_r$ for all p values (TRP-specific and polarization-common L value). In one example, $L_{r,p}=L_p$ for all r values (TRP-common and polarization-specific L value). In one example, $L_{r,p}$ can be different across TRPs (TRP-specific and polarization-specific L value).

[237] In one example, when $N_{TRP}=2$, the components W_1 is given by:

$$\boldsymbol{W}_1 = \begin{bmatrix} B_{1,1} & 0 & 0 & 0 \\ 0 & B_{2,1} & 0 & 0 \\ 0 & 0 & B_{1,2} & 0 \\ 0 & 0 & 0 & B_{2,2} \end{bmatrix}$$

where $B_{1,1}$ and $B_{1,2}$ are basis matrices for the first and second antenna polarizations of the 1st TRP, which correspond to the first and third diagonal blocks, and $B_{2,1}$ and $B_{2,2}$ are basis matrices for the first and second antenna polarizations of the 2nd TRP, which correspond to the second and fourth diagonal blocks. In general, r-th and ($r+N_{TRP}$)-th diagonal blocks correspond to the two antenna polarizations for the r-th TRP. In one example, $\boldsymbol{B}_{r,p} = [\boldsymbol{b}_{r,p,0}, \boldsymbol{b}_{r,p,1}, \dots, \boldsymbol{b}_{r,p,L_{r,p}-1}]$ comprises $L_{r,p}$ columns or beams (or basis vectors) for p-th polarization of r-th TRP. In one example, $L_{r,p}=L$ for all r and p values (TRP-common and polarization-common L value) , for example L∈{2,3,4,6}. In one example, $L_{r,p}=L_r$ for all p values (TRP-specific and polarization-common L value). In one example, $L_{r,p}=L_p$ for all r values (TRP-common and polarization-specific L value). In one example, $L_{r,p}$ can be different across TRPs (TRP-specific and polarization-specific L value).

[238] In one example, $X = \sum_{r=1}^{N_{TRP}} a_r$, where $a_r=1$ for co-polarized (single polarized) antenna structure at r-th TRP, and $a_r=2$ for dual-polarized (cross-polarized) antenna structure at r-th TRP.

[239] In one example, when $N_{TRP}=2$, the components W_1 is given by:

$$\boldsymbol{W}_1 = \begin{bmatrix} B_1 & 0 & 0 \\ 0 & B_2 & 0 \\ 0 & 0 & B_2 \end{bmatrix}$$

where B_1 is a basis matrix for the 1st TRP, and B_2 is a basis matrix for the 2nd TRP and is common (the same) for the two polarizations, which correspond to the second and third diagonal blocks.

[240] In one example, when $N_{TRP}=2$, the components W_1 is given by:

$$\boldsymbol{W}_1 = \begin{bmatrix} B_1 & 0 & 0 \\ 0 & B_{2,1} & 0 \\ 0 & 0 & B_{2,2} \end{bmatrix}$$

where B_1 is a basis matrix for the 1st TRP, and $B_{2,1}$ and $B_{2,2}$ are basis matrices for the first and second antenna polarizations of the 2nd TRP, which correspond to the second and third diagonal blocks.

[241] FIGURE 17 illustrates an example D-MIMO where each TRP has multiple antenna panels according to embodiments of the disclosure. The embodiment of the example D-MIMO 1700 where each TRP has a multiple antenna panels illustrated in FIGURE 17 is for illustration only. FIGURE 17 does not limit the scope of this disclosure to any particular implementation of the example D-MIMO where each TRP has multiple antenna panels.

[242] As illustrated in FIGURE 17, in one embodiment, each TRP has multiple antenna panels. The component W_1 has a block diagonal structure comprising X diagonal blocks, where $N_{g,r}$ (co-pol) or $2N_{g,r}$ (dual-pol) diagonal blocks are associated with r-th TRP comprising $N_{g,r}$ panels and $N_{g,r}>1$ for all values of r. Note $N_{g,r}=2$ for both TRPs in FIGURE 17.

[243] One or more of the examples described above can be extended in a straightforward manner in this case (of multiple panels at TRPs) by adding the diagonal blocks corresponding to multiple panels in W_1.

[244] FIGURE 18 illustrates an example D-MIMO 1800 where each TRP can be an SP or MP according to embodiments of the disclosure. The embodiment of the example D-MIMO 1800 where each TRP can be an SP or MP example illustrated in FIGURE 18 is for illustration only. FIGURE 18 does not limit the scope of this disclosure to any particular implementation of the example D-MIMO where each TRP can be an SP or MP.

[245] As illustrated in FIGURE 18, in one embodiment, each TRP can have a single antenna panel or multiple antenna panels (cf. Fig. 11). The component W_1 has a block diagonal structure comprising X diagonal blocks, where $N_{g,r}$ (co-pol) or $2N_{g,r}$ (dual-pol) diagonal blocks are associated with r-th TRP comprising $N_{g,r}$ panels, and $N_{g,r}=1$ when r-th TRP has a single panel and $N_{g,r}>1$ when r-th TRP has multiple panels.

[246] One or more examples described above can be extended in a straightforward manner in this case (of multiple panels at TRPs) by adding the diagonal blocks corresponding to multiple panels in W_1.

[247] In one embodiment, the basis matrices comprising the diagonal blocks of the component W_1 have columns that are selected from a set of oversampled 2D DFT vectors. When the antenna port layout is the same across TRPs, for a given antenna port layout (N_1,N_2) and oversampling factors (O_1,O_2) for two dimensions, a DFT vector

$$v_{l,m} = \begin{bmatrix} u_m & e^{j\frac{2\pi l}{O_1N_1}}u_m & \ldots & e^{j\frac{2\pi l(N_1-1)}{O_1N_1}}u_m \end{bmatrix}^T$$
$$u_m = \begin{bmatrix} 1 & e^{j\frac{2\pi m}{O_2N_2}} & \ldots & e^{j\frac{2\pi m(N_2-1)}{O_2N_2}} \end{bmatrix}$$

where $l \in \{0,1,\ldots,O_1N_1-1\}$ and $m \in \{0,1,\ldots,O_2N_2-1\}$.

[248] When the antenna port layout can be different across TRPs, for a given antenna port layout ($N_{1,r}$,$N_{2,r}$) and oversampling factors ($O_{1,r}$,$O_{2,r}$) associated with r-th TRP, a DFT vector v_{l_r,m_r} can be expressed as follows.

$$v_{l_r,m_r} = \begin{bmatrix} u_{m_r} & e^{j\frac{2\pi l_r}{O_{1,r}N_{1,r}}}u_{m_r} & \ldots & e^{j\frac{2\pi l_r(N_{1,r}-1)}{O_{1,r}N_{1,r}}}u_{m_r} \end{bmatrix}^T$$
$$u_{m_r} = \begin{bmatrix} 1 & e^{j\frac{2\pi m_r}{O_{2,r}N_{2,r}}} & \ldots & e^{j\frac{2\pi m_r(N_{2,r}-1)}{O_{2,r}N_{2,r}}} \end{bmatrix}$$

where $l_r \in \{0,1,\ldots,O_{1,r}N_{1,r}-1\}$ and $m_r \in \{0,1,\ldots,O_{2,r}N_{2,r}-1\}$.

[249] In one example, the oversampling factor is TRP-common, hence remains the same across TRPs. For example, e.g., $O_{1,r}$=O_1=$O_{2,r}$=O_2=4. In one example, the oversampling factor is TRP-specific, hence is independent for each TRP. For example, $O_{1,r}$=$O_{2,r}$=x and x is chosen (fixed or configured) from {2,4,8}.

[250] In one embodiment, the basis matrices comprising the diagonal blocks of the component W_1 have columns that are selected from a set of port selection vectors. When the antenna port layout is the same across TRPs, for a given number of CSI-RS port P_{CSI-RS}, a port selection vector v_m is a P_{CSI-RS}/2-element column vector containing a value of 1 in element $\left(m \bmod \frac{P_{CSI-RS}}{2}\right)$ and zeros elsewhere (where the first element is element 0).

[251] When the antenna port layout can be different across TRPs, for a given number of CSI-RS port $P_{CSI-RS,r}$, a port selection vector v_{mr} is a $P_{CSI-RS,r}$/2-element column vector containing a value of 1 in element $\left(m_r \bmod \frac{P_{CSI-RS,r}}{2}\right)$ and zeros elsewhere (where the first element is element 0).

[252] In one embodiment, each TRP can have a single antenna panel or multiple antenna panels (cf. Fig. 9). The component W_1 has a block diagonal structure comprising X=2 diagonal blocks, where $N_{g,r}$ (co-pol) or $2N_{g,r}$ (dual-pol) diagonal blocks are associated with r-th TRP comprising $N_{g,r}$ panels, and $N_{g,r}$=1 when r-th TRP has a single panel and $N_{g,r}$>1 when r-th TRP has multiple panels.

[253] In one embodiment, the component W_f is according to at least one of the following

examples.

[254] In one example, the component W_f is TRP-common and layer-common, i.e., one common W_f is reported for all TRPs and for all layers (when number of layers or rank > 1).

[255] In one example, the component W_f is TRP-common and layer-specific, i.e., for each layer $l \in \{1,\ldots,\upsilon\}$, where υ is a rank value or number of layers, one common W_f is reported for all TRPs.

[256] In one example, the component W_f is TRP-specific and layer-common, i.e., for each TRP $r \in \{1,\ldots,N_{TRP}\}$, one common W_f is reported for all layers.

[257] In one example, the component W_f is TRP-specific and layer-specific, i.e., for each TRP $r \in \{1,\ldots,N_{TRP}\}$ and for each layer $l \in \{1,\ldots,\upsilon\}$, one W_f is reported.

[258] In one embodiment, let W_f comprise M_υ columns for a given rank value υ. The value of M_υ can be fixed (e.g., ½). or configured via higher layer (RRC) signaling (similar to R16 enhanced Type II codebook) or reported by the UE as part of the CSI report). The value of M_υ is according to at least one of the following examples.

[259] In one example, the value of M_υ is TRP-common, layer-common, and RI-common. The same M_υ value is used common for all values of N_{TRP}, υ, and layers $=1,\ldots,\upsilon$.

[260] In one example, the value of M_υ is TRP-common, layer-common, and RI-specific. For each RI value υ, the same M_υ value is used common for all values of N_{TRP} and layers $=1,\ldots,\upsilon$.

[261] In one example, the value of M_υ is TRP-common, layer-specific, and RI-common. For each layers $=1,\ldots,\upsilon$, the same M_υ value is used common for all values of N_{TRP} and υ.

[262] In one example, the value of M_υ is TRP-specific, layer-common, and RI-common. For each TRP $r \in \{1,\ldots,N_{TRP}\}$, the same M_υ value is used common for all values of υ and layers $=1,\ldots,\upsilon$.

[263] In one example, the value of M_υ is TRP-common, layer- specific, and RI-specific.

[264] In one example, the value of M_υ is TRP- specific, layer-specific, and RI-common.

[265] In one example, the value of M_υ is TRP-specific, layer-common, and RI-specific.

[266] In one example, the value of M_υ is TRP-specific, layer- specific, and RI-specific.

[267] In one embodiment, the columns of W_f are selected from a set of oversampled DFT vectors. When the antenna port layout is the same across TRPs, for a given N_3 and oversampling factors O_3, a DFT vector y_f can be expressed as follows.

$$y_f = \begin{bmatrix} 1 & e^{j\frac{2\pi f}{O_3 N_3}} & \cdots & e^{j\frac{2\pi f (N_3-1)}{O_3 N_3}} \end{bmatrix}$$

where $f \in \{0,1,\ldots,O_3N_3-1\}$.

[268] When N_3 value can be different across TRPs, for r-th TRP, a DFT vector y_{f_r} can be

expressed as follows.

$$y_{f_r} = \begin{bmatrix} 1 & e^{j\frac{2\pi f_r}{O_{3,r}N_{3,r}}} & \dots & e^{j\frac{2\pi f_r(N_3-1)}{O_{3,r}N_{3,r}}} \end{bmatrix}$$

where $f_r \in \{0,1,\dots,O_{3,r}N_{3,r}-1\}$..

[269] In one example, the oversampling factor is TRP-common, hence remains the same across TRPs. For example, e.g., $O_{3,r}=O_3$. In one example, the oversampling factor is TRP-specific, hence is independent for each TRP. For example, $O_{3,r}=x$ and x is chosen (fixed or configured) from {1,2,4,8}. In one example, the oversampling factor = 1. Then, the DFT vector y_f can be expressed as follows.

$$y_f = \begin{bmatrix} 1 & e^{j\frac{2\pi f}{N_3}} & \dots & e^{j\frac{2\pi f(N_3-1)}{N_3}} \end{bmatrix}.$$

[270] In one embodiment, the columns of W_f are selected from a set of port selection vectors. When N_3 value is the same across TRPs, for a given N_3 value, a port selection vector v_m is a N_3-element column vector containing a value of 1 in element (m mod N_3) and zeros elsewhere (where the first element is element 0).

[271] When N_3 value can be different across TRPs, for a given $N_{3,r}$ value, a port selection vector v_{m_r} is a N_3-element column vector containing a value of 1 in element (m_r mod N_3) and zeros elsewhere (where the first element is element 0).

[272] In one embodiment, a maximum value of the (i.e., an upper bound on) number of non-zero coefficients in component W_2 is common for TRPs (i.e., TRP-common upper bound). In one example, a ratio β of a maximum value of the non-zero coefficients (K_0) to a total number (K) of elements in component W_2 is common for TRPs, i.e., $\beta=K_0/K$ is a same for all TRPs. In one example, $K_0 = \lceil \beta K \rceil$. In one example, the value of β can be fixed or configured via higher-layer parameter, MAC-CE, or DCI. In one example, $\beta \in \{\frac{1}{2},\frac{2}{3},\frac{3}{4},1\}$. In another example, $\beta \in \{\frac{1}{2},\frac{3}{4},1\}$. In one example, the value of β is layer-common, i.e., it is the same for all layers. In another example, the value of β is layer-specific. In one example the value of β is layer-pair-specific, and it can be different for different layer pairs (l,l+1), e.g., similar to β in Rel-16 codebook)

[273] In one example, β and other parameter(s) are jointly indicated by a parameter (e.g., an RRC parameter). For example, a parameter to jointly indicate β, L and/or M_v (as in Rel. 16 codebook) or jointly indicate M,α,β (as in Rel. 17 codebook) can be used.

[274] In one embodiment, $\beta = \frac{K_{0,tot}}{K_{tot}}$, a ratio of a maximum value of (i.e., an upper bound on) the number of non-zero coefficients ($K_{0,tot}$) across TRPs to the total number of non-zero coefficients (K_{tot}) across TRPs is fixed or configured via higher-layer parameter,

MAC-CE, or DCI. In this case, since β for each TRP is not restricted, any number of non-zero coefficients for each TRP can be allocated under the constraint that $K_{0,tot} = \lceil \beta K_{tot} \rceil$. In one example, $\beta \in \{\frac{1}{2}, \frac{2}{3}, \frac{3}{4}, 1\}$. In another example, β∈ $\{\frac{1}{2}, \frac{3}{4}, 1\}$. In one example, the value of β is layer-common, i.e., it is the same for all layers. In another example, the value of β is layer-specific. In one example the value of β is layer-pair-specific, and it can be different for different layer pairs (l,l+1), e.g., similar to β in Rel-16 codebook)

[275] In one example, β and other parameter(s) are jointly indicated by a parameter (e.g., an RRC parameter). For example, a parameter to jointly indicate β, L and/or M_v (as in Rel. 16 codebook) or jointly indicate M,α,β (as in Rel. 17 codebook) can be used.

[276] In one example, a ratio of a maximum value of (i.e., an upper bound on) the number of non-zero coefficients (K_0) for a TRP (per TRP) to the total number of non-zero coefficients (K_{tot}) across TRPs is β×s, where s is a scaling factor. In one example, the scaling factor is fixed, e.g., $s = \frac{1}{N_{TRP}}$. In another example, s is configured via higher-layer parameter, MAC-CE, or DCI. In another example, s can be TRP-specifically configured/fixed.

[277] In one embodiment, β_l and β_{tot} can be fixed or configured via higher-layer parameter, MAC-CE, or DCI, where β_l is per TRP restriction as described above, and β_{tot} is for all TRP restriction as described above:

[278] ● In one example, β_l is configured and β_{tot} is determined based on β_l, e.g., $K_{0,tot}=2\beta_l K$ or $a\beta_l K$ in general, where a can be fixed, configured, or reported. For example, a is fixed to N_{TRP}.

[279] ● In one example, β_{tot} is configured, and β_l is determined based on β_{tot}.

[280] ● In one example, both of β_l and β_{tot} are configured via higher-layer parameter, MAC-CE, or DCI.

[281] ● In one example, both of β_l and β_{tot} are fixed.

[282] ● In one example, one of them is reported by the UE, and the other is fixed/configured.

[283] In one example, for rank in S_1, β_l and/or β_{tot} are designed based on the above, and for rank in S_2, β_l and/or β_{tot} are designed based on a further restriction of the above.

[284] ● In one example, $S_1=\{1,2\}$ and $S_2=\{3,4\}$.

[285] ● For rank in S_2, β_l and β_{tot} can be designed in a manner that combines the approach for rank 3-4 design from Rel. 16 codebook with the above design principle. For example, $K_{0,tot}=2\beta_l K$ for rank in S_2

[286] In one example, when $N_{TRP} \leq x$, β_l and/or β_{tot} is a first value (or pair), and when $N_{TRP} > x$, β_l and/or β_{tot} is a second value (or pair), where x is a threshold value, which can be

fixed e.g., 2 or configured. In one example, (the first value, the second value) or (the first pair or the second pair) are configured or fixed.

[287] For example, if x is fixed to 2, β_l is configured or fixed, and

[288] ● $\beta_{tot}= a\beta_l K$ when $N_{TRP}=2$. In one example, a=2 or can be configured or reported.

[289] ● $\beta_{tot}= b\beta_l K$ when $N_{TRP}=3$ or 4. In one example, b=3 or can be configured or reported.

[290] In one example, β_l and/or β_{tot} is N_{TRP}-specific, rank-specific, and layer-specific.

[291] In one example, β_l and/or β_{tot} is N_{TRP}-specific, rank-specific, and layer-common.

[292] In one example, β_l and/or β_{tot} is N_{TRP}-specific, rank-common, and layer-specific.

[293] In one example, β_l and/or β_{tot} is N_{TRP}-specific, rank-common, and layer-common.

[294] In one example, β_l and/or β_{tot} is N_{TRP}-common, rank-specific, and layer-specific.

[295] In one example, β_l and/or β_{tot} is N_{TRP}-common, rank-specific, and layer-common.

[296] In one example, β_l and/or β_{tot} is N_{TRP}-common, rank-common, and layer-specific.

[297] In one example, β_l and/or β_{tot} is N_{TRP}-common, rank-common, and layer-common.

[298] In one embodiment, a maximum value of the (i.e., an upper bound on) number of non-zero coefficients in component W_2 is TRP-specific (i.e., one separate value for each TRP). In one example, a ratio β of a maximum value of the non-zero coefficients to a total number of elements in component W_2 is TRP-specific, i.e., the value of β is independent for each TRP.

[299] In one example, when $N_{TRP}=4$, the component W_2 can be expressed as

$$\boldsymbol{W}_2 = \begin{bmatrix} \boldsymbol{W}_{2,1} \\ \boldsymbol{W}_{2,2} \\ \boldsymbol{W}_{2,3} \\ \boldsymbol{W}_{2,4} \end{bmatrix},$$

where $W_{2,r}$ is a coefficient matrix for TRP r, and the value of β_r is a ratio of a maximum value of (i.e., an upper bound on) the number of non-zero coefficients ($K_{0,r}$) to a total number (K_r) of elements of in $W_{2,r}$, i.e., $\beta_r=K_{0,r}/K_r$ is TRP-specific. In one example, $K_{0,r} = \lceil \beta_r K_r \rceil$.

[300] In one example, for each TRP r={1,...,N_{TRP}}, β_r is configured via higher-layer parameter, MAC-CE, or DCI. In one example, $\beta_r \in \{\frac{1}{2}, \frac{2}{3}, \frac{3}{4}, 1\}$. In another example, $\beta_r \in \{\frac{1}{2}, \frac{3}{4}, 1\}$. In one example, the value of β_r is layer-common, i.e., it is the same for all layers. In another example, the value of β_r is layer-specific. In another example, β_r can be fixed.

[301] In one example, some rules on choosing/indicating $\{\beta_r\}$ are pre-defined. For example, $\beta_1 \geq \beta_2 \geq \ldots \geq \beta_{NTRP}$ where β_r is a ratio of non-zero coefficients for the r-th strongest TRP.

[302] In one example, when $N_{TRP} = 2$, $(\beta_1, \beta_2) = (1, \frac{3}{4})$, i.e., $\beta_1 = 1$ for the stronger TRP

and $\beta_1 = \frac{3}{4}$ for the weaker TRP.

[303] In another example, when $N_{TRP} = 4, (\beta_1, \beta_2, \beta_3, \beta_4) = (1, \frac{3}{4}, \frac{2}{3}, \frac{1}{2})$.

[304] In one example, β_r is configured via higher-layer parameter, MAC-CE, or DCI. In one example, $\beta_r \in \{\frac{1}{2}, \frac{2}{3}, \frac{3}{4}, 1\}$ for r-th strongest TRP for r=1,...,N_{TRP}. In another example, $\beta_r \in \{\frac{1}{2}, \frac{3}{4}, 1\}$ for r-th strongest TRP for r=1,...,N_{TRP}.

[305] In one example, β_r can be configured for each TRP r.

[306] In one example, β_r can be configured for each TRP pair (r,r+1), i.e., one value for TRP pair (1,2) and another value TRP pair (3,4). For example, when N_{TRP}=4, $\beta_{12}=\beta_1=\beta_2=1$ and $\beta_{34}=\beta_3=\beta_4=\frac{3}{4}$. Here, β_{12} and β_{34} are configured or fixed or reported by UE.

[307] In another example, $\{\beta_r\}$ are jointly indicated by a parameter. For example, in the case of 2 TRPs, a parameter to indicate (β_1,β_2) pair can be designed, as shown in the following table.

[308]

index	(β_1, β_2)
0	(1,1)
1	(1,3/4)
2	(1,2/3)
3	(3/4,3/4)
4	(3/4,2/3)
5	(3/4,1/2)
6	(2/3,2/3)
7	(2/3,1/2)

[309] In one example, $\{\beta_r\}$ are jointly indicated by a parameter for some case, but are independently indicated by multiple parameters each for β_r. For example, $\{\beta_r\}$ are jointly indicated by a parameter for the case of 2 TRPs (i.e., N_{TRP}=2) , and are independent indicated for the cases of 3 and 4 TRPs (i.e., N_{TRP}=3,4).

[310] In another example, $\{\beta_r\}$ and other parameter(s) are jointly indicated by a parameter (i.e., a parameter indicating combinations of multiple parameters). For example, a parameter to indicate $\{\beta_r\}$, L, and/or M_v (similar to Rel-16 codebook) jointly can be

used. In another example, a parameter to indicate $\{\beta_r\}$, α, and/or M_v (similar to Rel. 17 codebook).

[311] In another example, $\beta_r=\beta a^{r-1}$, where $a\leq 1$ is a scaling factor. For example, a can be fixed (e.g., 1/2) or configured via higher-layer parameter, MAC-CE, or DCI. In one example, $a\in\{\frac{3}{4},\frac{4}{5}\}$. In another example, $a \in \{\frac{3}{4}, 1\}$. In this case, β and a are configured to the UE. In one example, a is reported by the UE, as part of the CSI report. Such a reporting can be via a UCI parameter (new or existing) in UCI part 1 of a two-part UCI to report CSI.

