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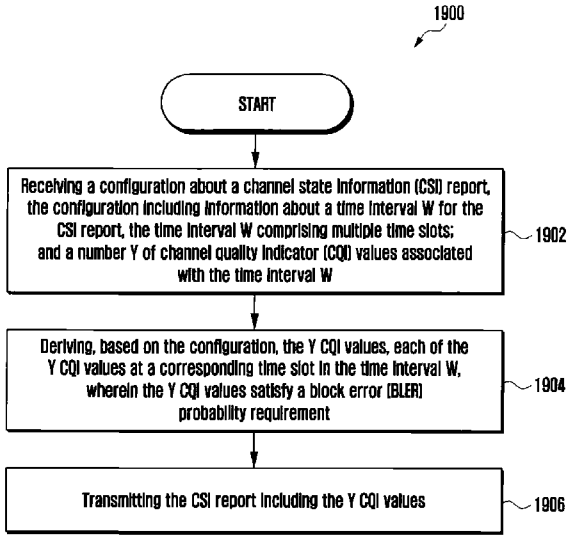
[Figure 19]



(57) Abstract: A method for operating a user equipment (UE) comprises receiving a configuration about a channel state information (CSI) report, the configuration including information about a time interval W for the CSI report, the time interval W comprising multiple time slots; and a number (Y) of channel quality indicator (CQI) values associated with the time interval W; deriving, based on the configuration, the Y CQI values, each of the Y CQI values at a corresponding time slot in the time interval W, wherein the Y CQI values satisfy a block error (BLER) probability requirement; and transmitting the CSI report including the Y CQI values, wherein $Y \geq 1$.

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【DESCRIPTION】

【Invention Title】

METHOD AND APPARATUS FOR CSI REPORTING

【Technical Field】

The present disclosure relates generally to wireless communication systems and more specifically to CSI reporting.

【Background Art】

Understanding and correctly estimating the channel between a user equipment (UE) and a base station (BS) (e.g., gNode B (gNB)) is important for efficient and effective wireless communication. In order to correctly estimate the DL channel conditions, the gNB may transmit a reference signal, e.g., CSI-RS, to the UE for DL channel measurement, and the UE may report (e.g., feedback) information about channel measurement, e.g., CSI, to the gNB. With this DL channel measurement, the gNB is able to select appropriate communication parameters to efficiently and effectively perform wireless data communication with the UE. 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 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.

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.

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.

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.

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.

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】

【Technical Problem】

With the development of mobile communications and the diversification of services, user equipment positioning has gradually become one of the most important applications in communication networks, the requirements for positioning delay and accuracy are getting higher and higher, especially for IIoT (Industrial Internet of Things) application scenarios, and the demand for positioning of a user equipment in an inactive state or an idle mode is also increasing.

The objectives of the embodiments are to reduce power consumption of the UE, to prolong battery life of the UE, and to reduce delay and signaling overhead of message transmission, to improve security and reliability of information.

【Technical Solution】

Embodiments of the present disclosure provide methods and apparatuses for signaling on CSI format.

In one embodiment, a UE in a wireless communication system is provided. The UE includes a transceiver configured to: receive a configuration about a channel state information (CSI) report, the configuration including information about a time interval W for the CSI report, the time interval W comprising multiple time slots; and a number (Y) of channel quality indicator (CQI)

values associated with the time interval W. The UE further includes a processor operably coupled to the transceiver. The processor is configured to derive, based on the configuration, Y CQI values, each at a corresponding time slot in the time interval W, wherein the Y CQI values satisfy a block error (BLER) probability requirement. The transmitter is further configured to transmit the CSI report including the Y CQI values, and $Y \geq 1$.

In another embodiment, a BS in a wireless communication system is provided. The BS includes a processor configured to: generate a configuration about a CSI report, the configuration including information about a time interval W for the CSI report, the time interval W comprising multiple time slots; and a number (Y) of CQI values associated with the time interval W. The BS further includes a transceiver operably coupled to the processor. The transceiver is configured to: transmit the configuration; and receive the CSI report, wherein: the CSI report includes the Y CQI values, the Y CQI values are based on the configuration, each Y CQI value is at a corresponding time slot in the time interval W, the Y CQI values satisfy a BLER probability requirement, and $Y \geq 1$.