[312] In another example, when β_r is configured for each TRP pair (r,r+1), i.e., one value for TRP pair (1,2) and another value TRP pair (3,4), the values of β_{12} and β_{34} can be jointly indicated by a parameter (for the case of 4 TRPs), where $\beta_{12}=\beta_1=\beta_2$ and $\beta_{34}=\beta_3=\beta_4$. For example, a parameter to indicate (β_{12},β_{34}) pair can be designed, as shown in the following table.

[313]

index	(β_{12}, β_{34})
0	(1,1)
1	(1,3/4)
2	(1,2/3)
3	(3/4,3/4)
4	(3/4,2/3)
5	(3/4,1/2)
6	(2/3,2/3)
7	(2/3,1/2)

[314] In one example, $\{\beta_{r,r+1}\}$ are jointly indicated by a parameter for some case, but are independently indicated by multiple parameters each for β_r. For example, $\{\beta_{r,r+1}\}$ are jointly indicated by a parameter for the case of 4 TRPs (i.e., $N_{TRP}=4$).

[315] In another example, $\{\beta_{r,r+1}\}$ and other parameter(s) are jointly indicated by a parameter (i.e., a parameter indicating combinations of multiple parameters). For example, a parameter to indicate $\{\beta_{r,r+1}\}$, L, and/or M_v (similar to Rel-16 codebook) jointly can be used. In another example, a parameter to indicate $\{\beta_{r,r+1}\}$, α, and/or M_v (similar to Rel. 17 codebook).

[316] In another example, $\beta_{2r-1,2r}=\beta a^{r-1}$, where $a\leq 1$ is a scaling factor. For example, a can be

fixed (e.g., 1/2) or configured via higher-layer parameter, MAC-CE, or DCI. In one example, $a \in \{\frac{3}{4}, \frac{4}{5}\}$. In another example, $a \in \{\frac{3}{4}, 1\}$. In this case, β and a are configured to the UE. In one example, a is reported by the UE, as part of the CSI report. Such a reporting can be via a UCI parameter (new or existing) in UCI part 1 of a two-part UCI to report CSI.

[317] In one example, the UE reports information on the order of strongest TRPs (or weakest TRPs) for NW to identify which TRP corresponds to r-th strongest TRP. In this case, an indicator with $\lceil \log_2 N_{TRP}! \rceil$ is used to indicate/report the order of strongest TRPs in CSI reporting.

[318] In one example, the UE does not report information on the order of strongest TRPs (or weakest TRPs) and the UE reports non-zero coefficients for each TRP in the order of original TRP index r, when $\{\beta_r\}$ are different across TRPs. In this case, the NW can identify which TRP corresponds to r-th strongest TRP by counting the number of non-zero coefficients in W_2 or based on the sum power of the non-zero coefficients for each TRP or other implementation methods.

[319] In one example, the value of β_r is layer-common, i.e., it is the same for all layers.

[320] In one example, the value of β_r is layer-specific, and it can be different for different layer.

[321] In one example, the value of β_r is layer-pair-specific, and it can be different for different layer pairs (l,l+1), e.g., similar to β in Rel-16 codebook)

[322] In one example, β_r is layer-common for Type-II port selection-based codebook extension for multi-TRPs (similar to Rel7), and is layer-specific or layer-pair-specific for regular Type-II (similar to Rel-16).

[323] In one embodiment, a bitmap (or multiple bitmaps) is used to indicate the location (or index) of the non-zero coefficients of the component W_2. In one example, this bitmap is common for all layers, i.e., one bitmap is reported for all layers. In another example, this bitmap is layer-specific, i.e., one bitmap is reported for each layer value.

[324] In one example, a bitmap is used to indicate the location (or index) of the non-zero coefficients corresponding to each of the N_{TRP} TRPs (bit-map partitioning). In this case, N_{TRP} bitmaps are defined.

[325] In one embodiment, a strongest coefficient indicator (SCI) is used to indicate the location (or index) of the strongest coefficient of the component W_2. In one example, the SCI is common for all layers, i.e., one SCI is reported for all layers. In another example, the SCI is layer-specific, i.e., one SCI is reported for each layer value.

[326] In one example, a SCI is used for each TRP (i.e., TRP-specific). For example, the location (or index) of the strongest coefficient for each TRP is defined based on a number of coefficients for the associated TRP (e.g., for the case that a bitmap is

defined for each TRP in such case of one or more examples described above).

[327] In another example, N_{TRP} locations (or indices) corresponding to the strongest coefficients for N_{TRP} TRPs are defined based on the whole (total) number of coefficients for the N_{TRP} TRPs.

[328] In one example, a SCI for each TRP indicates a SD beam index for a strongest coefficient and the FD beam index corresponding to the strongest coefficient is fixed to 0 (similar to Rel-16 Type-II codebook).

[329] In one example, a SCI for each TRP indicates SD and FD beam indices for a strongest coefficient (similar to Rel-17 Type-II codebook).

[330] In one embodiment, amplitude and phase of the non-zero coefficients of the component W_2 are reported using respective codebooks. In one example, the phase codebook is fixed, e.g., 16PSK. In one example, the phase codebook with n_p-bit is configured, e.g., from 8PSK (n_p=3-bit per phase) and 16PSK (n_p=4-bit per phase). In one example, an n_a-bit amplitude codebook comprising equidistance points in [0,1] in dB-scale (or log, or linear-scale) is used (similar to Rel-15/16/17 codebooks for amplitudes). In one example, the amplitude codebook can be fixed or configured via higher-layer parameter, MAC-CE, or DCI.

[331] In one example, the amplitude codebook is TRP-common, i.e., a same amplitude codebook is used for coefficients associated with all TRPs.

[332] In one example, for reference amplitude values, i.e., on $p^{(1)}$, a lower-bit (say n_a bit) amplitude codebook (compared to Rel-16 codebook for amplitude) is configured/fixed when $N_{TRP}>\alpha$ or $N>\alpha$ where N is the number of cooperating TRPs $N\leq N_{TRP}$. (N can be configured via RRC, MAC-CE, or DCI or determined by UE and reported).

[333] ● In one example, α is fixed e.g., α=1,2,or 3. In another example, α is configured via RRC, MAC-CE, or DCI, e.g., $\alpha\in\{1,2,3\}$.

[334] ● In one example, n_a=3, 2 or 1 (fixed) when $N_{TRP}>\alpha$ or $N>\alpha$.

[335] ● In one example, $n_a\in\{1,2,3\}$ is configured via RRC, MAC-CE, or DCI when $N_{TRP}>\alpha$ or $N>\alpha$.

[336] ● In one example, $n_a\in\{1,2,3\}$ is determined by the UE and reported.

[337] In one example, for differential amplitude values, i.e., on $p^{(2)}$, a lower-bit (say n_a bit) amplitude codebook (compared to Rel-16 codebook for amplitude) is configured/fixed when $N_{TRP}>\alpha$ or $N>\alpha$ where N is the number of cooperating TRPs $N\leq N_{TRP}$. (N can be configured via RRC, MAC-CE, or DCI or determined by UE and reported).

[338] ● In one example, α is fixed e.g., α=1,2,or 3. In another example, α is configured via RRC, MAC-CE, or DCI, e.g., $\alpha\in\{1,2,3\}$.

[339] ● In one example, n_a=2 or 1 (fixed) when $N_{TRP}>\alpha$ or $N>\alpha$.

[340] ● In one example, $n_a\in\{1,2\}$ is configured via RRC, MAC-CE, or DCI when $N_{TRP}>\alpha$ or $N>\alpha$.

[341] ● In one example, $n_a \in \{1,2\}$ is determined by the UE and reported.

[342] In one example, for both reference and differential amplitude values, lower-bit (say $n_{a,ref}$,$n_{a,diff}$ bits) amplitude codebooks (compared to Rel-16 codebook for amplitude) are configured/fixed when $N_{TRP}>\alpha$ or $N>\alpha$ where N is the number of cooperating TRPs $N \leq N_{TRP}$. (N can be configured via RRC, MAC-CE, or DCI or determined by UE and reported).

[343] In one example, the amplitude codebook is TRP-specific, i.e., a different amplitude codebook can be used for coefficients associated with each TRP.

[344] In one example, for reference amplitude values, i.e., on $p^{(1)}$, an $n_{a,r}$-bit amplitude codebook is configured to use for r-th strongest TRP. In one example, $n_{a,r} \in \{3,4\}$ or $n_{a,r} \in \{2,3,4\}$ and one of the values is configured to the UE for each r. In one example, $n_{a,1} \geq n_{a,2} \geq \ldots \geq n_{a,NTRP}$ or $n_{a,1} \geq n_{a,2} \geq \ldots \geq n_{a,N}$ ($N \leq N_{TRP}$) can be configured to the UE and $n_{a,r}$ is for the r-th strongest TRP.

[345] In one example, for differential amplitude values, i.e., on $p^{(2)}$, an $n_{a,r}$-bit amplitude codebook is configured to use for r-th strongest TRP. In one example, $n_{a,r} \in \{2,3\}$ or $n_{a,r} \in \{1,2,3\}$ and one of the values is configured to the UE for each r. In one example, $n_{a,1} \geq n_{a,2} \geq \ldots \geq n_{a,NTRP}$ or $n_{a,1} \geq n_{a,2} \geq \ldots \geq n_{a,N}$ ($N \leq N_{TRP}$) can be configured to the UE and $n_{a,r}$ is for the r-th strongest TRP.

[346] In one embodiment, for reference amplitude values, i.e., on $p^{(1)}$, two amplitude codebooks (with $n_{a,1}$ and $n_{a,2}$ bits) for non-zero coefficients in two groups G1 and G2, respectively, are used when $N_{TRP}>\alpha$ or $N>\alpha$.

[347] ● In one example, G1 and G2 are configured by NW via RRC, MAC-CE, or DCI.

[348] ● In one example, G1 and G2 are determined by UE and reported.

[349] ● In one example, G1 and G2 are determined implicitly. For example, G1 includes the strongest TRP and G2 includes the other TRPs)

[350] ● In one example, α is fixed e.g., α=1,2,or 3. In another example, α is configured via RRC, MAC-CE, or DCI, e.g., $\alpha \in \{1,2,3\}$.

[351] ● $n_{a,1}$ and $n_{a,2}$ are fixed or configured or determined by UE and reported.

[352] ● In one example, $n_{a,1} \geq n_{a,2}$, where $n_{a,1} \in \{3,4\}$ and $n_{a,2} \in \{2,3\}$.

[353] In one embodiment, for differential amplitude values, i.e., on $p^{(2)}$, two amplitude codebooks (with $n_{a,1}$ and $n_{a,2}$ bits) for non-zero coefficients in two groups G1 and G2, respectively, are used when $N_{TRP}>\alpha$ or $N>\alpha$.

[354] ● In one example, G1 and G2 are configured by NW via RRC, MAC-CE, or DCI.

[355] ● In one example, G1 and G2 are determined by UE and reported.

[356] ● In one example, G1 and G2 are determined implicitly. For example, G1 includes the strongest TRP and G2 includes the other TRPs)

[357] ● In one example, α is fixed e.g., α=1,2,or 3. In another example, α is configured via RRC, MAC-CE, or DCI, e.g., $\alpha \in \{1,2,3\}$.

[358] ● $n_{a,1}$ and $n_{a,2}$ are fixed or configured or determined by UE and reported.

[359] ● In one example, $n_{a,1} \geq n_{a,2}$, where $n_{a,1} \in \{2,3\}$ and $n_{a,2} \in \{1,2\}$.

[360] In one embodiment, for reference amplitude values, i.e., on $p^{(1)}$, two amplitude codebooks (with $n_{a,1}$ and $n_{a,2}$ bits) for non-zero coefficients in two groups G1 and G2, respectively, are used regardless of the value of N_{TRP} or N.

[361] ● In one example, G1 includes 1 TRP, and G2 includes N_{TRP}-1 or N-1 TRPs.

[362] ● In one example, G1 includes $\lfloor N_{TRP}/2 \rfloor$ or $\lfloor N/2 \rfloor$ TRP, and G2 includes $\lceil N_{TRP}/2 \rceil$ or $\lceil N/2 \rceil$ TRPs.

[363] ● In one example, G1 includes $\lceil N_{TRP}/2 \rceil$ or $\lceil N/2 \rceil$ TRP, and G2 includes $\lfloor N_{TRP}/2 \rfloor$ or $\lfloor N/2 \rfloor$ TRPs.

[364] ● In one example, G1 includes one TRP, and G2 includes one TRP for the case when N_{TRP}=2 or when the number of co-operating TRPs N=2, where $N \leq N_{TRP}$.

[365] ● In one example, G1 includes one TRP, and G2 includes two TRPs for the case when N_{TRP}=3 or when the number of co-operating TRPs N=3, where $N \leq N_{TRP}$.

[366] ● In one example, G1 includes one TRP, and G2 includes three TRPs for the case when N_{TRP}=4 or when the number of co-operating TRPs N=4, where $N \leq N_{TRP}$.

[367] ● In one example, G1 includes two TRPs, and G2 includes one TRP for the case of N_{TRP}=3 or when the number of co-operating TRPs N=3, where $N \leq N_{TRP}$.

[368] ● In one example, G1 includes two TRPs, and G2 includes two TRPs for the case of N_{TRP}=4 or when the number of co-operating TRPs N=4, where $N \leq N_{TRP}$.

[369] ● In one example, G1 includes three TRPs, and G2 includes one TRP for the case of N_{TRP}=4 or when the number of co-operating TRPs N=4, where $N \leq N_{TRP}$.

[370] ● $n_{a,1}$ and $n_{a,2}$ are fixed or configured or determined by UE and reported.

[371] ● In one example, $n_{a,1} \geq n_{a,2}$, where $n_{a,1} \in \{3,4\}$ and $n_{a,2} \in \{2,3\}$.

[372] In one embodiment, for differential amplitude values, i.e., on $p^{(2)}$, two amplitude codebooks (with $n_{a,1}$ and $n_{a,2}$ bits) for non-zero coefficients in two groups G1 and G2, respectively, are used regardless of the value of N_{TRP} or N.

[373] ● In one example, G1 includes 1 TRP, and G2 includes N_{TRP}-1 or N-1 TRPs.

[374] ● In one example, G1 includes $\lfloor N_{TRP}/2 \rfloor$ or $\lfloor N/2 \rfloor$ TRP, and G2 includes $\lceil N_{TRP}/2 \rceil$ or $\lceil N_{TRP}/2 \rceil$ TRPs.

[375] ● In one example, G1 includes $\lceil N_{TRP}/2 \rceil$ or $\lceil N/2 \rceil$ TRP, and G2 includes $\lfloor N_{TRP}/2 \rfloor$ or $\lfloor N/2 \rfloor$ TRPs.

[376] ● In one example, G1 includes one TRP, and G2 includes one TRP for the case when N_{TRP}=2 or when the number of co-operating TRPs N=2, where $N \leq N_{TRP}$.

[377] ● In one example, G1 includes one TRP, and G2 includes two TRPs for the case

when N_{TRP}=3 or when the number of co-operating TRPs N=3, where $N \leq N_{TRP}$.

[378] ● In one example, G1 includes one TRP, and G2 includes three TRPs for the case when N_{TRP}=4 or when the number of co-operating TRPs N=4, where $N \leq N_{TRP}$.

[379] ● In one example, G1 includes two TRPs, and G2 includes one TRP for the case of N_{TRP}=3 or when the number of co-operating TRPs N=3, where $N \leq N_{TRP}$.

[380] ● In one example, G1 includes two TRPs, and G2 includes two TRPs for the case of N_{TRP}=4 or when the number of co-operating TRPs N=4, where $N \leq N_{TRP}$.

[381] ● In one example, G1 includes three TRPs, and G2 includes one TRP for the case of N_{TRP}=4 or when the number of co-operating TRPs N=4, where $N \leq N_{TRP}$.

[382] ● $n_{a,1}$ and $n_{a,2}$ are fixed or configured or determined by UE and reported.

[383] ● In one example, $n_{a,1} \geq n_{a,2}$, where $n_{a,1} \in \{3,4\}$ and $n_{a,2} \in \{2,3\}$.

[384] In one example, the phase codebook is TRP-common, i.e., a same phase codebook is used for coefficients associated with all TRPs.

[385] In one example, a lower-bit (say n_p bits) phase codebook (compared to Rel-16 codebook for phase) is configured/fixed when $N_{TRP} > \alpha$ or $N > \alpha$ where N is the number of cooperating TRPs $N \leq N_{TRP}$. (N can be configured via RRC, MAC-CE, or DCI or determined by UE and reported).

[386] ● In one example, α is fixed e.g., α=1,2,or 3. In another example, α is configured via RRC, MAC-CE, or DCI, e.g., $\alpha \in \{1,2,3\}$.

[387] ● In one example, n_p=2 or 1 (fixed) when $N_{TRP} > \alpha$ or $N > \alpha$.

[388] ● In one example, $n_p \in \{1,2\}$ is configured via RRC, MAC-CE, or DCI when $N_{TRP} > \alpha$ or $N > \alpha$.

[389] ● In one example, $n_p \in \{1,2\}$ is determined by the UE and reported.

[390] In one example, the phase codebook is TRP-specific, i.e., a different phase codebook can be used for coefficients associated with each TRP. In one example, an $n_{p,r}$-bit phase codebook is configured to use for r-th strongest TRP. In one example, $n_{p,r} \in \{3,4\}$ or $n_{p,r} \in \{2,3,4\}$ and one of the value is configured to the UE for each r. In one example, $n_{p,1} \geq n_{p,2} \geq \ldots \geq n_{p,NTRP}$ can be configured to the UE and $n_{p,r}$ is for the r-th strongest TRP.

[391] In one embodiment, two phase codebooks (with $n_{p,1}$, $n_{p,2}$ bits) for non-zero coefficients in two groups G1 and G2, respectively, are used when $N_{TRP} > \alpha$ or $N > \alpha$.

[392] ● In one example, G1 and G2 are configured by NW via RRC, MAC-CE, or DCI.

[393] ● In one example, G1 and G2 are determined by UE and reported.

[394] ● In one example, G1 and G2 are determined implicitly. For example, G1 includes the strongest TRP and G2 includes the other TRPs)

[395] ● In one example, α is fixed e.g., α=1,2,or 3. In another example, α is configured via RRC, MAC-CE, or DCI, e.g., $\alpha \in \{1,2,3\}$.

[396] ● $n_{p,1}$ and $n_{p,2}$ are fixed or configured or determined by UE and reported.

[397] ● In one example, $n_{a,1} \geq n_{a,2}$, where $n_{a,1} \in \{3,4\}$ and $n_{a,2} \in \{1,2\}$.

[398] In one embodiment, two phase codebooks (with $n_{p,1}$, $n_{p,2}$ bits) for non-zero coefficients in two groups G1 and G2, respectively, are used regardless of the value of N_{TRP} or N.

[399] ● In one example, G1 includes 1 TRP, and G2 includes N_{TRP}-1 or N-1 TRPs.

[400] ● In one example, G1 includes $\lfloor N_{TRP}/2 \rfloor$ or $\lfloor N/2 \rfloor$ TRP, and G2 includes $\lceil N_{TRP}/2 \rceil$ or $\lceil N/2 \rceil$ TRPs.

[401] ● In one example, G1 includes $\lceil N_{TRP}/2 \rceil$ or $\lceil N/2 \rceil$ TRP, and G2 includes $\lfloor N_{TRP}/2 \rfloor$ or $\lfloor N/2 \rfloor$ TRPs.

[402] ● In one example, G1 includes one TRP, and G2 includes one TRP for the case when N_{TRP}=2 or when the number of co-operating TRPs N=2, where $N \leq N_{TRP}$.

[403] ● In one example, G1 includes one TRP, and G2 includes two TRPs for the case when N_{TRP}=3 or when the number of co-operating TRPs N=3, where $N \leq N_{TRP}$.

[404] ● In one example, G1 includes one TRP, and G2 includes three TRPs for the case when N_{TRP}=4 or when the number of co-operating TRPs N=4, where $N \leq N_{TRP}$.

[405] ● In one example, G1 includes two TRPs, and G2 includes one TRP for the case of N_{TRP}=3 or when the number of co-operating TRPs N=3, where $N \leq N_{TRP}$.

[406] ● In one example, G1 includes two TRPs, and G2 includes two TRPs for the case of N_{TRP}=4 or when the number of co-operating TRPs N=4, where $N \leq N_{TRP}$.

[407] ● In one example, G1 includes three TRPs, and G2 includes one TRP for the case of N_{TRP}=4 or when the number of co-operating TRPs N=4, where $N \leq N_{TRP}$.

[408] ● $n_{p,1}$ and $n_{p,2}$ are fixed or configured or determined by UE and reported.

[409] ● In one example, $n_{p,1} \geq n_{p,2}$, where $n_{a,1} \in \{3,4\}$ and $n_{a,2} \in \{1,2\}$.

[410] In one embodiment, the codebook includes additional components due to $N_{TRP}>1$ TRPs.

[411] In one example, the additional components include inter-TRP phase. In one example, the inter-TRP phase values correspond to N_{TRP}-1 phase values (e.g., assuming one of the TRPs is a reference and has a fixed phase value = 1). In another example, the inter-TRP phase values correspond to N_{TRP} phase values. The inter-TRP phase values can be quantized/reported as scalars using a scalar codebook (e.g., QPSK, 2 bits per phase or 8PSK, 3 bits per phase) or as a vector using a vector codebook (e.g., a DFT codebook). Also, for a dual-polarized antenna at an TRP, the inter-TRP phase can be the same for two polarizations of the TRP. Alternatively, it can be independent for two polarizations for the TRP. At least one of the following example is used for the inter-TRP phase reporting.

[412] ● In one example, the inter-TRP phase is reported in a wideband (WB) manner, i.e., one value is reported for all SBs in the configured CSI reporting band. Due to WB

reporting, it can be included in the W_1 component of the codebook. Alternatively, it can be included in a new component, say W_3 of the codebook.

[413] ● In one example, the inter-TRP phase is reported in a subband (SB) manner, i.e., one value is reported for each SB in the configured CSI reporting band. Due to SB reporting, it can be included in the W_2 component of the codebook. Alternatively, it can be included in a new component, say W_3 of the codebook.

[414] ● In one example, the inter-TRP phase is reported in a WB plus SB manner, i.e., one WB phase value is reported for all SBs in the configured CSI reporting band, and one SB value is reported for each SB in the configured CSI reporting band. Due to WB plus SB reporting, the WB part can be included in the W_1 component of the codebook and the SB part can be included in the W_2 component of the codebook. Alternatively, both WB and SB parts can be included in a new component, say W_3 of the codebook.

[415] In one example, the additional components include inter-TRP phase and inter-TRP amplitude, wherein the details about the inter-TRP phase are as explained in example 0.18.1. Note that inter-TRP amplitude is needed due to unequal distance of the UE from TRPs. In one example, the inter-TRP amplitude values correspond to N_{TRP}-1 amplitude values (e.g., assuming one of the TRPs is a reference and has a fixed amplitude value = 1). In another example, the inter-TRP amplitude values correspond to N_{TRP} amplitude values. The inter-TRP amplitude values can be quantized/reported as scalars using a scalar codebook (e.g., 2 bits per amplitude or 3 bits per amplitude) or as a vector using a vector codebook. Also, for a dual-polarized antenna at an TRP, the inter-TRP amplitude can be the same for two polarizations of the TRP. Alternatively, it can be independent for two polarizations for the TRP. At least one of the following example is used for the inter-TRP amplitude and phase reporting.

[416] ● In one example, the inter-TRP amplitude is reported in a wideband (WB) manner, i.e., one value is reported for all SBs in the configured CSI reporting band. Due to WB reporting, it can be included in the W_1 component of the codebook. Alternatively, it can be included in a new component, say W_3 of the codebook. At least one of the following example is used for the inter-TRP phase.

[417] ○ In one example, the inter-TRP phase is reported according to one or more examples described above.

[418] ● In one example, the inter-TRP amplitude is reported in a subband (SB) manner, i.e., one value is reported for each SB in the configured CSI reporting band. Due to SB reporting, it can be included in the W_2 component of the codebook. Alternatively, it can be included in a new component, say W_3 of the codebook. At least one of the following example is used for the inter-TRP phase.

[419] ○ In one example, the inter-TRP phase is reported according to one or more examples described above.

[420] ● In one example, the inter-TRP amplitude is reported in a WB plus SB manner, i.e., one WB amplitude value is reported for all SBs in the configured CSI reporting band, and one SB value is reported for each SB in the configured CSI reporting band. Due to WB plus SB reporting, the WB part can be included in the W_1 component of the codebook and the SB part can be included in the W_2 component of the codebook. Alternatively, both WB and SB parts can be included in a new component, say W_3 of the codebook. At least one of the following example is used for the inter-TRP phase.

[421] ○ In one example, the inter-TRP phase is reported according to one or more examples described above.

[422] In one example, the additional components include inter-TRP amplitude, wherein the details about the inter-TRP amplitude are as explained according to one or more examples described above.

[423] In one example, the additional components include inter-TRP power, wherein the details about the inter-TRP power are as explained according to one or more examples described above by replacing amplitude with power. In one example, a square of inter-TRP amplitude equals inter-TRP power.

[424] In one example, the additional components include inter-TRP phase and inter-TRP power, wherein the details about the inter-TRP phase are as explained according to one or more examples described above, and the details about the inter-TRP power are as explained according to one or more examples described above by replacing amplitude with power. In one example, a square of inter-TRP amplitude equals inter-TRP power.

[425] In one example, an inter-TRP phase codebook is TRP-common, i.e., a same inter-TRP phase codebook is used for all TRPs. It can be fixed or configured via higher-layer parameter, MAC-CE, or DCI. In one example, a 3-bit PSK codebook is used to select each of the N_{TRP}-1 inter-TRP phases.

[426] In one example, an inter-TRP phase codebook is TRP-specific, i.e., a different inter-TRP phase codebook can be used for each TRP. It can be fixed or configured via higher-layer parameter, MAC-CE, or DCI. In one example, a 3-bit PSK codebook is used to select each of some inter-TRP phases and a 4-bit PSK codebook is used to select each of the other inter-TRP phases.

[427] In one example, an inter-TRP amplitude (power) codebook is TRP-common, i.e., a same inter-TRP amplitude (power) codebook is used for all TRPs. It can be fixed or configured via higher-layer parameter, MAC-CE, or DCI. In one example, a 3-bit inter-TRP amplitude (power) codebook is used to select each of the N_{TRP}-1 inter-TRP amplitudes (powers).

[428] In one example, an inter-TRP amplitude (power) codebook is TRP-specific, i.e., a different inter-TRP amplitude (power) codebook can be used for each TRP. It can be fixed or configured via higher-layer parameter, MAC-CE, or DCI. In one example, a

3-bit inter-TRP amplitude (power) codebook is used to select each of some inter-TRP amplitudes (powers) and a 4-bit inter-TRP amplitude (power) codebook is used to select each of the other inter-TRP amplitudes (powers).

[429] In one example, inter-TRP amplitude (power) values are computed in a differential manner. For example, inter-TRP amplitude value can be computed as follows: $b_r = \prod_{i=1}^{r} \bar{b}_i$ is the inter-TRP amplitude value for r-th strongest TRP, and $\bar{b}_i$ for i≥2 is selected from an inter-TRP amplitude codebook and $\bar{b}_i$=1. In another example, $\bar{b}_i$ can be selected from a different inter-TRP amplitude codebook for each i≥2. In this case, { $\bar{b}_i$ } for i≥2 are selected and reported and the NW computes inter-TRP amplitude using $b_r = \prod_{i=1}^{r} \bar{b}_i \cdot$

[430] In one example, the additional components include an indicator indicating the strongest TRP (for reference). Due to distributed architecture, the strongest TRP can be reported in order to indicate the reference TRP with respect to which the inter-TRP components (such as amplitude and/or phase) are reported. The inter-TRP amplitude and phase associated with the strongest TRP can be set to a fixed value, for example 1. At least one of the following example is used for the strongest TRP reporting.

[431] ● In one example, the strongest TRP (indicator) is reported in a WB manner, i.e., one value (indicator) is reported for all SBs. Due to WB reporting, it can be included in the W_1 component of the codebook. Alternatively, it can be included in a new component, say W_3 of the codebook.

[432] ● In one example, the strongest TRP (indicator) is reported in a SB manner, i.e., one value (indicator) is reported for each SB. Due to SB reporting, it can be included in the W_2 component of the codebook. Alternatively, it can be included in a new component, say W_3 of the codebook.

[433] In one example, the strongest TRP is reported in a layer-common manner, i.e., one strongest TRP is reported common for all layers when number of layers > 1 (or rank > 1).

[434] In one example, the strongest TRP is reported in a layer-specific manner, i.e., one strongest TRP is reported for each layer of the number of layers when number of layers > 1 (or rank > 1).

[435] The amplitude/phase associated with the strongest TRP can be fixed, e.g., to 1. In an alternate design, the strongest TRP can be configured (e.g., via RRC signaling), or can be fixed (e.g., TRP 1 is always strongest).

[436] In one example, the additional components include an indicator indicating information on the order of strongest TRPs (or the order of weakest TRPs). At least one of the following example is used for the strongest TRP order reporting.

[437] ● In one example, an indicator to indicate the strongest TRP order is reported in a WB manner, i.e., one indicator is reported for all SBs. Due to WB reporting, it can be included in the W_1 component of the codebook. Alternatively, it can be included in a new component, say W_3 of the codebook.

[438] ● In one example, an indicator to indicate the strongest TRP order is reported in a SB manner, i.e., one indicator is reported for each SB. Due to SB reporting, it can be included in the W_2 component of the codebook. Alternatively, it can be included in a new component, say W_3 of the codebook.

[439] In one example, the strongest TRP order is reported in a layer-common manner, i.e., one strongest TRP order is reported common for all layers when number of layers > 1 (or rank > 1).

[440] In one example, the strongest TRP order is reported in a layer-specific manner, i.e., one strongest TRP order is reported for each layer of the number of layers when number of layers > 1 (or rank > 1).

[441] The amplitude/phase associated with the strongest TRP can be fixed, e.g., to 1. In an alternate design, the strongest TRP or the strongest TRP order can be configured (e.g., via RRC signaling), or can be fixed (e.g., TRP 1/2/3/4 is always in the order of strongest TRPs)

[442] In the disclosure, the codebook component W_1 and W_f refer to pre-coder (or pre-coding matrix) components that are indicated via the components of the first PMI indicator i_1. Likewise, the codebook component W_2 refers to pre-coder (or pre-coding matrix) components that are indicated via the components of the second PMI indicator i_2. Likewise, the new codebook component W_3 refers to pre-coder (or pre-coding matrix) components that are indicated via the components of the third PMI indicator i_3.

[443] In one embodiment, a UE is configured with a CSI report for $N_{TRP}\geq 1$ TRPs (or N_{TRP} NZP CSI-RS resources) based on a codebook, where the codebook is configured according to one or more embodiments described above. When $N_{TRP}=1$, a bit-map indicator for indicating non-zero coefficients for the codebook can be defined as the

Let $K_0 = \lceil \beta 2LM_1 \rceil$. The bitmap whose nonzero bits identify which coefficients in $i_{2,4,l}$ and $i_{2,5,l}$ are reported, is indicated by $i_{1,7,l}$

$$i_{1,7,l} = \left[k_{l,0}^{(3)} \dots k_{l,M_\upsilon-1}^{(3)}\right]$$

$$k_{l,f}^{(3)} = \left[k_{l,0,f}^{(3)} \dots k_{l,2L-1,f}^{(3)}\right]$$

$$k_{l,i,f}^{(3)} \in \{0,1\}$$

for $l = 1, \dots, \upsilon$, such that $K_l^{NZ} = \sum_{i=0}^{2L-1} \sum_{f=0}^{M_\upsilon-1} k_{l,i,f}^{(3)} \leq K_0$ is the number of nonzero coefficients for layer $l = 1, \dots, \upsilon$ and $K^{NZ} = \sum_{l=1}^{\upsilon} K_l^{NZ} \leq 2K_0$ is the total number of nonzero coefficients.

[444] In one embodiment, when $N_{TRP} \geq 1$, a bitmap indicator whose nonzero bits identify which coefficients are reported (e.g., $i_{2,4,l}$ and $i_{2,5,l}$) can be determined according to at least one of the following examples.

[445] In one example, the bitmap indicator is polarization-specific (one for each polarization), layer-specific (one for each layer), and TRP-specific (one for each TRP). For example, the bitmap $i_{1,7,l}$ can be expressed as

[446]

$$i_{1,7,l} = \left[k_{l,0,r}^{(3)} \dots k_{l,M_\upsilon-1,r}^{(3)}\right]$$

$$k_{l,f}^{(3)} = \left[k_{l,0,f}^{(3)} \dots k_{l,2L-1,f}^{(3)}\right]$$

$$k_{l,i,f}^{(3)} = \left[k_{l,i,f,1}^{(3)} \dots k_{l,i,f,N_{TRP}}^{(3)}\right]$$

$$k_{l,i,f,r}^{(3)} \in \{0,1\}$$

[447] for $l=1,\dots,\upsilon$.

[448] In one example, the bitmap indicator is polarization-common (one for both polarizations), layer-specific (one for each layer), and TRP-specific (one for each TRP). For example, the bitmap $i_{1,7,l}$ can be expressed as

$$i_{1,7,l} = \left[k_{l,0,r}^{(3)} \dots k_{l,M_\upsilon-1,r}^{(3)}\right]$$

$$k_{l,f}^{(3)} = \left[k_{l,0,f}^{(3)} \dots k_{l,L-1,f}^{(3)}\right]$$

$$k_{l,i,f}^{(3)} = \left[k_{l,i,f,1}^{(3)} \dots k_{l,i,f,N_{TRP}}^{(3)}\right]$$

$$k_{l,i,f,r}^{(3)} \in \{0,1\}$$

[449] for $l=1,\ldots,\upsilon$, which is common for both polarizations. That is, the bitmap $i_{1,7,l}$ common for both polarizations is reported.

[450] In one example, the bitmap indicator is polarization-specific (one for each polarization), layer-common (one for all layers), and TRP-specific (one for each TRP). For example, the bitmap $i_{1,7}$ can be expressed as

$$i_{1,7} = \left[k^{(3)}_{0,r} \ldots k^{(3)}_{M_\upsilon-1,r}\right]$$

$$k^{(3)}_{f} = \left[k^{(3)}_{0,f} \ldots k^{(3)}_{2L-1,f}\right]$$

$$k^{(3)}_{i,f} = \left[k^{(3)}_{i,f,1} \ldots k^{(3)}_{i,f,N_{TRP}}\right]$$

$$k^{(3)}_{i,f,r} \in \{0,1\}$$

[451] which is common for all layers $l=1,\ldots,\upsilon$. That is, the bitmap $i_{1,7}$ common for all layers is reported.

[452] In one example, the bitmap indicator is polarization-common (one for both polarizations), layer-common (one for all layers), and TRP-specific (one for each TRP). For example, the bitmap $i_{1,7}$ can be expressed as

$$i_{1,7} = \left[k^{(3)}_{0,r} \ldots k^{(3)}_{M_\upsilon-1,r}\right]$$

$$k^{(3)}_{f} = \left[k^{(3)}_{0,f} \ldots k^{(3)}_{L-1,f}\right]$$

$$k^{(3)}_{i,f} = \left[k^{(3)}_{i,f,1} \ldots k^{(3)}_{i,f,N_{TRP}}\right]$$

$$k^{(3)}_{i,,r} \in \{0,1\}$$

[453] which is common for all layers $l=1,\ldots,\upsilon$ and for both polarizations. That is, the bitmap $i_{1,7}$ common for all layers and for both polarizations is reported.

[454] In one example, the bitmap indicator is polarization-specific (one for each polarization), layer-specific (one for each layer), and TRP-common (one for all TRPs). For example, the bitmap $i_{1,7,l}$ for each $l=1,\ldots,\upsilon$ can be expressed as

$$i_{1,7,l} = \left[k^{(3)}_{l,0} \ldots k^{(3)}_{l,M_\upsilon-1}\right]$$

$$k^{(3)}_{l,f} = \left[k^{(3)}_{l,0,f} \ldots k^{(3)}_{l,2L-1,f}\right]$$

$$k^{(3)}_{l,i,f} \in \{0,1\}$$

[455] which is common for all TRPs $r=1,\ldots,N_{TRP}$. That is, the bitmap $i_{1,7,l}$ common for all TRPs is reported.

[456] In one example, the bitmap indicator is polarization-common (one for both polarizations), layer-specific (one for each layer), and TRP-common (one for all TRPs). For example, the bitmap $i_{1,7,l}$ for each $l=1,\dots,\upsilon$ can be expressed as

$$i_{1,7,l} = \left[k_{l,0}^{(3)} \dots k_{l,M_\upsilon-1}^{(3)}\right]$$

$$k_{l,f}^{(3)} = \left[k_{l,0,f}^{(3)} \dots k_{l,L-1,f}^{(3)}\right]$$

$$k_{l,i,f}^{(3)} \in \{0,1\}$$

[457] which is common for all TRPs $r=1,\dots,N_{TRP}$ and for both polarizations. That is, one bitmap $i_{1,7,l}$ common for all TRPs and both polarizations are reported.

[458] In one example, the bitmap indicator is polarization-specific (one for each polarization), layer-common (one for all layers), and TRP-common (one for all TRPs). For example, the bitmap $i_{1,7}$ can be expressed as

$$i_{1,7} = \left[k_{0}^{(3)} \dots k_{M_\upsilon-1}^{(3)}\right]$$

$$k_{f}^{(3)} = \left[k_{0,f}^{(3)} \dots k_{2L-1,f}^{(3)}\right]$$

$$k_{i,f}^{(3)} \in \{0,1\}$$

[459] which is common for all layers $l=1,\dots,\upsilon$ and for all TRPs $r=1,\dots,N_{TRP}$. That is, one bitmap $i_{1,7}$ common for all layers and for all TRPs is reported.

[460] In one example, the bitmap indicator is polarization-common (one for both polarizations), layer-common (one for all layers), and TRP-common (one for all TRPs). For example, the bitmap $i_{1,7}$ can be expressed as

$$i_{1,7} = \left[k_{0}^{(3)} \dots k_{M_\upsilon-1}^{(3)}\right]$$

$$k_{f}^{(3)} = \left[k_{0,f}^{(3)} \dots k_{L-1,f}^{(3)}\right]$$

$$k_{i,f}^{(3)} \in \{0,1\}$$

[461] which is common for all layers $l=1,\dots,\upsilon$ and for all TRPs $r=1,\dots,N_{TRP}$ and for both polarizations. That is, one bitmap $i_{1,7}$ common for all layers and for all TRPs and for both polarizations is reported.

[462] When the number of FD basis vectors M_υ is independent for each TRP r (and L is common for all TRPs), M_υ can be replaced by $M_{\upsilon,r}$.

[463] ● In one example, the bitmap can be determined according to one or more examples described above replacing M_υ by $M_{\upsilon,r}$.

[464] When the number of SD basis vectors L is independent for each TRP r (and M_υ is common for all TRPs), L can be replaced by L_r.

[465] ● In one example, the bitmap can be determined according to one or more examples described above replacing L by L_r.

[466] When the numbers of SD/FD basis vectors L and M_υ are independent for each TRP r, L and M_υ can be replaced by L_r and $M_{\upsilon,r}$, respectively.

[467] ● In one example, the bitmap can be determined according to one or more examples described above replacing L and M_υ by L_r and $M_{\upsilon,r}$, respectively.

[468] In one embodiment, an upper bound of the number of non-zero coefficients can be defined as at least one of the following examples.

[469] In one example, the upper bound can be given by $K_{l,r}^{NZ} = \sum_{i=0}^{2L_r-1}\sum_{f=0}^{M_{\upsilon,r}-1} k_{l,i,f,r}^{(3)} \le K_{0,l,r}$ per layer l per TRP r.

- In another example, $K_{l,r}^{NZ} = \sum_{i=0}^{2L-1}\sum_{f=0}^{M_{\upsilon,r}-1} k_{l,i,f,r}^{(3)} \le K_{0,l,r}$.
- In another example, $K_{l,r}^{NZ} = \sum_{i=0}^{2L_r-1}\sum_{f=0}^{M_\upsilon-1} k_{l,i,f,r}^{(3)} \le K_{0,l,r}$.
- In another example, $K_{l,r}^{NZ} = \sum_{i=0}^{2L-1}\sum_{f=0}^{M_\upsilon-1} k_{l,i,f,r}^{(3)} \le K_{0,l,r}$.

[470] In one example, $K_{0,l,r}$ is common for all TRPs, i.e., $K_{0,l,r}=K_{0,l}$ for ∀r.

[471] In one example, $K_{0,l,r}$ is common for all layers, i.e., $K_{0,l,r}=K_{0,r}$ for ∀l.

[472] In one example, $K_{0,l,r}$ is common for all layers and all TRPs, i.e., $K_{0,l,r}=K_0$ for ∀l.

[473] In one example, $K_{0,l,r}$ can be computed using parameters $\beta\ (or\ \beta_l, or\ \beta_r, or\ \beta_{l,r}, \ldots), L\ (or\ L_r), M\ \ (\text{or}\ \ M_\upsilon, or\ M_{\upsilon,r}\ )$, similar to the K_0 of Rel-16 codebook. Here the β can be given by at least one of the examples in one or more embodiments described above.

[474]

- In one example, $K_{0,l,r} = \lceil \beta 2L \quad {}_1 \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta 2LM_{1,r} \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta 2L_rM_1 \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta 2L_rM_{1,r} \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_l 2LM_1 \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_l 2LM_{1,r} \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_l 2L_rM_1 \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_l 2L_rM_{1,r} \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_r 2LM_1 \rceil$.

[475]

- In one example, $K_{0,l,r} = \lceil \beta_r 2LM_{1,r} \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_r 2L_r M_1 \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_r 2L_r M_{1,r} \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_{l,r} 2LM_1 \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_{l,r} 2LM_{1,r} \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_{l,r} 2L_r M_1 \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_{l,r} 2L_r M_{1,r} \rceil$.
- In one example, $K_{0,l,r} = \left\lceil \frac{\beta_{tot}}{N} 2LM_1 \right\rceil$.
- In one example, $K_{0,l,r} = \left\lceil \frac{\beta_{tot}}{N} 2LM_{1,r} \right\rceil$.
- In one example, $K_{0,l,r} = \left\lceil \frac{\beta_{tot}}{N} 2L_r M_1 \right\rceil$.
- In one example, $K_{0,l,r} = \left\lceil \frac{\beta_{tot}}{N} 2L_r M_{1,r} \right\rceil$.
- In one example, $K_{0,l,r} = \lceil \beta 2LM_v \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta 2LM_{v,r} \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta 2L_r M_v \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta 2L_r M_{v,r} \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_l 2LM_v \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_l 2LM_{v,r} \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_l 2L_r M_v \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_l 2L_r M_{v,r} \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_r 2LM_v \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_r 2LM_{v,r} \rceil$.

[476]

- In one example, $K_{0,l,r} = \lceil \beta_r 2L_r M_v \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_r 2L_r M_{v,r} \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_{l,r} 2LM_v \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_{l,r} 2LM_{v,r} \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_{l,r} 2L_r M_v \rceil$.
- In one example, $K_{0,l,r} = \lceil \beta_{l,r} 2L_r M_{v,r} \rceil$.
- In one example, $K_{0,l,r} = \left\lceil \frac{\beta_{tot}}{N} 2LM_v \right\rceil$.
- In one example, $K_{0,l,r} = \left\lceil \frac{\beta_{tot}}{N} 2LM_{v,r} \right\rceil$.
- In one example, $K_{0,l,r} = \left\lceil \frac{\beta_{tot}}{N} 2L_r M_v \right\rceil$.
- In one example, $K_{0,l,r} = \left\lceil \frac{\beta_{tot}}{N} 2L_r M_{v,r} \right\rceil$.

[477] In one example, the upper bound can be given by $K_l^{NZ} = \sum_{r=1}^{N_{TRP}} \sum_{i=0}^{2L_r-1} \sum_{f=0}^{M_{v,r}-1} k_{l,i,f,r}^{(3)} \leq aK_{0,l}$ per layer l. For example, $a = 1$, $a = 2$ or $a = \min(2, N_{TRP})$.

- In another example, $K_l^{NZ} = \sum_{r=1}^{N_{TRP}} \sum_{i=0}^{2L-1} \sum_{f=0}^{M_{v,r}-1} k_{l,i,f,r}^{(3)} \leq aK_{0,l}$.
- In another example, $K_l^{NZ} = \sum_{r=1}^{N_{TRP}} \sum_{i=0}^{2L_r-1} \sum_{f=0}^{M_v-1} k_{l,i,f,r}^{(3)} \leq aK_{0,l}$.
- In another example, $K_l^{NZ} = \sum_{r=1}^{N_{TRP}} \sum_{i=0}^{2L-1} \sum_{f=0}^{M_v-1} k_{l,i,f,r}^{(3)} \leq aK_{0,l}$.

[478] In one example, $K_{0,l}$ is common for all layers, i.e., $K_{0,l}=K_0$ for ∀l.

[479] In one example, $K_{0,l}$ can be computed using parameters β (or β_l,or β_{tot},…),L (or L_r),M (or M_v,or $M_{v,r}$), similar to the K_0 of Rel-16 codebook. Here the β can be given by at least one of the examples in one or more embodiments described above.

[480]

- In one example, $K_{0,l} = \lceil \beta 2LM_1 \rceil$.
- In one example, $K_{0,l} = \lceil \beta 2LM_1N \rceil$.
- In one example, $K_{0,l} = \left\lceil \beta 2L \sum_{r=1}^{N} M_{1,r} \right\rceil$.
- In one example, $K_{0,l} = \lceil \beta 2M_1 \sum_{r=1}^{N} L_r \rceil$.
- In one example, $K_{0,l} = \left\lceil \beta 2 \sum_{r=1}^{N} L_r M_{1,r} \right\rceil$.
- In one example, $K_{0,l} = \lceil \beta_l 2LM_1 \rceil$.
- In one example, $K_{0,l} = \lceil \beta_l 2LM_1N \rceil$.
- In one example, $K_{0,l} = \left\lceil \beta_l 2L \sum_{r=1}^{N} M_{1,r} \right\rceil$.
- In one example, $K_{0,l} = \lceil \beta_l 2M_1 \sum_{r=1}^{N} L_r \rceil$.