In yet another embodiment, a method for operating a UE is provided. The method comprises: receiving a configuration about a CSI report, the configuration including information about a time interval W for the CSI report, the time interval W comprising multiple time slots; and a number (Y) of CQI values associated with the time interval W; deriving, based on the configuration, Y CQI values, each at a corresponding time slot in the time interval W, wherein the Y CQI values satisfy a BLER probability requirement; and transmitting the CSI report including the Y CQI values, wherein $Y \geq 1$.

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

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.

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.

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.

【Description of Drawings】

For a more complete understanding of the present disclosure and its advantages, reference is now made to the following description taken in conjunction with the accompanying drawings, in which like reference numerals represent like parts:

FIGURE 1 illustrates an example wireless network according to embodiments of the present disclosure;

FIGURE 2 illustrates an example gNB according to embodiments of the present disclosure;

FIGURE 3 illustrates an example UE according to embodiments of the present disclosure;

FIGURE 4A illustrates a high-level diagram of an orthogonal frequency division multiple access transmit path according to embodiments of the present disclosure;

FIGURE 4B illustrates a high-level diagram of an orthogonal frequency division multiple access receive path according to embodiments of the present disclosure;

FIGURE 5 illustrates a transmitter block diagram for a PDSCH in a subframe according to embodiments of the present disclosure;

FIGURE 6 illustrates a receiver block diagram for a PDSCH in a subframe according to embodiments of the present disclosure;

FIGURE 7 illustrates a transmitter block diagram for a PUSCH in a subframe according to embodiments of the present disclosure;

FIGURE 8 illustrates a receiver block diagram for a PUSCH in a subframe according to embodiments of the present disclosure;

FIGURE 9 illustrates an example antenna blocks or arrays forming beams according to embodiments of the present disclosure;

FIGURE 10 illustrates channel measurements with and without Doppler components according to embodiments of the present disclosure;

FIGURE 11 illustrates an antenna port layout according to embodiments of the present disclosure;

FIGURE 12 illustrates a 3D grid of oversampled DFT beams according to embodiments of the present disclosure;

FIGURE 13 illustrates an example of a UE configured to receive a burst of NZP CSI-RS resources according to embodiments of the present disclosure;

FIGURE 14 illustrates an example of a UE configured to determine a value of N_4 based on the value B in a CSI-RS burst according to embodiments of the present disclosure;

FIGURE 15 illustrates an example of a UE configured to determine a value of N_4 with $J \geq 1$ CSI-RS bursts that occupy a frequency band and a time span according to embodiments of the present disclosure;

FIGURE 16 illustrates an example of the time and frequency granularities of reporting *X* according to embodiments of the present disclosure;

FIGURE 17 illustrates an example of the F-T granularity according to embodiments of the present disclosure;

FIGURE 18 illustrates a timing relation between CSI-RS occasion, CSI reference resource, and CSI report according to embodiments of the present disclosure;

FIGURE 19 illustrates a flow chart of a method for operating a UE according to embodiments of the present disclosure; and

FIGURE 20 illustrates a flow chart of a method for operating a BS according to embodiments of the present disclosure.

【Mode for Invention】

FIGURE 1 through FIGURE 20, discussed below, and the various embodiments used to describe the principles of the present 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 present disclosure may be implemented in any suitably arranged system or device.

The following documents and standards descriptions are hereby incorporated by reference into the present 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 v16.6.0, "E-UTRA, Medium Access Control (MAC) protocol specification" (herein "REF 4"); 3GPP TS 36.331 v16.7.0, "E-UTRA, Radio Resource Control (RRC) protocol specification" (herein "REF 5"); 3GPP TR 22.891 v1.2.0 (herein "REF 6"); 3GPP TS 38.212 v17.0.0, "E-UTRA, NR, Multiplexing and channel coding" (herein "REF 7"); 3GPP TS 38.214 v17.0.0, "E-UTRA, NR, Physical layer procedures for data" (herein "REF 8"); RP-192978, "Measurement results on Doppler spectrum for various UE mobility environments and related CSI enhancements," Fraunhofer IIS, Fraunhofer HHI, Deutsche Telekom (herein "REF 9"); and 3GPP TS 38.211 v17.0.0, "E-UTRA, NR, Physical channels and modulation (herein "REF 10").