[481]

- In one example, $K_{0,l} = \left\lceil \beta_l 2 \sum_{r=1}^{N} L_r M_{1,r} \right\rceil$.
- In one example, $K_{0,l} = \lceil \beta_{tot} 2 L M_1 \rceil$.
- In one example, $K_{0,l} = \lceil \beta_{tot} 2 L M_1 N \rceil$.
- In one example, $K_{0,l} = \left\lceil \beta_{tot} 2 L \sum_{r=1}^{N} M_{1,r} \right\rceil$.
- In one example, $K_{0,l} = \lceil \beta_{tot} 2 M_1 \sum_{r=1}^{N} L_r \rceil$.
- In one example, $K_{0,l} = \left\lceil \beta_{tot} 2 \sum_{r=1}^{N} L_r M_{1,r} \right\rceil$.
- In one example, $K_{0,l} = \lceil \beta 2 L M_v \rceil$.
- In one example, $K_{0,l} = \lceil \beta 2 L M_v N \rceil$.
- In one example, $K_{0,l} = \left\lceil \beta 2 L \sum_{r=1}^{N} M_{v,r} \right\rceil$.
- In one example, $K_{0,l} = \lceil \beta 2 M_v \sum_{r=1}^{N} L_r \rceil$.
- In one example, $K_{0,l} = \left\lceil \beta 2 \sum_{r=1}^{N} L_r M_{v,r} \right\rceil$.
- In one example, $K_{0,l} = \lceil \beta_l 2 L M_v \rceil$.
- In one example, $K_{0,l} = \lceil \beta_l 2 L M_v N \rceil$.
- In one example, $K_{0,l} = \left\lceil \beta_l 2 L \sum_{r=1}^{N} M_{v,r} \right\rceil$.
- In one example, $K_{0,l} = \lceil \beta_l 2 M_v \sum_{r=1}^{N} L_r \rceil$.
- In one example, $K_{0,l} = \left\lceil \beta_l 2 \sum_{r=1}^{N} L_r M_{v,r} \right\rceil$.
- In one example, $K_{0,l} = \lceil \beta_{tot} 2 L M_v \rceil$.
- In one example, $K_{0,l} = \lceil \beta_{tot} 2 L M_v N \rceil$.
- In one example, $K_{0,l} = \left\lceil \beta_{tot} 2 L \sum_{r=1}^{N} M_{v,r} \right\rceil$.
- In one example, $K_{0,l} = \lceil \beta_{tot} 2 M_v \sum_{r=1}^{N} L_r \rceil$.
- In one example, $K_{0,l} = \left\lceil \beta_{tot} 2 \sum_{r=1}^{N} L_r M_{v,r} \right\rceil$.

[482] In one example, the upper bound can be given by $K_r^{NZ} = \sum_{l=1}^{v}\sum_{i=0}^{2L_r-1}\sum_{f=0}^{M_{v,r}-1} k_{l,i,f,r}^{(3)} \leq bK_{0,r}$ per TRP r. For example, $b = 1, b = 2$ or $b = \min(2, v)$.

- In another example, $K_r^{NZ} = \sum_{l=1}^{v}\sum_{i=0}^{2L-1}\sum_{f=0}^{M_{v,r}-1} k_{l,i,f,r}^{(3)} \leq bK_{0,r}$.
- In another example, $K_r^{NZ} = \sum_{l=1}^{v}\sum_{i=0}^{2L_r-1}\sum_{f=0}^{M_v-1} k_{l,i,f,r}^{(3)} \leq bK_{0,r}$.
- In another example, $K_r^{NZ} = \sum_{l=1}^{v}\sum_{i=0}^{2L-1}\sum_{f=0}^{M_v-1} k_{l,i,f,r}^{(3)} \leq bK_{0,r}$.

[483] In one example, $K_{0,r}$ is common for all TRPs, i.e., $K_{0,r}=K_0$ for ∀l.

[484] In one example, $K_{0,r}$ can be computed using parameters β (or β_r,or β_{tot},…),L (or L_r),M (or M_v,or $M_{v,r}$), similar to the K_0 of Rel-16 codebook. Here the β can be given by at least one of the examples in one or more embodiments described above.

[485]

- In one example, $K_{0,r} = \lceil \beta 2LM_1 \rceil$.
- In one example, $K_{0,r} = \lceil \beta 2LM_{1,r} \rceil$.
- In one example, $K_{0,r} = \lceil \beta 2L_rM_1 \rceil$.
- In one example, $K_{0,r} = \lceil \beta 2L_rM_{1,r} \rceil$.
- In one example, $K_{0,r} = \lceil \beta_r 2LM_1 \rceil$.
- In one example, $K_{0,r} = \lceil \beta_r 2LM_{1,r} \rceil$.
- In one example, $K_{0,r} = \lceil \beta_r 2L_rM_1 \rceil$.
- In one example, $K_{0,r} = \lceil \beta_r 2L_rM_{1,r} \rceil$.
- In one example, $K_{0,r} = \left\lceil \frac{\beta_{tot}}{N} 2LM_1 \right\rceil$.
- In one example, $K_{0,r} = \left\lceil \frac{\beta_{tot}}{N} 2LM_{1,r} \right\rceil$.
- In one example, $K_{0,r} = \left\lceil \frac{\beta_{tot}}{N} 2L_rM_1 \right\rceil$.
- In one example, $K_{0,r} = \left\lceil \frac{\beta_{tot}}{N} 2L_rM_{1,r} \right\rceil$.

[486]

- In one example, $K_{0,r} = \lceil \beta 2LM_v \rceil$.
- In one example, $K_{0,r} = \lceil \beta 2LM_{v,r} \rceil$.
- In one example, $K_{0,r} = \lceil \beta 2L_r M_v \rceil$.
- In one example, $K_{0,r} = \lceil \beta 2L_r M_{v,r} \rceil$.
- In one example, $K_{0,r} = \lceil \beta_r 2LM_v \rceil$.
- In one example, $K_{0,r} = \lceil \beta_r 2LM_{v,r} \rceil$.
- In one example, $K_{0,r} = \lceil \beta_r 2L_r M_v \rceil$.
- In one example, $K_{0,r} = \lceil \beta_r 2L_r M_{v,r} \rceil$.
- In one example, $K_{0,r} = \left\lceil \frac{\beta_{tot}}{N} 2LM_v \right\rceil$.
- In one example, $K_{0,r} = \left\lceil \frac{\beta_{tot}}{N} 2LM_{v,r} \right\rceil$.
- In one example, $K_{0,r} = \left\lceil \frac{\beta_{tot}}{N} 2L_r M_v \right\rceil$.
- In one example, $K_{0,r} = \left\lceil \frac{\beta_{tot}}{N} 2L_r M_{v,r} \right\rceil$.

[487] In one example, the upper bound can be given by $K^{NZ} = \sum_{l=1}^{v} K_l^{NZ} \le cK_0$. For example, c=1,c=2 or c=min(2,v).

[488] In one example, K_0 can be computed using parameters β (or β_{tot},...),L (or L_r),M (or M_v,or $M_{v,r}$), similar to the K_0 of Rel-16 codebook. Here the β can be given by at least one of the examples in one or more embodiments described above.

[489]

- In one example, $K_0 = \lceil \beta 2 L M_1 \rceil$.
- In one example, $K_0 = \lceil \beta 2 L M_1 N \rceil$.
- In one example, $K_0 = \left\lceil \beta 2 L \sum_{r=1}^{N} M_{1,r} \right\rceil$.
- In one example, $K_0 = \lceil \beta 2 M_1 \sum_{r=1}^{N} L_r \rceil$.
- In one example, $K_0 = \left\lceil \beta 2 \sum_{r=1}^{N} L_r M_{1,r} \right\rceil$.
- In one example, $K_0 = \lceil \beta_l 2 L M_1 \rceil$.
- In one example, $K_0 = \lceil \beta_l 2 L M_1 N \rceil$.
- In one example, $K_0 = \left\lceil \beta_l 2 L \sum_{r=1}^{N} M_{1,r} \right\rceil$.
- In one example, $K_0 = \lceil \beta_l 2 M_1 \sum_{r=1}^{N} L_r \rceil$.
- In one example, $K_0 = \left\lceil \beta_l 2 \sum_{r=1}^{N} L_r M_{1,r} \right\rceil$.
- In one example, $K_0 = \lceil \beta_{tot} 2 L M_1 \rceil$.
- In one example, $K_0 = \lceil \beta_{tot} 2 L M_1 N \rceil$.
- In one example, $K_0 = \left\lceil \beta_{tot} 2 L \sum_{r=1}^{N} M_{1,r} \right\rceil$.
- In one example, $K_0 = \lceil \beta_{tot} 2 M_1 \sum_{r=1}^{N} L_r \rceil$.
- In one example, $K_0 = \left\lceil \beta_{tot} 2 \sum_{r=1}^{N} L_r M_{1,r} \right\rceil$.
- In one example, $K_0 = \lceil \beta 2 L M_v \rceil$.
- In one example, $K_0 = \lceil \beta 2 L M_v N \rceil$.
- In one example, $K_0 = \left\lceil \beta 2 L \sum_{r=1}^{N} M_{v,r} \right\rceil$.
- In one example, $K_0 = \lceil \beta 2 M_1 \sum_{r=1}^{N} L_r \rceil$.
- In one example, $K_0 = \left\lceil \beta 2 \sum_{r=1}^{N} L_r M_{v,r} \right\rceil$.

[490]

- In one example, $K_0 = \lceil \beta_l 2 L M_v \rceil$.
- In one example, $K_0 = \lceil \beta_l 2 L M_v N \rceil$.
- In one example, $K_0 = \left\lceil \beta_l 2 L \sum_{r=1}^{N} M_{v,r} \right\rceil$.
- In one example, $K_0 = \lceil \beta_l 2 M_v \sum_{r=1}^{N} L_r \rceil$.
- In one example, $K_0 = \left\lceil \beta_l 2 \sum_{r=1}^{N} L_r M_{v,r} \right\rceil$.
- In one example, $K_0 = \lceil \beta_{tot} 2 L M_v \rceil$.
- In one example, $K_0 = \lceil \beta_{tot} 2 L M_v N \rceil$.
- In one example, $K_0 = \left\lceil \beta_{tot} 2 L \sum_{r=1}^{N} M_{v,r} \right\rceil$.
- In one example, $K_0 = \lceil \beta_{tot} 2 M_v \sum_{r=1}^{N} L_r \rceil$.
- In one example, $K_0 = \left\lceil \beta_{tot} 2 \sum_{r=1}^{N} L_r M_{v,r} \right\rceil$.

[491] In one example, any combination (or joint constraint) of upper bounds described in one or more examples described above can be an upper bound for the number of non-zero coefficient.

[492]

- For example, the upper bound can be given by $K_{l,r}^{NZ} = \sum_{i=0}^{2L_r-1} \sum_{f=0}^{M_{v,r}-1} k_{l,i,f,r}^{(3)} \leq K_{0,l,r}$ and $K_l^{NZ} = \sum_{r=1}^{N_{TRP}} \sum_{i=0}^{2L_r-1} \sum_{f=0}^{M_{v,r}-1} k_{l,i,f,r}^{(3)} \leq aK_{0,l}$ (i.e., the upper bound that intersects both of an upper bound described in examples described above).
- For example, the upper bound can be given by $K_{l,r}^{NZ} = \sum_{i=0}^{2L_r-1} \sum_{f=0}^{M_{v,r}-1} k_{l,i,f,r}^{(3)} \leq K_{0,l,r}$ and $K_r^{NZ} = \sum_{l=1}^{v} \sum_{i=0}^{2L_r-1} \sum_{f=0}^{M_{v,r}-1} k_{l,i,f,r}^{(3)} \leq bK_{0,r}$ (i.e., the upper bound that intersects both of an upper bound described in examples described above).
- For example, the upper bound can be given by $K_{l,r}^{NZ} = \sum_{i=0}^{2L_r-1} \sum_{f=0}^{M_{v,r}-1} k_{l,i,f,r}^{(3)} \leq K_{0,l,r}$ and $K^{NZ} = \sum_{l=1}^{v} K_l^{NZ} \leq K_0$ (i.e., the upper bound that intersects both of an upper bound described in examples described above).

[493]

- For example, the upper bound can be given by $K_l^{NZ} = \sum_{r=1}^{N_{TRP}} \sum_{i=0}^{2L_r-1} \sum_{f=0}^{M_{v,r}-1} k_{l,i,f,r}^{(3)} \leq aK_{0,l}$ and $K_r^{NZ} = \sum_{l=1}^{v} \sum_{i=0}^{2L_r-1} \sum_{f=0}^{M_{v,r}-1} k_{l,i,f,r}^{(3)} \leq bK_{0,r}$ (i.e., the upper bound that intersects both of an upper bound described in examples described above).
- For example, the upper bound can be given by $K_l^{NZ} = \sum_{r=1}^{N_{TRP}} \sum_{i=0}^{2L_r-1} \sum_{f=0}^{M_{v,r}-1} k_{l,i,f,r}^{(3)} \leq aK_{0,l}$ and $K^{NZ} = \sum_{l=1}^{v} K_l^{NZ} \leq K_0$ (i.e., the upper bound that intersects both of an upper bound described in examples described above).
- For example, the upper bound can be given by $K_r^{NZ} = \sum_{l=1}^{v} \sum_{i=0}^{2L_r-1} \sum_{f=0}^{M_{v,r}-1} k_{l,i,f,r}^{(3)} \leq bK_{0,r}$ and $K^{NZ} = \sum_{l=1}^{v} K_l^{NZ} \leq K_0$ (i.e., the upper bound that intersects both of an upper bound described in examples described above).

[494] In one example, the upper bound can be rank-dependent v, i.e., an independent upper bound for each rank v. For example, an upper bound described in one or more examples described above is the upper bound for a rank v.

[495] In one example, an upper bound can be rank-pair-specific, i.e., an independent upper bound for each rank-pair. For example, an upper bound described in one or more examples described above is the upper bound for a rank pair (e.g., v=1,2 or v=3,4).

[496]

- For example, for rank pair $v = 1{,}2$, the upper bound can be given by $K_l^{NZ} = \sum_{r=1}^{N_{TRP}} \sum_{i=0}^{2L_r-1} \sum_{f=0}^{M_{v,r}-1} k_{l,i,f,r}^{(3)} \leq aK_{0,l}$ (i.e., an upper bound described in one or more examples described above). For rank pair $v = 3{,}4$, the upper bound can be given by $K_l^{NZ} = \sum_{r=1}^{N_{TRP}} \sum_{i=0}^{2L_r-1} \sum_{f=0}^{M_{v,r}-1} k_{l,i,f,r}^{(3)} \leq aK_{0,l}$ and $K^{NZ} = \sum_{l=1}^{v} K_l^{NZ} \leq K_0$ (i.e., un upper bound described in one or more examples described above).

[497] In frequency division duplex (FDD) systems, DL channel state information is acquired at NW via a CSI feedback mechanism in 5G NR, wherein the NW transmits CSI-RS to a UE, the UE measures the CSI-RS, estimates DL channels, and reports DL CSI to the NW. This CSI feedback mechanism is essential for NW to acquire DL CSI, which is only available at the UE side in FDD, since the NW requires the DL CSI to design SU- or MU-MIMO beamforming.

[498] Currently, AI/ML-based approaches have been developed in many research areas including image processing, robotics, and wireless communications, because AI/ML-based algorithms can develop/identify underlying mapping/function or relationship, (which usually cannot be mathematically modelled) between input and output based on given data, and have already been validated in several areas about their prac-

ticality. Due to the favorable aspect, 3GPP adopts AI/ML for air interface as a study item in Rel-18 in order to find useful use cases for AI/ML-based air-interface.

[499] So far, in FDD, UL channels can be partially exploited to infer DL channels based on channel modeling in a mathematical form, and other remaining information that cannot be inferred based on the modeling is obtained via the CSI feedback mechanism in NR (e.g., using Rel-17 CSI codebook). Or the NW fully relies on the CSI feedback from the UE to acquire DL CSI, e.g., using Rel-15/16 CSI codebook. With AI/ML approaches, however, an underlying function/mapping/relationship between UL and DL channels in a given environment can be trained using UL and DL channel data. This disclosure proposes an air-interface framework wherein NW and UE exchange signals for NW to be able to train an AI/ML-based algorithm such as UL-to-DL channel mapping. In one aspect UL channels are available at NW, but DL channels are available at UE. In order to train an AI/ML-based algorithm for UL-to-DL channel mapping operation, a loss function should be computed based on inferred DL channels (through the AI/ML-based algorithm) and actual DL channels to update parameters of the algorithm in minimizing the loss function. However, the NW is not able to directly access actual DL channels, and thus, several signaling procedures need to be defined to resolve the issue.

[500] This disclosure proposes a framework wherein NW signals the UE to measure DL RS and compute a loss function based on the measured DL RS and some configured/indicated target information, and perform reporting of information for the NW to train its own algorithm.

[501] The framework proposed in the disclosure can be applicable in both TDD and FDD scenarios. Note that even in TDD scenarios, due to hardware impairments in the circuitry of transmit and receive antenna RF chains, UL and DL channel reciprocity may not hold, and thus, NW may need those approaches and can use the framework of this disclosure to train its AI/ML-based UL-to-DL channel mapping algorithm.

[502] FIGURE 19 illustrates an example signal flow 1900 for UL-to-DL channel mapping training according to embodiments of the disclosure. The embodiment of the example signal flow 1900 for UL-to-DL channel mapping training illustrated in FIGURE 19 is for illustration only. FIGURE 19 does not limit the scope of this disclosure to any particular implementation of the example signal flow for UL-to-DL channel mapping training.

[503] In one embodiment, a UE is configured with a "UL-to-DL channel mapping training", wherein the UE is configured to perform UL RS transmission(s), perform DL RS reception(s), receive associated target information, and/or report information for UL-to-DL channel mapping training. This configuration can be performed via higher-layer (RRC) signaling. Optionally, DL RS reception, target information

reception, and training information reporting can be dynamically triggered via L1 or L2 signaling (PDCCH or MAC-CE). Figure 5 shows an illustration of signal flow for the UL-to-DL channel mapping training between NW and UE.

[504] The three steps depicted in the flow diagram of FIGURE 19 (UE transmission of UL RS, UE reception of DL RS and associated target information, and UE reporting of training information) can be configured or activated jointly. Optionally, at least one of the three steps can be configured or activated separately. Optionally, all the three steps can be configured or activated separately. For instance, the UE can be configured or triggered (in case of semi-persistent and aperiodic SRS) to transmit SRS separately (as it normally is). But the reception of the DL RS (such as aperiodic CSI-RS) and target information can be configured and/or triggered jointly with the reporting of the information for the UL-to-DL channel mapping training. In one example, this joint triggering can be performed via one or more dedicated triggering states (higher-layer configured) using the CSI request DCI field. Any combination of the three steps can be configured periodically, semi-persistently, or aperiodically.

[505] In one embodiment, target information X includes quantity(-ies), which is used for UE to determine information (e.g., on loss values) for UL-to-DL channel mapping training.

[506] In one example, target information X includes (target or expected) channel magnitudes (or channel powers or channel coefficient amplitudes). The channel magnitudes are indicated/configured with at least one of the following examples.

[507] ● In one example, channel magnitudes are indicated in a subband (SB) (or other granularity) manner, i.e., each channel magnitude is associated with one corresponding SB. Each of the channel magnitude is selected from a set (e.g., amplitude codebook) and indicated/configured to the UE.

[508] ● In one example, a channel magnitude is indicated in a wideband (WB) manner, i.e., one channel magnitude is associated with one whole configured WB or CSI reporting band. The channel magnitude is selected from a set (e.g., amplitude codebook) and indicated/configured to the UE.

[509] ● In one example, channel magnitudes are indicated in a WB plus SB manner, i.e., one channel magnitude is associated with one whole configured WB, and other channel magnitudes are associated with SBs.

[510] ○ In one example, the channel magnitude associated with the whole configured WB is a reference channel magnitude and the other channel magnitudes associated with SBs are determined in a differential manner based on the reference channel magnitude. For example, the reference channel magnitude X_R is selected/indicated from a set C_{Ref}, and each SB channel magnitude X_i for SB i is defined as $X_i=X_R+\Delta X_i$, where ΔX_i is

selected/indicated from another set C_{SB}. In this example, X_R and $\{\Delta X_i\}$ are configured/ indicated to the UE.

[511] In this example, the UE can be configured with at least one DL RS (e.g., NZP CSI-RS resource or SSB) that is associated with or linked to the target information X.

[512] In one example, target information X includes (target or expected) SNR value(s). The SNR values are indicated/configured with at least one of the following examples.

[513] ● In one example, SNR values are indicated in a SB (or other granularity) manner, i.e., each SNR value is associated with one corresponding SB. Each of the SNR value is selected from a set and indicated/configured to the UE.

[514] ● In one example, a SNR value is indicated in a WB manner, i.e., one SNR value is associated with one whole configured WB. The SNR value is selected from a set and indicated/configured to the UE.

[515] ● In one example, SNR values are indicated in a WB plus SB manner, i.e., one SNR value is associated with one whole configured WB, and other SNR values are associated with SBs.

[516] ○ In one example, the SNR value associated with the whole configured WB is a reference SNR and the other SNR values associated with SBs are determined in a differential manner based on the reference SNR. For example, the reference SNR X_R is selected/indicated from a set C_{Ref}, and each SB SNR X_i for SB i is defined as $X_i=X_R+\Delta X_i$, where ΔX_i is selected/indicated from another set C_{SB}. In this example, X_R and $\{\Delta X_i\}$ are configured/indicated to the UE.

[517] In this example, the UE can be configured with at least one DL RS (e.g., NZP CSI-RS resource or SSB) for signal part of the SNR values that is associated with or linked to the target information X.

[518] In one example, target information X includes (target or expected) SINR value(s). The SINR values are indicated/configured with at least one of the following examples.

[519] ● In one example, SINR values are indicated in a SB (or other granularity) manner, i.e., each SINR value is associated with one corresponding SB. Each of the SINR value is selected from a set and indicated/configured to the UE.

[520] ● In one example, a SINR value is indicated in a WB manner, i.e., one SINR value is associated with one whole configured WB. The SINR value is selected from a set and indicated/configured to the UE.

[521] ● In one example, SINR values are indicated in a WB plus SB manner, i.e., one SINR value is associated with one whole configured WB, and other SINR values are associated with SBs.

[522] ○ In one example, the SINR value associated with the whole configured WB is a

reference SINR and the other SINR values associated with SBs are determined in a differential manner based on the reference SINR. For example, the reference SINR X_R is selected/indicated from a set C_{Ref}, and each SB SINR X_i for SB i is defined as $X_i=X_R+\Delta X_i$, where ΔX_i is selected/indicated from another set C_{SB}. In this example, X_R and $\{\Delta X_i\}$ are configured/indicated to the UE.

[523] In this example, the UE can be configured with at least one DL RS (e.g., NZP CSI-RS resource or SSB) for signal part of the SINR value, and at least one interference RS (e.g., NZP CSI-RS resource or CSI-IM resource) for signal part of the SINR value, that are associated with or linked to the target information X.

[524] In one example, target information X includes (target or expected) RSRP value(s). The RSRP values are indicated/configured with at least one of the following examples.

[525] ● In one example, RSRP values are indicated in a SB (or other granularity) manner, i.e., each RSRP value is associated with one corresponding SB. Each of the RSRP value is selected from a set and indicated/configured to the UE.

[526] ● In one example, a RSRP value is indicated in a WB manner, i.e., one RSRP value is associated with one whole configured WB. The RSRP value is selected from a set and indicated/configured to the UE.

[527] ● In one example, RSRP values are indicated in a WB plus SB manner, i.e., one RSRP value is associated with one whole configured WB, and other RSRP values are associated with SBs.

[528] ○ In one example, the RSRP value associated with the whole configured WB is a reference RSRP and the other RSRP values associated with SBs are determined in a differential manner based on the reference RSRP. For example, the reference RSRP X_R is selected/indicated from a set C_{Ref}, and each SB RSRP X_i for SB i is defined as $X_i=X_R+\Delta X_i$, where ΔX_i is selected/indicated from another set C_{SB}. In this example, X_R and $\{\Delta X_i\}$ are configured/indicated to the UE.

[529] In one example, target information X includes (target or expected) RSRQ value(s). The RSRQ values are indicated/configured with at least one of the following examples.

[530] ● In one example, RSRQ values are indicated in a SB (or other granularity) manner, i.e., each RSRQ value is associated with one corresponding SB. Each of the RSRQ value is selected from a set and indicated/configured to the UE.

[531] ● In one example, a RSRQ value is indicated in a WB manner, i.e., one RSRQ value is associated with one whole configured WB. The RSRQ value is selected from a set and indicated/configured to the UE.

[532] ● In one example, RSRQ values are indicated in a WB plus SB manner, i.e., one RSRQ value is associated with one whole configured WB, and other RSRQ values are

associated with SBs.

[533] ○ In one example, the RSRQ value associated with the whole configured WB is a reference RSRQ and the other RSRQ values associated with SBs are determined in a differential manner based on the reference RSRQ. For example, the reference RSRQ X_R is selected/indicated from a set C_{Ref}, and each SB RSRQ X_i for SB i is defined as $X_i = X_R + \Delta X_i$, where ΔX_i is selected/indicated from another set C_{SB}. In this example, X_R and $\{\Delta X_i\}$ are configured/indicated to the UE.

[534] In one embodiment, target information X is indicated/configured via higher-layer parameter, or MAC-CE, or DCI (PDCCH), or PDSCH, or a combination of at least two of RRC, MAC CE, and DCI.

[535] In one embodiment, target information X is associated with the DL RS (e.g., NZP CSI-RS or SSB), and the number of values in the target information X is determined based on report configuration for the DL RS (e.g., CSI report). For example, a CSI report configuration includes reportFreqConfiguration to configure a plurality of SBs or WB CQIs/PMIs report. Similarly, the number of values in target information X corresponds to the number of SBs configured in a report configuration for the DL RS associated with the 'UL-to-DL mapping training' operation.

[536] FIGURE 20 illustrates an example block diagram 2000 where a UL channel to DL channel mapping is trained through over-the-air (OTA) signaling according to embodiments of the disclosure. The embodiment of the example block diagram 2000 where a UL channel to DL channel mapping is trained through over-the-air (OTA) signaling illustrated in FIGURE 20 is for illustration only. FIGURE 20 does not limit the scope of this disclosure to any particular implementation of the example block diagram 2000 where a UL channel to DL channel mapping is trained through over-the-air (OTA) signaling.

[537] In one embodiment, a UE is configured to perform DL RS reception (e.g., NZP CSI-RS or SSB) with N+1 antenna ports, where N is a number of (e.g., CSI-RS) antenna ports of the DL RS for UL-to-DL channel training. In one example, the N+1 ports can be partitioned into two groups, one group having N ports and the other group having one port. The group having N ports is for measuring (pure) DL channel, and the other group having one port is for measuring DL channel, which is the resultant DL channel when NW designs beamformed DL RS based on inferred DL channel from its AI/ML UL-to-DL channel mapping algorithm. In one example, N+1 antenna ports (e.g., CSI-RS ports) can belong two separate CSI-RS resources, one with N ports and another with 1 port. The configuration of the two resources can be separate (e.g., via two separate RRC configuration) or joint (e.g., one joint RRC configuration). In one example, two separate CSI-RS resources are linked or associated for UE to compute

(pure) DL channels and beamformed DL channels correctly.

[538] In one example, for the group having N ports, the NW transmits (non-beamformed) CSI-RS, and the UE measures the CSI-RS and estimates DL channel $h_{DL,k}$ for SB k (or other frequency unit k), (we assume that the UE has one antenna port for the sake of simplicity but it can be extended to the case of multiple antenna ports at the UE), and for the group having one port, the NW transmits beamformed CSI-RS where matched-filter (MF) beamforming is designed based on the inferred DL channel, i.e., $\boldsymbol{v}_k = \alpha_k \widehat{\boldsymbol{h}}_{DL,k}$, where α_k is a power scaling factor and $\widehat{\boldsymbol{h}}_{DL,k}$ is the inferred DL channel from an AI/ML algorithm at the NW, and the UE measures the beamformed CSI-RS and estimates the resultant DL channel $\alpha_k \boldsymbol{h}_{DL,k}^H \widehat{\boldsymbol{h}}_{DL,k}$. Note that once the UE estimates $h_{DL,k}$ and $\alpha_k \boldsymbol{h}_{DL,k}^H \widehat{\boldsymbol{h}}_{DL,k}$, the UE can compute cosine similarity between $h_{DL,k}$ and $\widehat{\boldsymbol{h}}_{DL,k}$ based on simple manipulation, $CS(\boldsymbol{h}_{DL,k}, \widehat{\boldsymbol{h}}_{DL,k}) = \frac{|\boldsymbol{h}_{DL,k}^H \widehat{\boldsymbol{h}}_{DL,k}|}{||\boldsymbol{h}_{DL,k}|| \cdot ||\widehat{\boldsymbol{h}}_{DL,k}||}$ provided that a magnitude value of $||\alpha_k \widehat{\boldsymbol{h}}_{DL,k}||$ (i.e., a form of channel magnitude in example I.1.1) is informed by NW.

[539] Note that the cosine similarity is one of the popular loss functions being used in AI/ML-based algorithm in order to update parameters. Therefore, for example, once the UE computes the cosine similarities for all SBs as loss values, the UE reports those values (or gradient values corresponding to those values) to the NW, and the NW can update parameters of its own AI/ML-based algorithm based on the loss values.

[540] In another example, a mean-squared error (MSE) can be used for loss function and the UE computes loss values based on the DL-RS measurement and/or target information. For example, for the MSE of SNR for loss function, the UE may compute it: $MSE(SNR_{actual\ DL}, SNR_{inferred\ DL}) = \left(\frac{||\boldsymbol{h}_{DL,k}||^2}{N} - \frac{|\boldsymbol{h}_{DL,k}^H \widehat{\boldsymbol{h}}_{DL,k}|^2}{N}\right)^2$ where N is a noise power. Once the UE compute the loss function, the UE reports the loss value (or gradient corresponding to the loss value) to the NW to update its parameters in minimizing loss function. As an example, a relevant block diagram to update a deep neural network (DNN) in the NW through over-the-air (OTA) signaling is described in FIGURE 20. As shown in FIGURE 20, a mapping f_1 (UL CH;θ_1) from UL channel to DL channel using a DNN can be trained using reported information from the UE, for example, an MSE of SNR between the SNR based on the actual DL channel and the

SNR based on the inferred DL channel (or gradient value(s) of an MSE of SNR). Since the NW transmits N+1-port CSI-RS to the UE in this example, the UE can compute $\boldsymbol{h}_{DL,k}$ and $\boldsymbol{h}_{DL,k}^H\widehat{\boldsymbol{h}}_{DL,k}$ to find the MSE of SNR between them, and report the MSE of SNR (or the gradient of it) to the NW.

[541] In another embodiment, a UE is configured to perform DL RS reception with one antenna port for AI/ML training. In one example, a NW transmits beamformed DL RS (e.g., CSI-RS) where matched-filter (MF) beamforming is designed based on the inferred DL channel, i.e., $\boldsymbol{v}_k = \alpha_k\widehat{\boldsymbol{h}}_{DL,k}$, where α_k is a power scaling factor, and the UE measures the beamformed CSI-RS and estimates the resultant DL channel $\alpha_k\boldsymbol{h}_{DL,k}^H\widehat{\boldsymbol{h}}_{DL,k}$. Note that once the UE estimates $\alpha_k\boldsymbol{h}_{DL,k}^H\widehat{\boldsymbol{h}}_{DL,k}$, the UE can compute (approximate) cosine similarity between $\boldsymbol{h}_{DL,k}$ and $\widehat{\boldsymbol{h}}_{DL,k}$ based on simple manipulation $\widehat{CS}(\boldsymbol{h}_{DL,k},\widehat{\boldsymbol{h}}_{DL,k}) = \frac{|\boldsymbol{h}_{DL,k}^H\widehat{\boldsymbol{h}}_{DL,k}|}{||\widehat{\boldsymbol{h}}_{DL,k}|| \cdot ||\widehat{\boldsymbol{h}}_{DL,k}||}$ provided that a channel power value of $||\alpha_k|| \cdot ||\widehat{\boldsymbol{h}}_{DL,k}||^2$ (i.e., a form of channel power as described above) is informed by NW. Although $||\widehat{\boldsymbol{h}}_{DL,k}||$ is used for the normalized factor for $h_{DL,k}$ in the denominator instead of $||\boldsymbol{h}_{DL,k}||$, the (approximate) cosine similarity between $h_{DL,k}$ and $\widehat{\boldsymbol{h}}_{DL,k}$ can be utilized assuming $||\boldsymbol{h}_{DL,k}|| \approx ||\widehat{\boldsymbol{h}}_{DL,k}||$. This embodiment is useful in terms of resource overhead for DL RS, since the DL RS only associates with one port (cf. N+1 ports in the previous embodiment).

[542] In one embodiment, a UE computes loss value(s) (or gradient values of loss function) based on the DL RS measurement and target information, and performs reporting of information for (AI/ML) training. In one example, the training information in the report includes the loss value(s). In one example, the training information in the report includes DL CSI similar to CSI report. In another example, the training information in the report includes assistance information such as UE position, UE speed, and/or local information available at the UE. In one example, any combination of the above information is included in the training information of the report.

[543] In one example, a loss value (or gradient values corresponding a loss value) is reported in a WB manner, i.e., one value is reported for all SBs in the configured reporting band (or CSI reporting band).

[544] In one example, loss values (or gradient values corresponding loss values) are reported in a SB manner, i.e., one value is reported for each SB in the configured

reporting band (or CSI reporting band).

[545] In one example, loss values (or gradient values corresponding loss values) are reported in another frequency unit (other than SB) such as subcarrier or multiple of subcarriers, i.e., one value is reported for each frequency unit in the configured reporting band (or CSI reporting band).

[546] In one example, loss values (or gradient values corresponding loss values) are selected from a set S comprising 2^{n_a} points in [0,1], where the set S is represented using a n_a-bit indicator. In one example, n_a-bit is fixed. In another example, n_a-bit is configured via higher-layer parameter, MAC-CE, or DCI.

[547] - In one example, the set includes equidistance points in [0,1] in log-scale (dB-scale).

[548] - In one example, the set includes equidistance points in [0,1] in linear-scale.

[549] In one example, the loss value is computed based on cosine similarity (e.g., as described above), which belongs to the interval [0,1].

[550] In one example, loss values (or gradient values corresponding loss values) are selected from a set S comprising 2^{n_a} points in [-1,1], where the set S is represented using a n_a-bit indicator. In one example, n_a-bit is fixed. In another example, n_a-bit is configured via higher-layer parameter, MAC-CE, or DCI.

[551] - In one example, the set includes 2^{n_a-1} equidistance points in [0,1] in log-scale (dB-scale) and the points that derive from -1 times 2^{n_a-1} equidistance points in [0,1] in log-scale (for getting the points in the interval [-1,0]).

[552] - In one example, the set includes equidistance points in [-1,1] in linear-scale.

[553] In one embodiment, a UE is configured to report information for validation, and the UE computes loss value(s) or other metric based on the measured DL RS and target information, and performs reporting of information for validation. Based on a criterion, the UE determines the information in the reporting. In one example, the criterion is fixed or configured via higher-layer parameter, MAC-CE, or DCI. As an example, the criterion is given by that cosine similarity (or loss value) is greater than or equal to X_{TH}, where $X_{TH} \leq 1$ is a threshold value. In one example,

[554] X_{TH} is fixed or configured.

[555] In one example, the validation information in the report includes a 1-bit indicator to inform the loss value(s) is satisfied with a criterion or not. Optionally, if the loss value is not satisfied with the criterion, the validation information includes the loss value(s), where the loss value(s) is determined in examples of embodiments as described above.

[556] In another example, the validation information in the report includes DL CSI similar to CSI report. In another example, the validation information in the report includes assistance information such as UE position, UE speed, and/or local information available

at the UE. In one example, any combination of the above information is included in the validation information of the report.

[557] FIGURE 21 illustrates a structure of a base station according to an embodiment of the disclosure.

[558] As shown in FIGURE 21, the base station according to an embodiment may include a transceiver 2110, a memory 2120, and a processor 2130. The transceiver 2110, the memory 2120, and the processor 2130 of the base station may operate according to a communication method of the base station described above. However, the components of the base station are not limited thereto. For example, the base station may include more or fewer components than those described above. In addition, the processor 2130, the transceiver 2110, and the memory 2120 may be implemented as a single chip. Also, the processor 2130 may include at least one processor. Furthermore, the base station of FIGURE 21 corresponds to the gNB 102 of the FIGURE 2.

[559] The transceiver 2110 collectively refers to a base station receiver and a base station transmitter, and may transmit/receive a signal to/from a terminal(UE) or a network entity. The signal transmitted or received to or from the terminal or a network entity may include control information and data. The transceiver 2110 may include a RF transmitter for up-converting and amplifying a frequency of a transmitted signal, and a RF receiver for amplifying low-noise and down-converting a frequency of a received signal. However, this is only an example of the transceiver 2110 and components of the transceiver 2110 are not limited to the RF transmitter and the RF receiver.

[560] Also, the transceiver 2110 may receive and output, to the processor 2130, a signal through a wireless channel, and transmit a signal output from the processor 2130 through the wireless channel.

[561] The memory 2120 may store a program and data required for operations of the base station. Also, the memory 2120 may store control information or data included in a signal obtained by the base station. The memory 2120 may be a storage medium, such as read-only memory (ROM), random access memory (RAM), a hard disk, a CD-ROM, and a DVD, or a combination of storage media.

[562] The processor 2130 may control a series of processes such that the base station operates as described above. For example, the transceiver 2110 may receive a data signal including a control signal transmitted by the terminal, and the processor 2130 may determine a result of receiving the control signal and the data signal transmitted by the terminal.

[563] FIGURE 22 illustrates a structure of a UE according to an embodiment of the disclosure.

[564] As shown in FIGURE 22, the UE according to an embodiment may include a transceiver 2210, a memory 2220, and a processor 2230. The transceiver 2210, the

memory 2220, and the processor 2230 of the UE may operate according to a communication method of the UE described above. However, the components of the UE are not limited thereto. For example, the UE may include more or fewer components than those described above. In addition, the processor 2230, the transceiver 2210, and the memory 2220 may be implemented as a single chip. Also, the processor 2230 may include at least one processor. Furthermore, the UE of FIGURE 22 corresponds to the UE 116 of the FIGURE 3.

[565] The transceiver 2210 collectively refers to a UE receiver and a UE transmitter, and may transmit/receive a signal to/from a base station or a network entity. The signal transmitted or received to or from the base station or a network entity may include control information and data. The transceiver 2210 may include a RF transmitter for up-converting and amplifying a frequency of a transmitted signal, and a RF receiver for amplifying low-noise and down-converting a frequency of a received signal. However, this is only an example of the transceiver 2210 and components of the transceiver 2210 are not limited to the RF transmitter and the RF receiver.

[566] Also, the transceiver 2210 may receive and output, to the processor 2230, a signal through a wireless channel, and transmit a signal output from the processor 2230 through the wireless channel.

[567] The memory 2220 may store a program and data required for operations of the UE. Also, the memory 2220 may store control information or data included in a signal obtained by the UE. The memory 2220 may be a storage medium, such as read-only memory (ROM), random access memory (RAM), a hard disk, a CD-ROM, and a DVD, or a combination of storage media.

[568] The processor 2230 may control a series of processes such that the UE operates as described above. For example, the transceiver 2210 may receive a data signal including a control signal transmitted by the base station or the network entity, and the processor 2230 may determine a result of receiving the control signal and the data signal transmitted by the base station or the network entity.

[569] In one embodiment, a user equipment (UE) comprising: a transceiver configured to receive a configuration about a channel state information (CSI) report, the configuration including information about (i) N>1 groups of CSI reference signal (CSI-RS) ports and (ii) a codebook, wherein: the codebook includes a spatial-domain (SD) basis component, a frequency-domain (FD) basis component, and a coefficient component, the SD basis component includes L_r basis vectors for each group r=1,...,N, the FD basis component includes M_v basis vectors, and the coefficient component includes coefficients associated with (SD, FD) basis vector pairs; and a processor operably coupled to the transceiver, the processor, based on the configuration, configured to: measure the N groups of CSI-RS ports, and determine the SD basis

component, the FD basis component, and the coefficient component such that K_1 coefficients are non-zero and remaining coefficients are zero, where $K_1 \leq \sum_{r=1}^{N}(2L_r M_v)$, wherein the transceiver is further configured to transmit the CSI report including an indicator indicating locations of non-zero coefficients.

[570] In one embodiment, wherein each of the N groups of CSI-RS ports is associated with a respective non-zero power (NZP) CSI-RS resource.

[571] In one embodiment, wherein the M_v basis vectors are either common for all groups or independent for each group r=1,...,N.

[572] In one embodiment, wherein the indicator is a bitmap indicator whose non-zero bits identify which coefficients are non-zero, and is given by, for $l = 1, \dots, \upsilon:\ i_{1,7,l} = \left[k_{l,0}^{(3)} \dots k_{l,M_\upsilon-1}^{(3)}\right]$, $k_{l,f}^{(3)} = \left[k_{l,0,f}^{(3)} \dots k_{l,2L_r-1,f}^{(3)}\right]$, $k_{l,i,f}^{(3)} = \left[k_{l,i,f,1}^{(3)} \dots k_{l,i,f,N}^{(3)}\right]$, $k_{l,i,f,r}^{(3)} \in \{0,1\}$, where for an r-th group: L_r is a number of SD basis vectors, M_υ is a number of FD basis vectors, υ is a number of layers, and $i = 0,1,\cdots,2L_r - 1$ and $f = 0,1,\dots,M_\upsilon - 1$.

[573] In one embodiment, wherein a maximum number of non-zero coefficients across all groups is constrained by K_0, and is given by: $K_{1,l} = \sum_{r=1}^{N}\sum_{i=0}^{2L_r-1}\sum_{f=0}^{M_\upsilon-1} k_{l,i,f,r}^{(3)} \leq K_0$ for layer $l = 1,\dots,\upsilon$, where the constrained value of K_0 is given by either $K_0 = \lceil \beta 2M_1 \sum_{r=1}^{N} L_r \rceil$ or $K_0 = \lceil \beta 2M_\upsilon \sum_{r=1}^{N} L_r \rceil$, where $\beta \leq 1$ is a ratio value.

[574] In one embodiment, wherein a total number of non-zero coefficients summed across all layers is constrained by $2K_0$, and is given by: $\sum_{l=1}^{\upsilon} K_{1,l} \leq 2K_0$.

[575] In one embodiment, wherein a maximum number of non-zero coefficients for each group r is constrained by a value $K_{0,r}$, given by: $K_{l,r}^{NZ} = \sum_{i=0}^{2L_r-1}\sum_{f=0}^{M_\upsilon-1} k_{l,i,f,r}^{(3)} \leq K_{0,r}$ for layer $l = 1,\dots,\upsilon$, where the constrained value of $K_{0,r}$ is given by either $K_{0,r} = \lceil \beta_r 2M_1 L_r \rceil$ or $K_0 = \lceil \beta_r 2M_\upsilon L_r \rceil$, where $\beta_r \leq 1$ is a ratio value.

[576] In one embodiment, wherein: a total number of non-zero coefficients summed across all layers for each group r is constrained by a value $2K_{0,r}$ given by $K_r^{NZ} = \sum_{l=1}^{\upsilon} K_{l,r}^{NZ} \leq 2K_{0,r}$, and β_r values are common for all groups, $\beta_r = \beta, \forall r = 1,\dots,N$.

[577] In one embodiment, a base station (BS) comprising: a processor configured to generate a configuration about a channel state information (CSI) report, the configuration including information about (i) N>1 groups of CSI reference signal

(CSI-RS) ports and (ii) a codebook, wherein: the codebook includes a spatial-domain (SD) basis component, a frequency-domain (FD) basis component, and a coefficient component, the SD basis component includes L_r basis vectors for each group r=1,...,N, the FD basis component includes M_v basis vectors, and the coefficient component includes coefficients associated with (SD, FD) basis vector pairs; and a transceiver operably coupled to the processor, the transceiver configured to: transmit the configuration; transmit on the N groups of CSI-RS ports; and receive the CSI report including an indicator indicating locations of non-zero coefficients from among the SD basis component, the FD basis component, and the coefficient component that are based on the N groups of CSI-RS ports, wherein K_1 coefficients are non-zero and remaining coefficients are zero, where $K_1 \leq \sum_{r=1}^{N}(2L_r M_v)$.

[578] In one embodiment, wherein each of the N groups of CSI-RS ports is associated with a respective non-zero power (NZP) CSI-RS resource.

[579] In one embodiment, wherein the M_v basis vectors are either common for all groups or independent for each group r=1,...,N.

[580] In one embodiment, wherein the indicator is a bitmap indicator whose non-zero bits identify which coefficients are non-zero, and is given by, for $l = 1, \dots, \upsilon:\ i_{1,7,l} = \left[k_{l,0}^{(3)} \dots k_{l,M_\upsilon-1}^{(3)}\right],\ k_{l,f}^{(3)} = \left[k_{l,0,f}^{(3)} \dots k_{l,2L_n-1,f}^{(3)}\right],\ k_{l,i,f}^{(3)} = \left[k_{l,i,f,1}^{(3)} \dots k_{l,i,f,N}^{(3)}\right]$, $k_{l,i,f,r}^{(3)} \in \{0,1\}$ where for an r-th group: L_r is a number of SD basis vectors, M_υ is a number of FD basis vectors, υ is a number of layers, and $i = 0,1,\cdots,2L_r - 1$ and $f = 0,1,\dots,M_\upsilon - 1$.

[581] In one embodiment, wherein a maximum number of non-zero coefficients across all groups is constrained by K_0, and is given by: $K_{1,l} = \sum_{r=1}^{N}\sum_{i=0}^{2L_r-1}\sum_{f=0}^{M_\upsilon-1} k_{l,i,f,r}^{(3)} \leq K_0$ for layer $l = 1, \dots, \upsilon$, where the constrained value of K_0 is given by either $K_0 = \lceil \beta 2M_1 \sum_{r=1}^{N} L_r \rceil$ or $K_0 = \lceil \beta 2M_\upsilon \sum_{r=1}^{N} L_r \rceil$, where $\beta \leq 1$ is a ratio value.

[582] In one embodiment, wherein a total number of non-zero coefficients summed across all layers is constrained by $2K_0$, and is given by: $\sum_{l=1}^{\upsilon} K_{1,l} \leq 2K_0$.

[583] In one embodiment, wherein a maximum number of non-zero coefficients for each group r is constrained by a value $K_{0,r}$, given by: $K_{l,r}^{NZ} = \sum_{i=0}^{2L_r-1}\sum_{f=0}^{M_\upsilon-1} k_{l,i,f,r}^{(3)} \leq K_{0,r}$ for layer $l = 1, \dots, \upsilon$, where the constrained value of $K_{0,r}$ is given by either $K_{0,r} = \lceil \beta_r 2M_1 L_r \rceil$ or $K_0 = \lceil \beta_r 2M_\upsilon L_r \rceil$, where $\beta_r \leq 1$ is a ratio value.

[584] In one embodiment, wherein: a total number of non-zero coefficients summed across all layers for each group r is constrained by a value $2K_{0,r}$ given by $K_r^{NZ} = \sum_{l=1}^{v} K_{l,r}^{NZ} \leq 2K_{0,r}$, and β_r values that are common for all groups, $\beta_r = \beta, \forall r = 1, \dots, N$.

[585] In one embodiment, a method for operating a user equipment (UE), the method comprising: receiving a configuration about a channel state information (CSI) report, the configuration including information about (i) N>1 groups of CSI reference signal (CSI-RS) ports and (ii) a codebook, wherein: the codebook includes a spatial-domain (SD) basis component, a frequency-domain (FD) basis component, and a coefficient component, the SD basis component includes L_r basis vectors for each group r=1,...,N, the FD basis component includes M_v basis vectors, and the coefficient component includes coefficients associated with (SD, FD) basis vector pairs; based on the configuration: measuring the N groups of CSI-RS ports; and determining the SD basis component, the FD basis component, and the coefficient component such that K_1 coefficients are non-zero and remaining coefficients are zero, where $K_1 \leq \sum_{r=1}^{N}(2L_r M_v)$; and transmitting the CSI report including an indicator indicating a location of non-zero coefficients.