Aspects, features, and advantages of the disclosure are readily apparent from the following detailed description, simply by illustrating a number of particular embodiments and

implementations, including the best mode contemplated for carrying out the disclosure. The disclosure is also capable of other and different embodiments, and its several details can be modified in various obvious respects, all without departing from the spirit and scope of the disclosure. Accordingly, the drawings and description are to be regarded as illustrative in nature, and not as restrictive. The disclosure is illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings.

In the following, for brevity, both FDD and TDD are considered as the duplex method for both DL and UL signaling.

Although exemplary descriptions and embodiments to follow assume orthogonal frequency division multiplexing (OFDM) or orthogonal frequency division multiple access (OFDMA), the present disclosure can be extended to other OFDM-based transmission waveforms or multiple access schemes such as filtered OFDM (F-OFDM).

To meet the demand for wireless data traffic having increased since deployment of 4G communication systems, efforts have been made to develop an improved 5G or pre-5G communication system. Therefore, the 5G or pre-5G communication system is also called a "beyond 4G network" or a "post LTE system."

The 5G communication system is considered to be implemented in higher frequency (mmWave) bands, e.g., 60GHz bands, so as to accomplish higher data rates or in lower frequency bands, such as below 6 GHz, to enable robust coverage and mobility support. To decrease propagation loss of the radio waves and increase the transmission coverage, the beamforming, massive multiple-input multiple-output (MIMO), full dimensional MIMO (FD-MIMO), array antenna, an analog beam forming, large scale antenna techniques and the like are discussed in 5G communication systems.

In addition, in 5G 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 communication, moving network, cooperative communication, coordinated multi-points (CoMP) transmission and reception, interference mitigation and cancelation and the like.

The discussion of 5G systems and frequency bands associated therewith is for reference as certain embodiments of the present disclosure may be implemented in 5G systems. However, the present disclosure is not limited to 5G systems, or the frequency bands associated therewith, and embodiments of the present disclosure may be utilized in connection with any frequency band. For

example, aspects of the present disclosure may also be applied to deployment of 5G communication systems, 6G or even later releases which may use terahertz (THz) bands.

FIGURES 1-4B 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 present disclosure may be implemented in any suitably-arranged communications system. The present disclosure covers several components which can be used in conjunction or in combination with one another or can operate as standalone schemes.

FIGURE 1 illustrates an example wireless network according to embodiments of the present 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.

As shown in FIGURE 1, the wireless network includes a gNB 101, 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.

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 (E); a UE 113, which may be located in a WiFi hotspot (HS); a UE 114, which may be located in a first residence (R); a UE 115, which may be located in a second residence (R); and a UE 116, which may be a mobile device (M), 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, LTE, LTE-A, WiMAX, WiFi, or other wireless communication techniques.

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 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 3GPP new radio interface/access (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).

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.

As described in more detail below, one or more of the UEs 111-116 include circuitry, programing, or a combination thereof, for receiving a configuration about a channel state information (CSI) report, the configuration including information about a time interval W for the CSI report, the time interval W comprising multiple time slots; and a number (Y) of channel quality indicator (CQI) values associated with the time interval W; deriving, based on the configuration, Y CQI values, each at a corresponding time slot in the time interval W, wherein the Y CQI values satisfy a block error (BLER) probability requirement; and transmitting the CSI report including the Y CQI values, wherein $Y \geq 1$. One or more of the gNBs 101-103 includes circuitry, programing, or a combination thereof, for generating a configuration about a channel state information (CSI) report, the configuration including information about a time interval W for the CSI report, the time interval W comprising multiple time slots; and a number (Y) of channel quality indicator (CQI) values associated with the time interval W; and transmitting the configuration; and receiving the CSI report, wherein: the CSI report includes the Y CQI values, the Y CQI values are

based on the configuration, each Y CQI value is at a corresponding time slot in the time interval W, the Y CQI values satisfy a block error (BLER) probability requirement, and $Y \geq 1$.