[586] In one embodiment, wherein each of the N groups of CSI-RS ports is associated with a respective non-zero power (NZP) CSI-RS resource.

[587] In one embodiment, wherein the M_v basis vectors are either common for all groups or independent for each group r=1,...,N.

[588] In one embodiment, wherein the indicator is a bitmap indicator whose non-zero bits identify which coefficients are non-zero, and is given by, for $l = 1, \dots, v$: $i_{1,7,l} = \left[k_{l,0}^{(3)} \dots k_{l,M_v-1}^{(3)}\right]$, $k_{l,f}^{(3)} =$, $k_{l,i,f}^{(3)} = \left[k_{l,i,f,1}^{(3)} \dots k_{l,i,f,N}^{(3)}\right]$, $k_{l,i,f,r}^{(3)} \in \{0,1\}$ where for an r-th group: L_r is a number of SD basis vectors, M_v is a number of FD basis vectors, and v is a number of layers, and $i = 0,1,\cdots,2L_r - 1$ and $f = 0,1,\dots,M_v - 1$.

[589] Any of the above variation embodiments can be utilized independently or in combination with at least one other variation embodiment.

[590] Those skilled in the art will understand that the various illustrative logical blocks, modules, circuits, and steps described in this application may be implemented as hardware, software, or a combination of both. To clearly illustrate this interchangeability between hardware and software, various illustrative components, blocks, modules, circuits, and steps are generally described above in the form of their functional sets. Whether such function sets are implemented as hardware or software depends on the specific application and the design constraints imposed on the overall

system. Technicians may implement the described functional sets in different ways for each specific application, but such design decisions should not be interpreted as causing a departure from the scope of this application.

[591] The above flowcharts illustrate example methods that can be implemented in accordance with the principles of the disclosure and various changes could be made to the methods illustrated in the flowcharts herein. For example, while shown as a series of steps, various steps in each figure could overlap, occur in parallel, occur in a different order, or occur multiple times. In another example, steps may be omitted or replaced by other steps.

[592] Although the figures illustrate different examples of user equipment, various changes may be made to the figures. For example, the user equipment can include any number of each component in any suitable arrangement. In general, the figures do not limit the scope of this disclosure to any particular configuration(s). Moreover, while figures illustrate operational environments in which various user equipment features disclosed in this patent document can be used, these features can be used in any other suitable system.

[593] Although the disclosure has been described with exemplary embodiments, various changes and modifications may be suggested to one skilled in the art. It is intended that the disclosure encompass such changes and modifications as fall within the scope of the appended claims. None of the description in this application should be read as implying that any particular element, step, or function is an essential element that must be included in the claims scope. The scope of patented subject matter is defined by the claims.

[594] The various illustrative logic blocks, modules, and circuits described in this application may be implemented or performed by a general purpose processor, a Digital Signal Processor (DSP), an Application Specific Integrated Circuit (ASIC), a Field Programmable Gate Array (FPGA) or other programmable logic devices, discrete gates or transistor logics, discrete hardware components, or any combination thereof designed to perform the functions described herein. The general purpose processor may be a microprocessor, but in an alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. The processor may also 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 co-operating with a DSP core, or any other such configuration.

[595] The steps of the method or algorithm described in this application may be embodied directly in hardware, in a software module executed by a processor, or in a combination thereof. The software module may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, register, hard disk, removable

disk, or any other form of storage medium known in the art. A storage medium is coupled to a processor to enable the processor to read and write information from/to the storage media. In an alternative, the storage medium may be integrated into the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a user terminal. In an alternative, the processor and the storage medium may reside in the user terminal as discrete components.

[596] In one or more designs, the functions may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, each function may be stored as one or more pieces of instructions or codes on a computer-readable medium or delivered through it. The computer-readable medium includes both a computer storage medium and a communication medium, the latter including any medium that facilitates the transfer of computer programs from one place to another. The storage medium may be any available medium that can be accessed by a general purpose or special purpose computer.

[597] While the disclosure has been shown and described with reference to various embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the disclosure as defined by the appended claims and their equivalents.

Claims

[Claim 1] A user equipment (UE) in wireless communication system, the UE comprising:

a transceiver configured to receive a configuration about a channel state information (CSI) report, the configuration including information about (i) N>1 groups of CSI reference signal (CSI-RS) ports and (ii) a codebook, wherein:

the codebook includes a spatial-domain (SD) basis component, a frequency-domain (FD) basis component, and a coefficient component,

the SD basis component includes L_r basis vectors for each group r=1,...,N,

the FD basis component includes M_v basis vectors, and

the coefficient component includes coefficients associated with (SD, FD) basis vector pairs; and

a processor operably coupled to the transceiver, the processor, based on the configuration, configured to:

measure the N groups of CSI-RS ports, and

determine the SD basis component, the FD basis component, and the coefficient component such that K_1 coefficients are non-zero and remaining coefficients are zero, where $K_1 \leq \sum_{r=1}^{N}(2L_rM_v)$,

wherein the transceiver is further configured to transmit the CSI report including an indicator indicating locations of non-zero coefficients.

[Claim 2] The UE of Claim 1, wherein each of the N groups of CSI-RS ports is associated with a respective non-zero power (NZP) CSI-RS resource.

[Claim 3] The UE of Claim 1, wherein the M_v basis vectors are either common for all groups or independent for each group r=1,...,N.

[Claim 4] The UE of Claim 1, wherein the indicator is a bitmap indicator whose non-zero bits identify which coefficients are non-zero, and is given by, for $l=1,\ldots,\upsilon$:

$$i_{1,7,l} = \left[k_{l,0}^{(3)} \ldots k_{l,M_v-1}^{(3)}\right]$$

$$k_{l,f}^{(3)} = \left[k_{l,0,f}^{(3)} \ldots k_{l,2L_r-1,f}^{(3)}\right]$$

$$k_{l,i,f}^{(3)} = \left[k_{l,i,f,1}^{(3)} \ldots k_{l,i,f,N}^{(3)}\right]$$

$$k_{l,i,f,r}^{(3)} \in \{0,1\}$$

where for an r-th group:
L_r is a number of SD basis vectors,
M_υ is a number of FD basis vectors,
υ is a number of layers, and
$i=0,1,...,2L_r-1$ and $f=0,1,\ldots,M_\upsilon-1$.

[Claim 5] The UE of Claim 4, wherein a maximum number of non-zero coefficients across all groups is constrained by K_0, and is given by:

$$K_{1,l} = \sum_{r=1}^{N} \sum_{i=0}^{2L_r-1} \sum_{f=0}^{M_\upsilon-1} k_{l,i,f,r}^{(3)} \leq K_0 \text{ for layer } l = 1, \ldots, \upsilon,$$

where the constrained value of K_0 is given by either $K_0 = \lceil \beta 2M_1 \sum_{r=1}^{N} L_r \rceil$ or $K_0 = \lceil \beta 2M_\upsilon \sum_{r=1}^{N} L_r \rceil$, where $\beta \leq 1$ is a ratio value.

[Claim 6] The UE of Claim 5, wherein a total number of non-zero coefficients summed across all layers is constrained by $2K_0$, and is given by:

$$\sum_{l=1}^{\upsilon} K_{1,l} \leq 2K_0 .$$

[Claim 7] The UE of Claim 4, wherein a maximum number of non-zero coefficients for each group r is constrained by a value $K_{0,r}$, given by:

$$K_{l,r}^{NZ} = \sum_{i=0}^{2L_r-1} \sum_{f=0}^{M_\upsilon-1} k_{l,i,f,r}^{(3)} \leq K_{0,r} \text{ for layer } l = 1, \ldots, \upsilon,$$

where the constrained value of $K_{0,r}$ is given by either $K_{0,r} = \lceil \beta_r 2M_1 L_r \rceil$ or $K_0 = \lceil \beta_r 2M_\upsilon L_r \rceil$, where $\beta_r \leq 1$ is a ratio value.

[Claim 8] The UE of Claim 7, wherein:
a total number of non-zero coefficients summed across all layers for each group r is constrained by a value $2K_{0,r}$ given by

$$K_r^{NZ} = \sum_{l=1}^{\upsilon} K_{l,r}^{NZ} \leq 2K_{0,r} \text{, and}$$

β_r values are common for all groups, $\beta_r=\beta, \forall r=1,\ldots,N$.

[Claim 9] A base station (BS) in wireless communication system, the BS comprising:
a processor configured to generate a configuration about a channel state information (CSI) report, the configuration including information about (i) N>1 groups of CSI reference signal (CSI-RS) ports and (ii) a codebook, wherein:
the codebook includes a spatial-domain (SD) basis component, a frequency-domain (FD) basis component, and a coefficient component,
the SD basis component includes L_r basis vectors for each group $r=1,...,N$,
the FD basis component includes M_v basis vectors, and
the coefficient component includes coefficients associated with (SD,

FD) basis vector pairs; and
a transceiver operably coupled to the processor, the transceiver configured to:
transmit the configuration;
transmit on the N groups of CSI-RS ports; and
receive the CSI report including an indicator indicating locations of non-zero coefficients from among the SD basis component, the FD basis component, and the coefficient component that are based on the N groups of CSI-RS ports,
wherein K_1 coefficients are non-zero and remaining coefficients are zero, where $K_1 \leq \sum_{r=1}^{N}(2L_r M_v)$.

[Claim 10] The BS of Claim 9, wherein each of the N groups of CSI-RS ports is associated with a respective non-zero power (NZP) CSI-RS resource.

[Claim 11] The BS of Claim 9, wherein the M_v basis vectors are either common for all groups or independent for each group r=1,...,N.

[Claim 12] The BS of Claim 9, wherein the indicator is a bitmap indicator whose non-zero bits identify which coefficients are non-zero, and is given by, for l=1,…,υ:

$$i_{1,7,l} = \left[k_{l,0}^{(3)} \dots k_{l,M_v-1}^{(3)}\right]$$

$$k_{l,f}^{(3)} = \left[k_{l,0,f}^{(3)} \dots k_{l,2L_n-1,f}^{(3)}\right]$$

$$k_{l,i,f}^{(3)} = \left[k_{l,i,f,1}^{(3)} \dots k_{l,i,f,N}^{(3)}\right]$$

$$k_{l,i,f,r}^{(3)} \in \{0,1\}$$

where for an r-th group:
L_r is a number of SD basis vectors,
$M_υ$ is a number of FD basis vectors,
υ is a number of layers, and
i=0,1,...$2L_r$-1 and f=0,1,…,$M_υ$-1.

[Claim 13] The BS of Claim 12, wherein a maximum number of non-zero coefficients across all groups is constrained by K_0, and is given by:

$K_{1,l} = \sum_{r=1}^{N}\sum_{i=0}^{2L_r-1}\sum_{f=0}^{M_v-1} k_{l,i,f,r}^{(3)} \leq K_0$ for layer $l = 1, \dots, \upsilon$,

where the constrained value of K_0 is given by either $K_0 = \lceil \beta 2M_1 \sum_{r=1}^{N} L_r \rceil$ or $K_0 = \lceil \beta 2M_v \sum_{r=1}^{N} L_r \rceil$, where $\beta \leq 1$ is a ratio value.

[Claim 14] The BS of Claim 13, wherein a total number of non-zero coefficients summed across all layers is constrained by $2K_0$, and is given by:

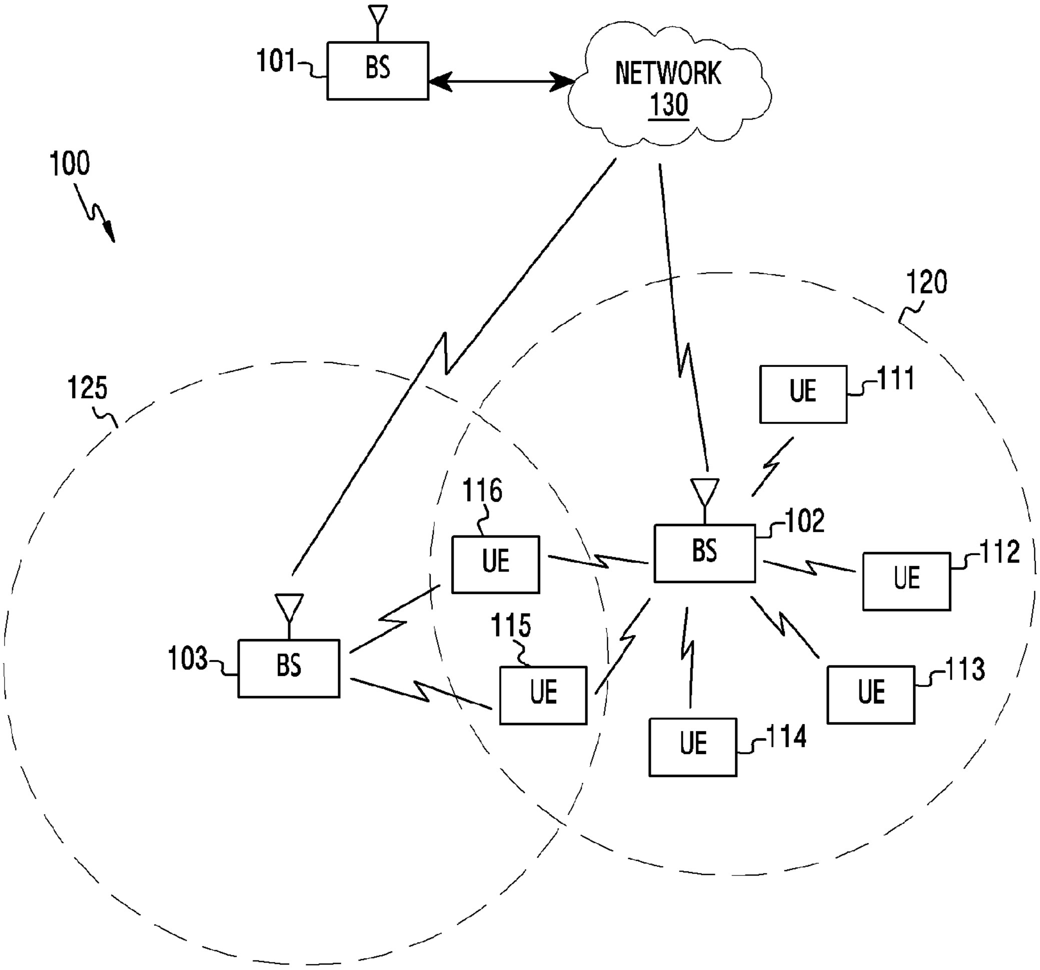
$$\sum_{l=1}^{\upsilon} K_{1,l} \leq 2K_0.$$

[Claim 15] The BS of Claim 12, wherein a maximum number of non-zero coefficients for each group r is constrained by a value $K_{0,r}$, given by:

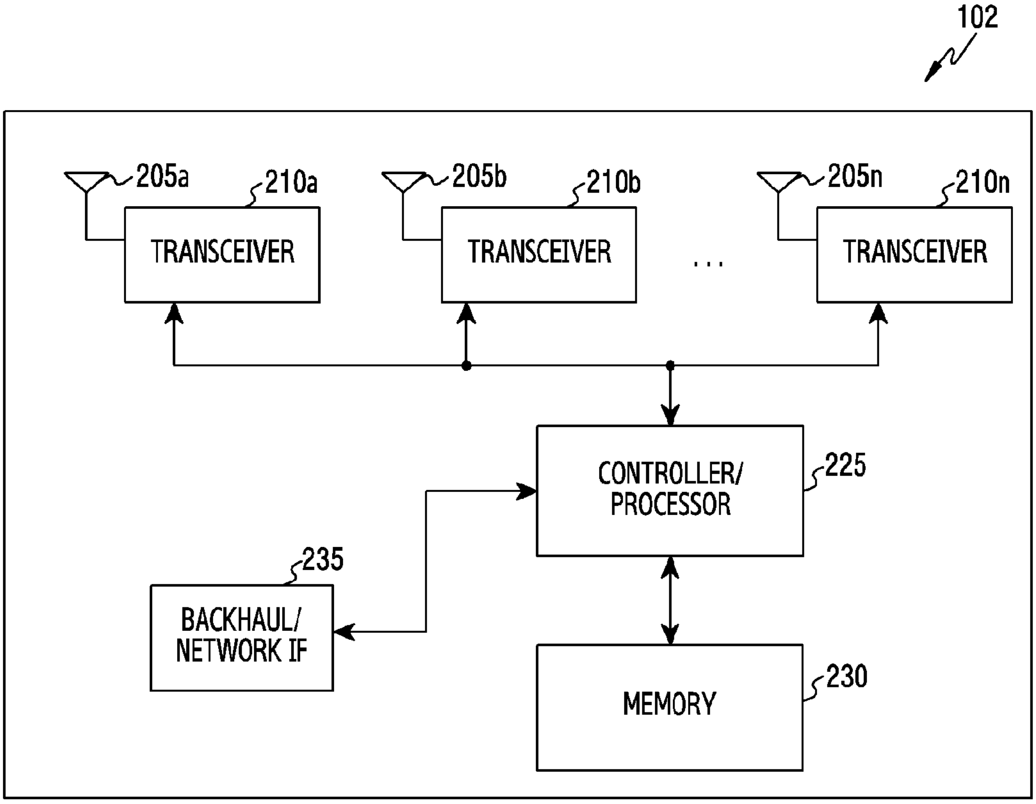
$$K_{l,r}^{NZ} = \sum_{i=0}^{2L_r-1} \sum_{f=0}^{M_\upsilon-1} k_{l,i,f,r}^{(3)} \leq K_{0,r} \text{ for layer } l = 1, \ldots, \upsilon,$$

where the constrained value of $K_{0,r}$ is given by either $K_{0,r} = \lceil \beta_r 2M_1 L_r \rceil$ or $K_0 = \lceil \beta_r 2M_\upsilon L_r \rceil$, where $\beta_r \leq 1$ is a ratio value.

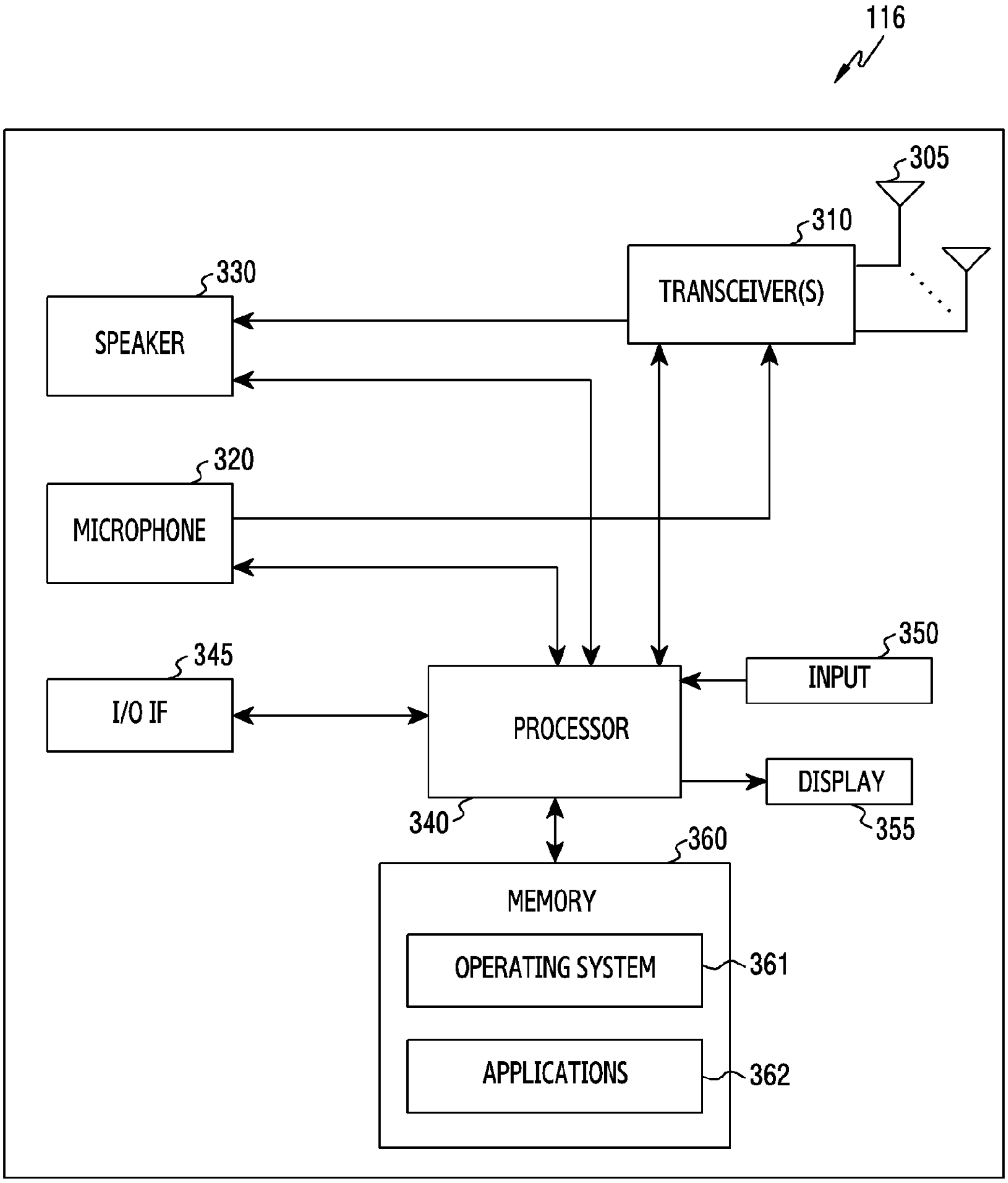
[Fig. 1]


101
BS
NETWORK
130
100
120
125
UE
111
116
UE
BS
102
UE
112
103
BS
115
UE
UE
113
UE
114

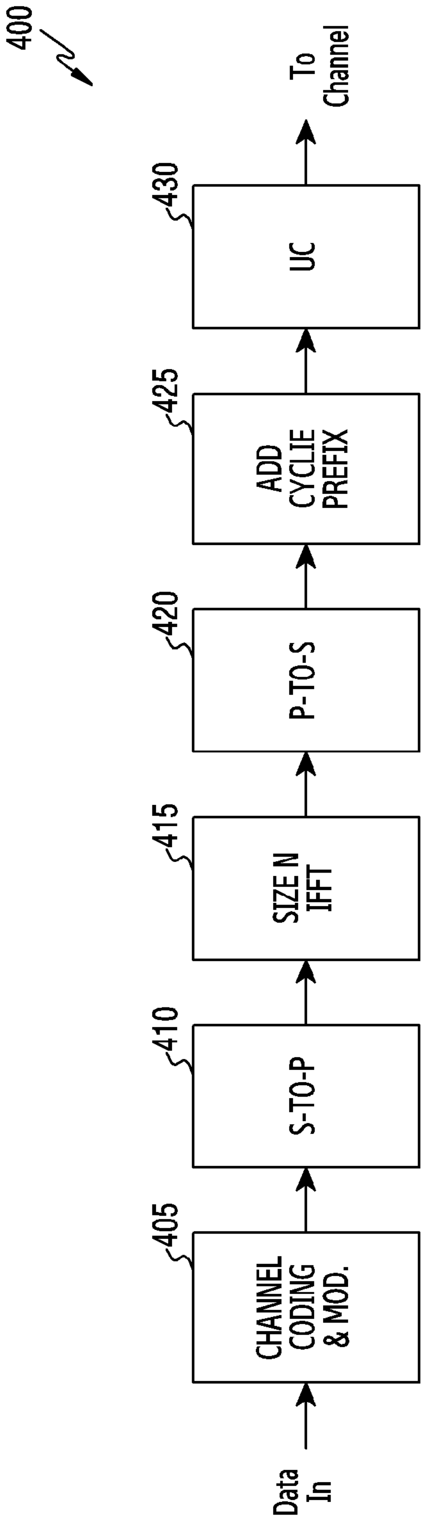
[Fig. 2]


102
205a
210a
TRANSCEIVER
205b
210b
TRANSCEIVER
...
205n
210n
TRANSCEIVER
CONTROLLER/
PROCESSOR
225
235
BACKHAUL/
NETWORK IF
MEMORY
230

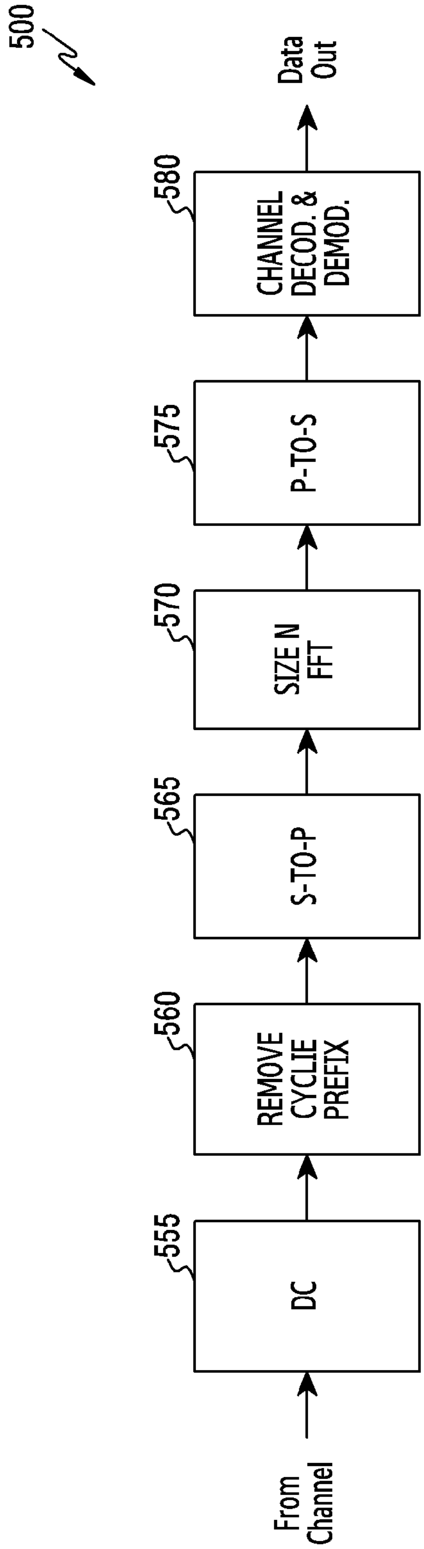
[Fig. 3]


116
305
310
TRANSCEIVER(S)
330
SPEAKER
320
MICROPHONE
345
I/O IF
350
INPUT
PROCESSOR
340
DISPLAY
355
360
MEMORY
OPERATING SYSTEM
361
APPLICATIONS
362

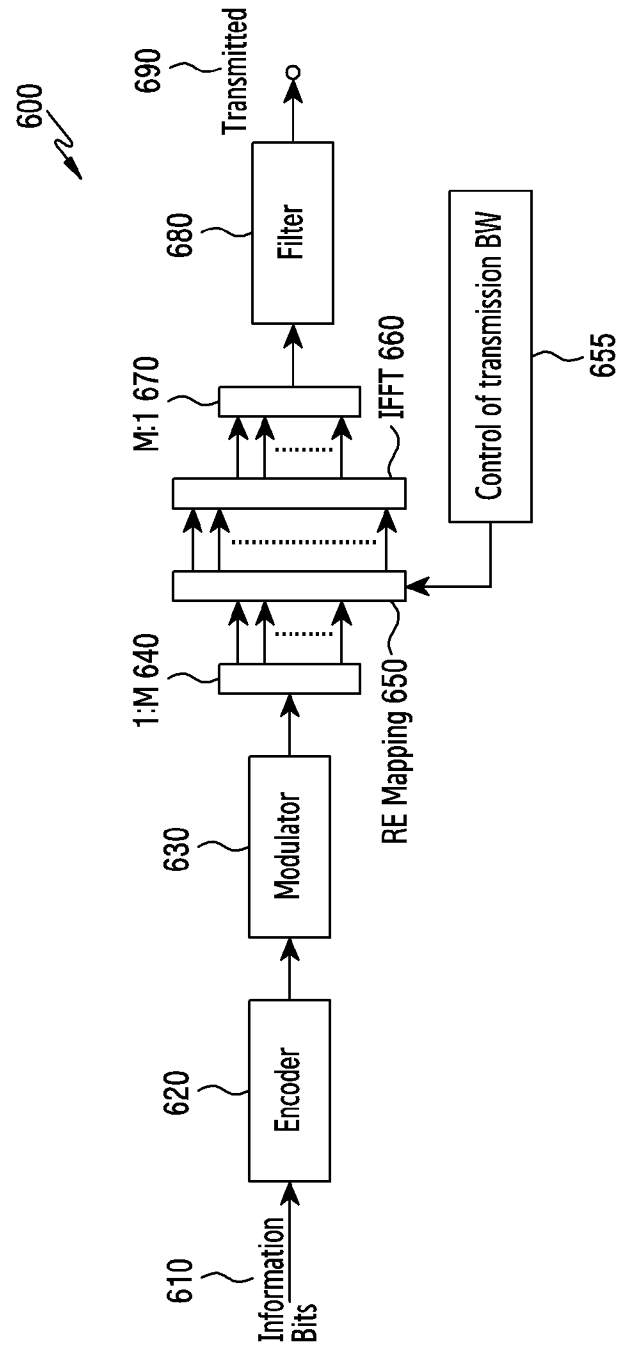
[Fig. 4]


400
Data In
CHANNEL CODING & MOD.
405
S-TO-P
410
SIZE N IFFT
415
P-TO-S
420
ADD CYCLIE PREFIX
425
UC
430
To Channel

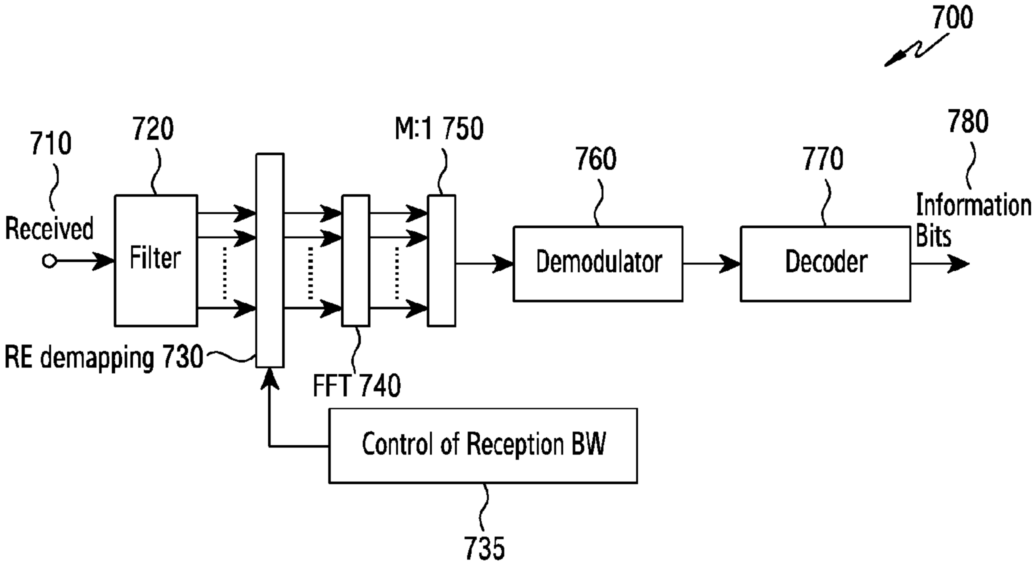
[Fig. 5]


500
From Channel
555
DC
560
REMOVE CYCLIE PREFIX
565
S-TO-P
570
SIZE N FFT
575
P-TO-S
580
CHANNEL DECOD. & DEMOD.
Data Out

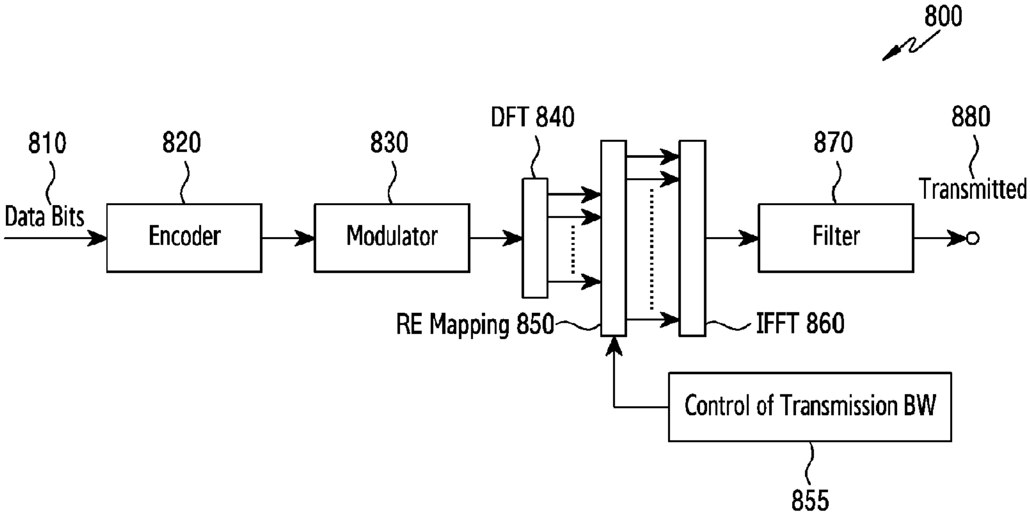
[Fig. 6]


600
610
Information Bits
620
Encoder
630
Modulator
1:M 640
RE Mapping 650
Control of transmission BW
655
IFFT 660
M:1 670
680
Filter
690
Transmitted

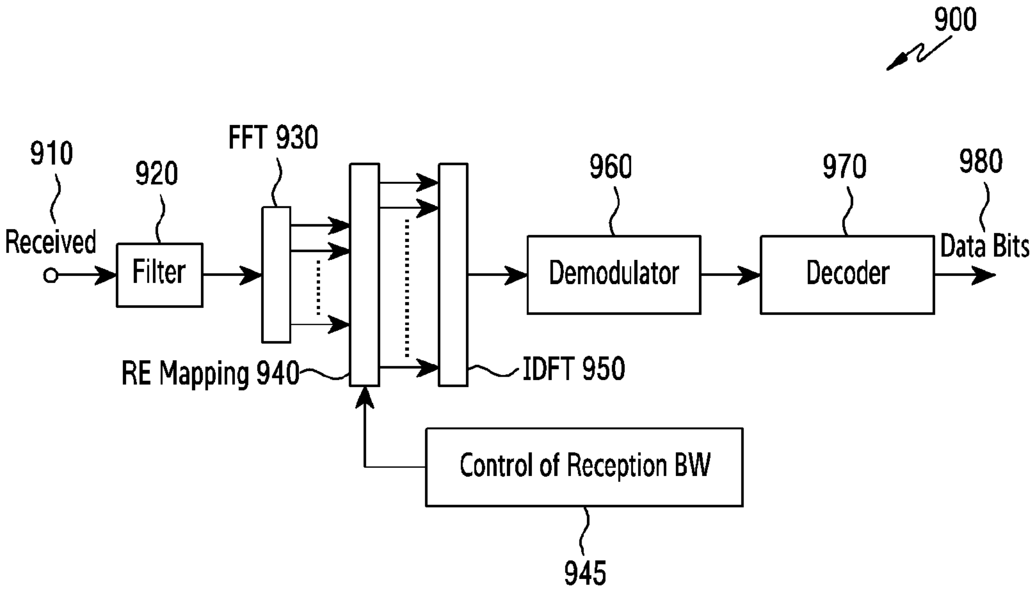
[Fig. 7]



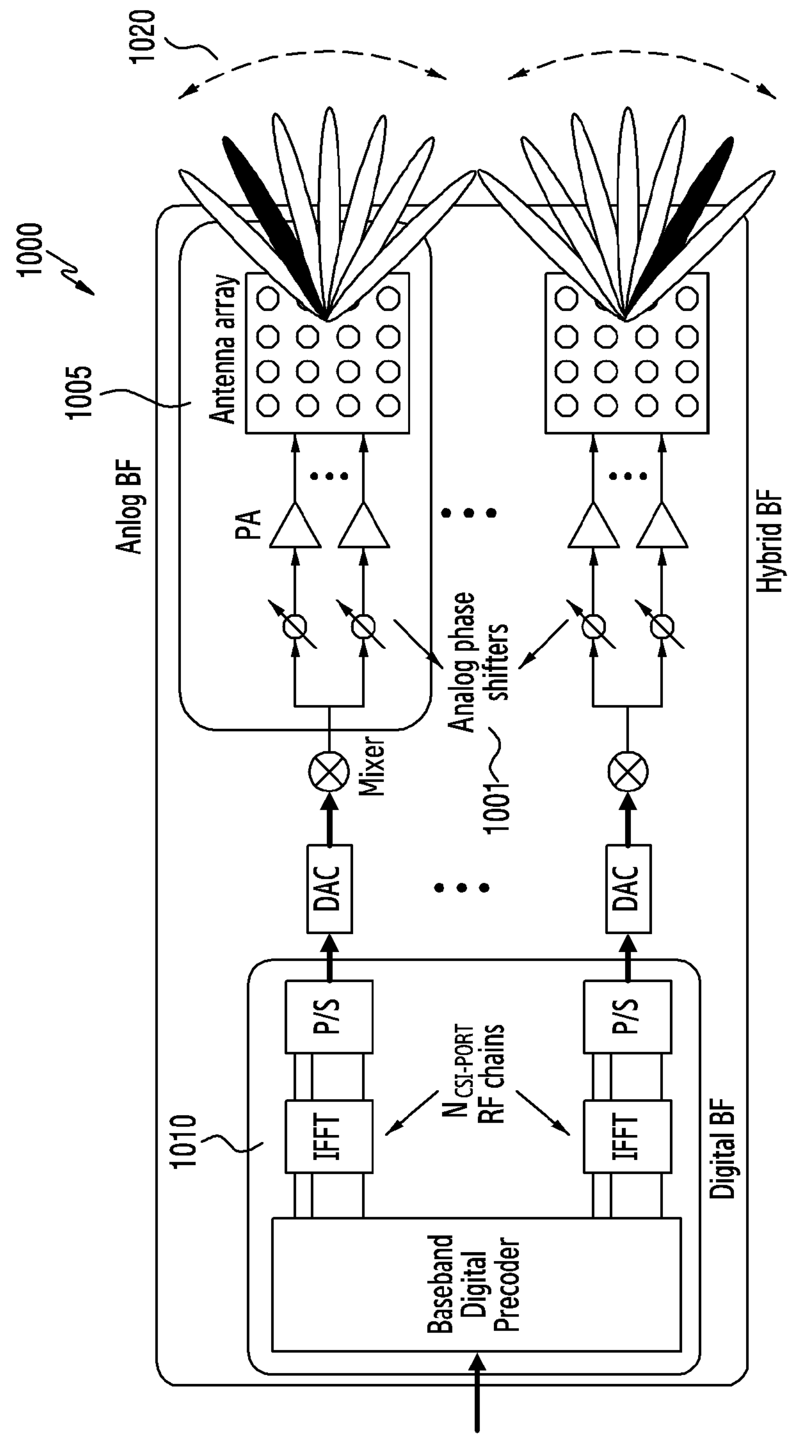
[Fig. 8]



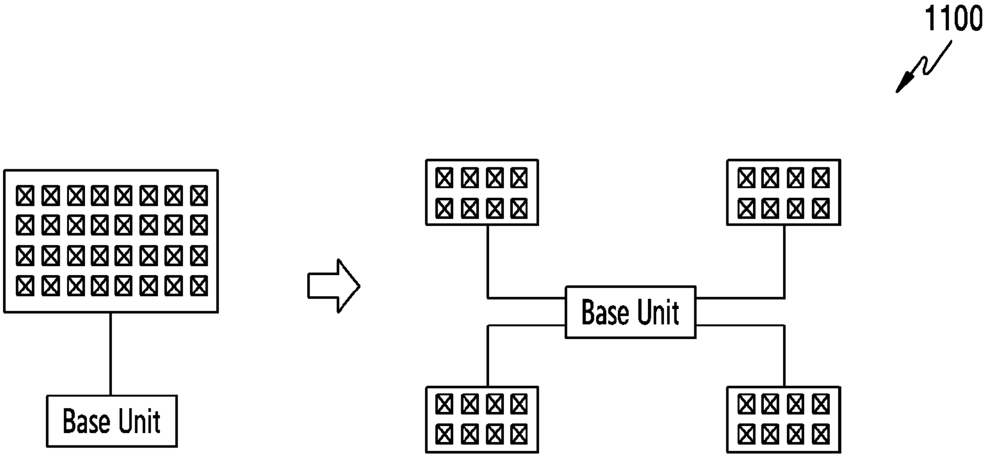
[Fig. 9]



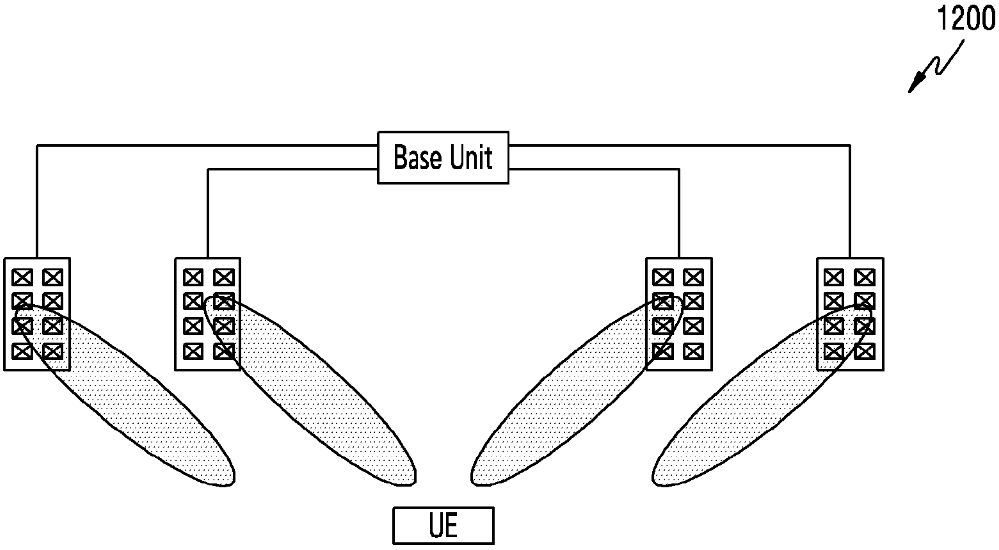
[Fig. 10]


1020
1000
1005
Antenna array
Anlog BF
PA
Analog phase shifters
Mixer
1001
DAC
DAC
Hybrid BF
P/S
P/S
IFFT
IFFT
N_CSI-PORT RF chains
1010
Digital BF
Baseband Digital Precoder

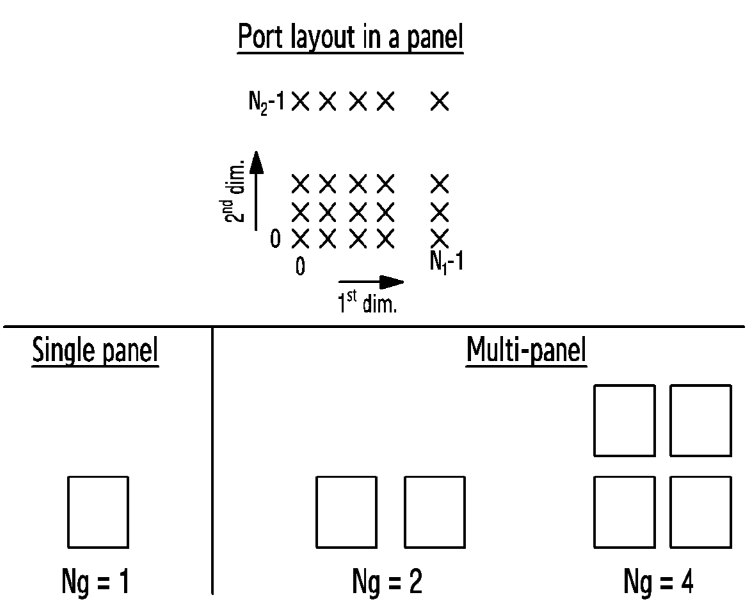
[Fig. 11]



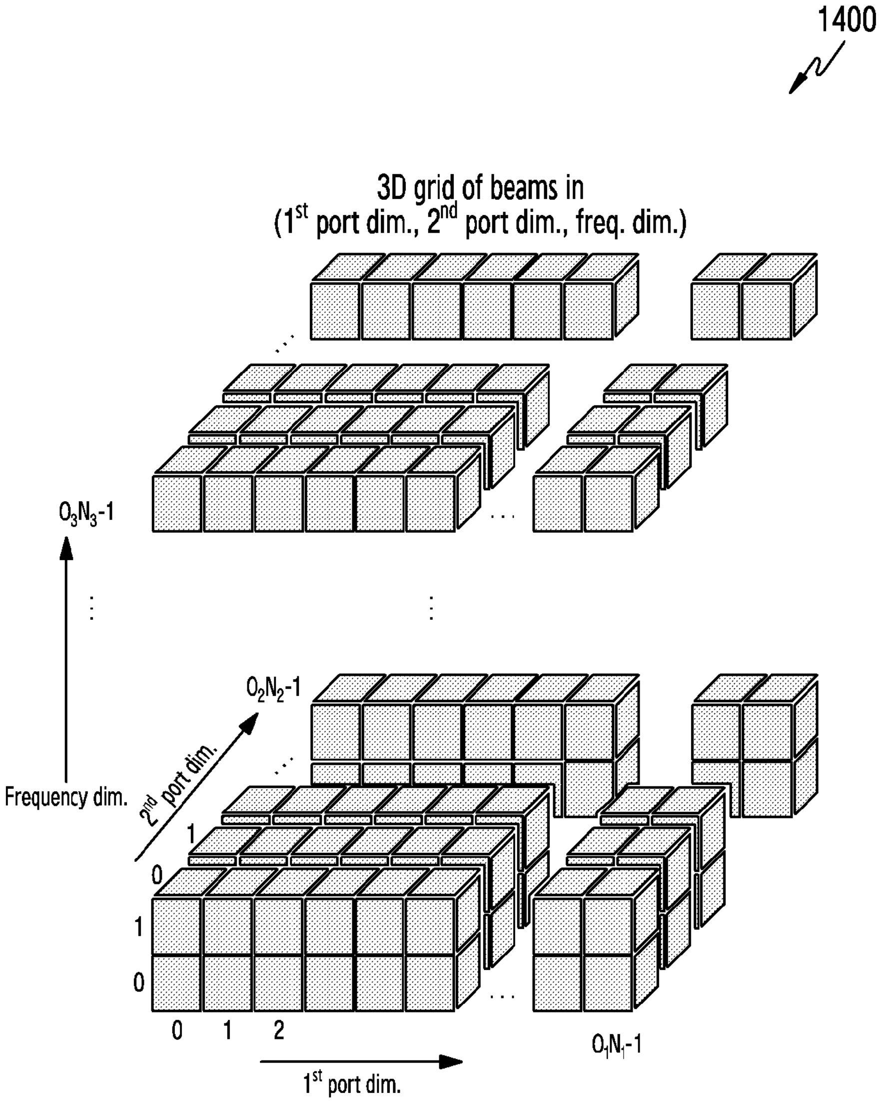
[Fig. 12]



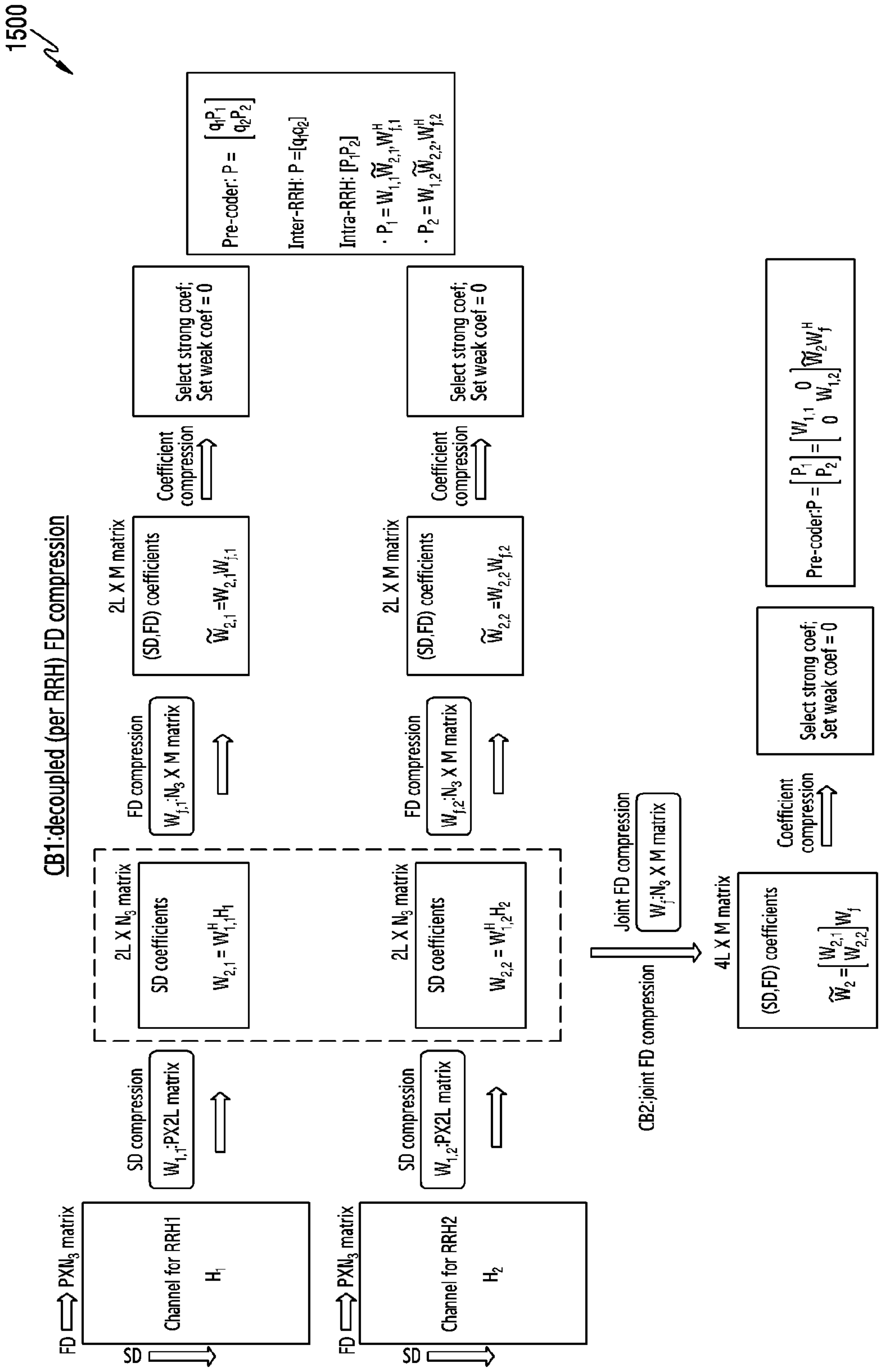
[Fig. 13]



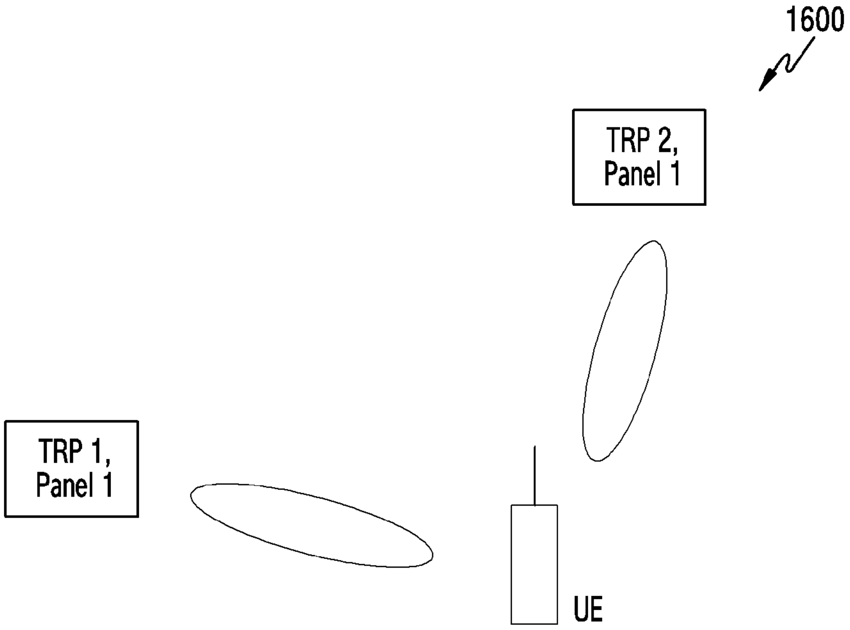
[Fig. 14]


1400
3D grid of beams in
(1st port dim., 2nd port dim., freq. dim.)
O3N3-1
Frequency dim.
O2N2-1
2nd port dim.
1
0
1
0
0
1
2
O1N1-1
1st port dim.

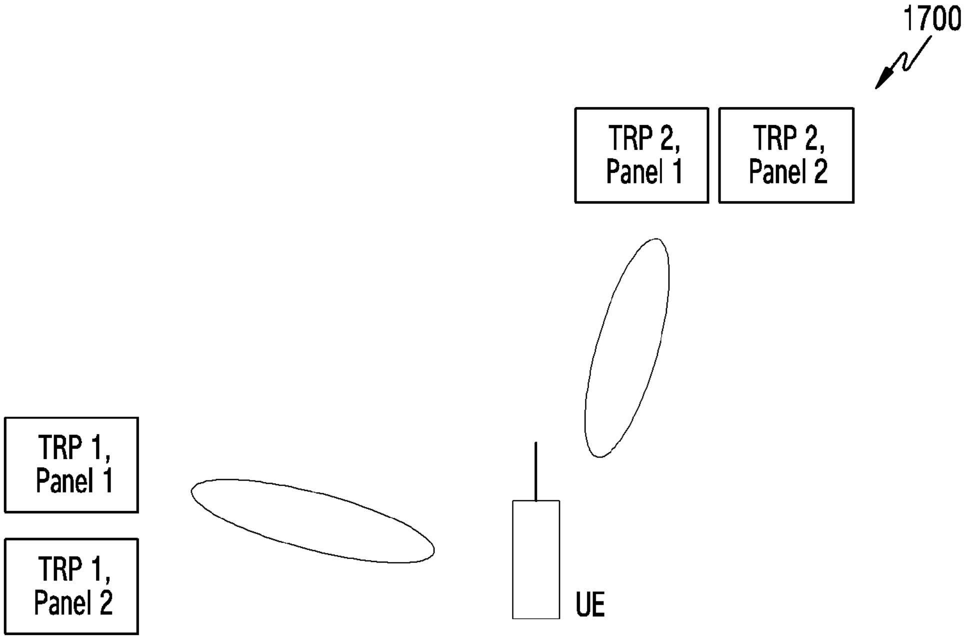
[Fig. 15]


1500
CB1:decoupled (per RRH) FD compression
FD
PXN$_3$ matrix
SD
Channel for RRH1
H_1
SD compression
$W_{1,1}$:PX2L matrix
2L X N$_3$ matrix
SD coefficients
$W_{2,1} = W_{1,1}^H H_1$
FD compression
$W_{f,1}$:N$_3$ X M matrix
2L X M matrix
(SD,FD) coefficients
$\tilde{W}_{2,1} = W_{2,1} W_{f,1}$
Coefficient compression
Select strong coef; Set weak coef = 0
Pre-coder: $P = \begin{bmatrix} q_1 P_1 \\ q_2 P_2 \end{bmatrix}$
Inter-RRH: $P = [q_1 q_2]$
Intra-RRH: $[P_1 P_2]$
· $P_1 = W_{1,1} \tilde{W}_{2,1} W_{f,1}^H$
· $P_2 = W_{1,2} \tilde{W}_{2,2} W_{f,2}^H$
FD
PXN$_3$ matrix
SD
Channel for RRH2
H_2
SD compression
$W_{1,2}$:PX2L matrix
2L X N$_3$ matrix
SD coefficients
$W_{2,2} = W_{1,2}^H H_2$
FD compression
$W_{f,2}$:N$_3$ X M matrix
2L X M matrix
(SD,FD) coefficients
$\tilde{W}_{2,2} = W_{2,2} W_{f,2}$
Coefficient compression
Select strong coef; Set weak coef = 0
Joint FD compression
W_f:N$_3$ X M matrix
CB2:joint FD compression
4L X M matrix
(SD,FD) coefficients
$\tilde{W}_2 = \begin{bmatrix} W_{2,1} \\ W_{2,2} \end{bmatrix} W_f$
Coefficient compression
Select strong coef; Set weak coef = 0
Pre-coder: $P = \begin{bmatrix} P_1 \\ P_2 \end{bmatrix} = \begin{bmatrix} W_{1,1} & 0 \\ 0 & W_{1,2} \end{bmatrix} \tilde{W}_2 W_f^H$

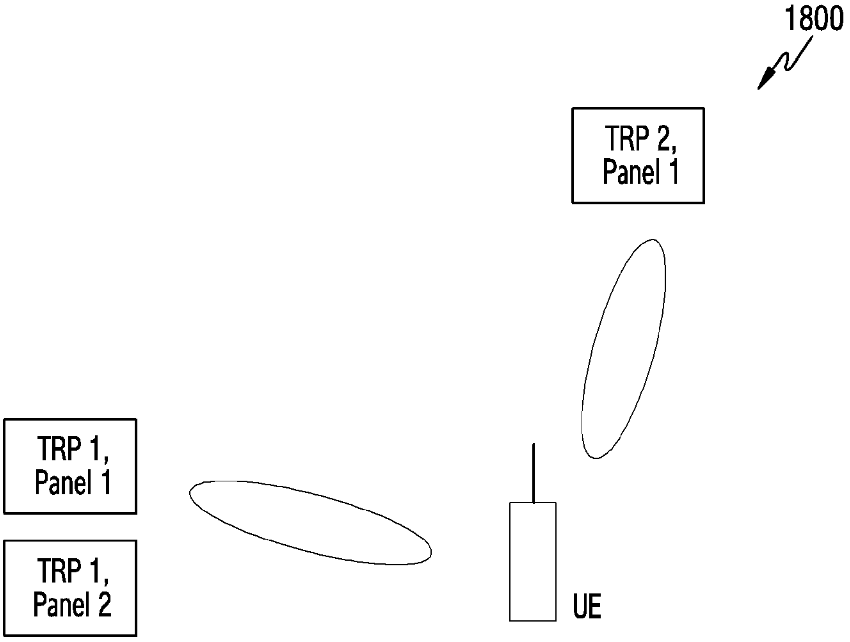
[Fig. 16]


1600
TRP 2,
Panel 1
TRP 1,
Panel 1
UE

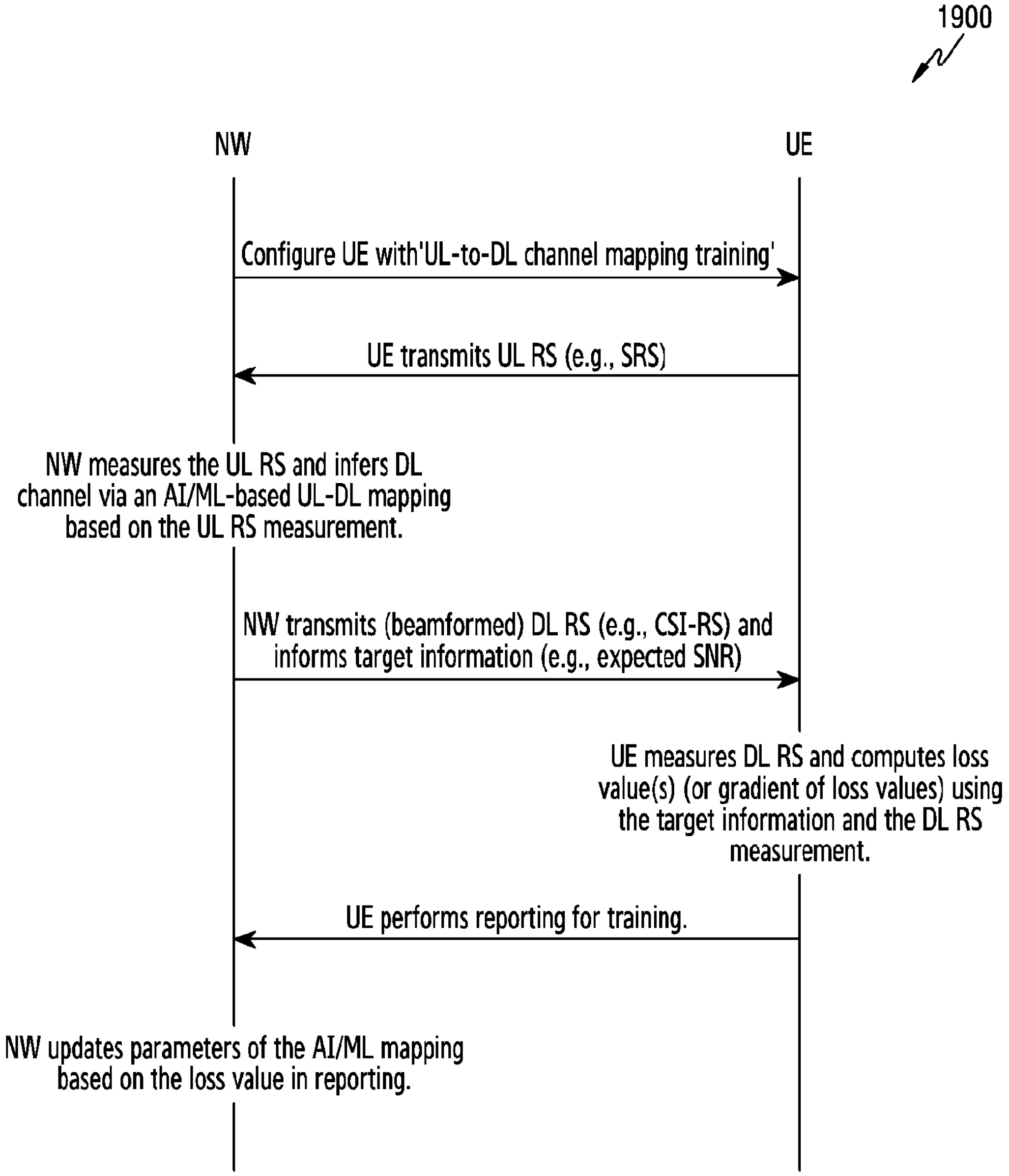
[Fig. 17]


1700
TRP 2,
Panel 1
TRP 2,
Panel 2
TRP 1,
Panel 1
TRP 1,
Panel 2
UE

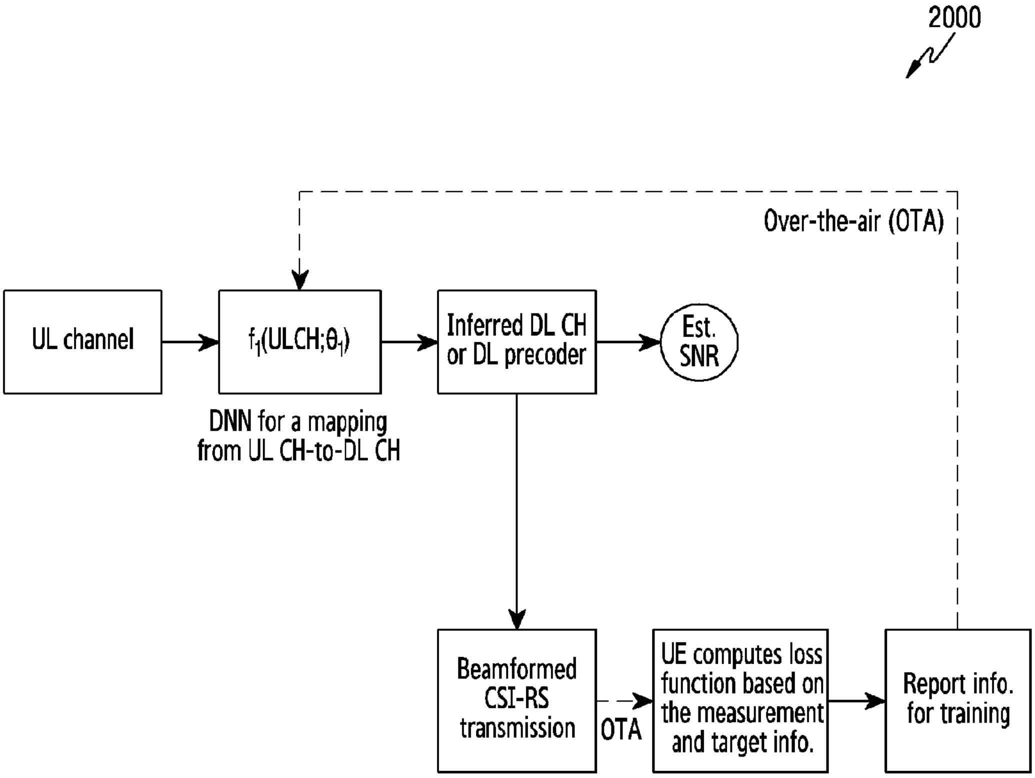
[Fig. 18]



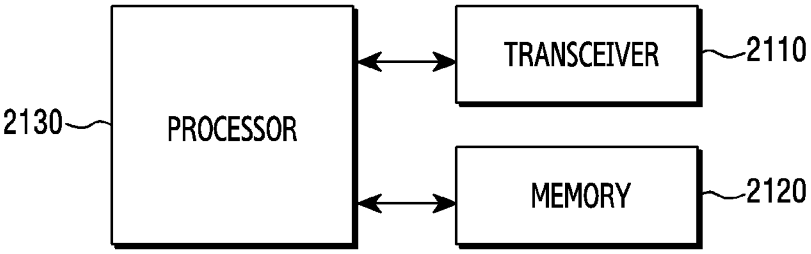
[Fig. 19]


1900
NW
UE
Configure UE with'UL-to-DL channel mapping training'
UE transmits UL RS (e.g., SRS)
NW measures the UL RS and infers DL channel via an AI/ML-based UL-DL mapping based on the UL RS measurement.
NW transmits (beamformed) DL RS (e.g., CSI-RS) and informs target information (e.g., expected SNR)
UE measures DL RS and computes loss value(s) (or gradient of loss values) using the target information and the DL RS measurement.
UE performs reporting for training.
NW updates parameters of the AI/ML mapping based on the loss value in reporting.

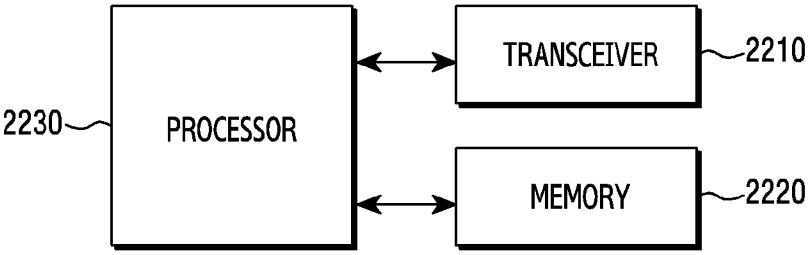
[Fig. 20]



[Fig. 21]



[Fig. 22]



INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2023/001540

A. CLASSIFICATION OF SUBJECT MATTER

H04B 7/0456(2017.01)i; **H04B 7/06**(2006.01)i; **H04B 7/0417**(2017.01)i; **H04L 5/00**(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04B 7/0456(2017.01); H04B 7/00(2006.01); H04B 7/06(2006.01); H04L 5/00(2006.01)

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

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: user equipment, base station, channel state information(CSI), reference signal(RS), code book, spatial, frequency, domain, coefficient, group, zero

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2021-0044340 A1 (SAMSUNG ELECTRONICS CO., LTD.) 11 February 2021 (2021-02-11) paragraphs [0029]-[0212]; and figures 1-15	1-15
A	ERICSSON, `CSI enhancements for Multi-TRP and FR1 FDD reciprocity`, R1-2105807, 3GPP TSG-RAN WG1 Meeting #105-e Online, 12 May 2021 section 2.1-3.4	1-15
A	SAMSUNG, `Views on Rel-17 CSI enhancements`, R1-2103828, 3GPP TSG RAN WG1#104b-e e-Meeting, 14 April 2021 section 2-4	1-15
A	WO 2021-028284 A1 (FRAUNHOFER-GESELLSCHAFT ZUR FÖRDERUNG DER ANGEWANDTEN FORSCHUNG E.V.) 18 February 2021 (2021-02-18) claim 1; and figure 1	1-15
A	MD SAIFUR RAHMAN et al, `CSI feedback based on space-frequency compression`, 2020 IEEE 17th Annual Consumer Communications & Networking Conference, 10 January 2010 <URL: https://ieeexplore.ieee.org/document/9045228> section I-V	1-15

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

*	Special categories of cited documents:
"A"	document defining the general state of the art which is not considered to be of particular relevance
"D"	document cited by the applicant in the international application
"E"	earlier application or patent but published on or after the international filing date
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O"	document referring to an oral disclosure, use, exhibition or other means
"P"	document published prior to the international filing date but later than the priority date claimed
"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&"	document member of the same patent family

Date of the actual completion of the international search

12 May 2023

Date of mailing of the international search report

12 May 2023

Name and mailing address of the ISA/KR

Korean Intellectual Property Office
189 Cheongsa-ro, Seo-gu, Daejeon
35208, Republic of Korea

Facsimile No. **+82-42-481-8578**

Authorized officer

BYUN, Sung Cheal

Telephone No. **+82-42-481-8262**

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/KR2023/001540

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
US 2021-0044340 A1	11 February 2021	CN 114342278 A	12 April 2022
		EP 3997804 A1	18 May 2022
		JP 2022-543477 A	12 October 2022
		KR 10-2021-0018781 A	18 February 2021
		US 11277187 B2	15 March 2022
		US 2022-0200683 A1	23 June 2022
		WO 2021-025538 A1	11 February 2021
WO 2021-028284 A1	18 February 2021	CN 114223145 A	22 March 2022
		CN 114270722 A	01 April 2022
		EP 3780455 A1	17 February 2021
		EP 3780456 A1	17 February 2021
		EP 4014403 A1	22 June 2022
		EP 4018585 A1	29 June 2022
		JP 2022-544552 A	19 October 2022
		JP 2022-544664 A	20 October 2022
		KR 10-2022-0048475 A	19 April 2022
		KR 10-2022-0048476 A	19 April 2022
		US 2022-0286165 A1	08 September 2022
		US 2022-0286176 A1	08 September 2022
		WO 2021-028425 A1	18 February 2021