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.

FIGURE 2 illustrates an example gNB 102 according to embodiments of the present 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 configuration. 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.

As shown in FIGURE 2, the gNB 102 includes multiple antennas 205a-205n, multiple RF transceivers 210a-210n, transmit (TX) processing circuitry 215, and receive (RX) processing circuitry 220. The gNB 102 also includes a controller/processor 225, a memory 230, and a backhaul or network interface 235.

The RF transceivers 210a-210n receive, from the antennas 205a-205n, incoming RF signals, such as signals transmitted by UEs in the network 100. The RF transceivers 210a-210n down-convert the incoming RF signals to generate IF or baseband signals. The IF or baseband signals are sent to the RX processing circuitry 220, which generates processed baseband signals by filtering, decoding, and/or digitizing the baseband or IF signals. The RX processing circuitry 220 transmits the processed baseband signals to the controller/processor 225 for further processing.

The TX processing circuitry 215 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 215 encodes, multiplexes, and/or digitizes the outgoing baseband data to generate processed baseband or IF signals. The RF transceivers 210a-210n receive the outgoing processed baseband or IF signals from the TX processing circuitry 215 and up-converts the baseband or IF signals to RF signals that are transmitted via the antennas 205a-205n.

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 RF transceivers 210a-210n, the RX processing circuitry 220, and the TX processing circuitry 215 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 signals from multiple antennas 205a-205n are weighted differently to effectively steer the outgoing signals in a desired direction. Any of a wide variety of other functions could be supported in the gNB 102 by the controller/processor 225.

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.

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, 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 RF transceiver.

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.

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. As a particular example, an access point could include a number of interfaces 235, and the controller/processor 225 could support routing functions to route data between different network addresses. As another particular example, while shown as including a single instance of TX processing circuitry 215 and a single instance of RX processing circuitry 220, the gNB 102

could include multiple instances of each (such as one per RF transceiver). Also, various components in FIGURE 2 could be combined, further subdivided, or omitted and additional components could be added according to particular needs.

FIGURE 3 illustrates an example UE 116 according to embodiments of the present 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.

As shown in FIGURE 3, the UE 116 includes an antenna 305, a radio frequency (RF) transceiver 310, TX processing circuitry 315, a microphone 320, and receive (RX) processing circuitry 325. The UE 116 also includes a speaker 330, a processor 340, an input/output (I/O) interface (IF) 345, a touchscreen 350, a display 355, and a memory 360. The memory 360 includes an operating system (OS) 361 and one or more applications 362.

The RF transceiver 310 receives, from the antenna 305, an incoming RF signal transmitted by a gNB of the network 100. The RF transceiver 310 down-converts the incoming RF signal to generate an intermediate frequency (IF) or baseband signal. The IF or baseband signal is sent to the RX processing circuitry 325, which generates a processed baseband signal by filtering, decoding, and/or digitizing the baseband or IF signal. The RX processing circuitry 325 transmits the processed baseband signal to the speaker 330 (such as for voice data) or to the processor 340 for further processing (such as for web browsing data).

The TX processing circuitry 315 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 315 encodes, multiplexes, and/or digitizes the outgoing baseband data to generate a processed baseband or IF signal. The RF transceiver 310 receives the outgoing processed baseband or IF signal from the TX processing circuitry 315 and up-converts the baseband or IF signal to an RF signal that is transmitted via the antenna 305.

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 RF transceiver 310, the RX processing circuitry 325, and the TX processing circuitry 315 in accordance with well-known principles. In some embodiments, the processor 340 includes at least one microprocessor or microcontroller.

The processor 340 is also capable of executing other processes and programs resident in the memory 360, such as processes for receiving a configuration about a channel state information (CSI) report, the configuration including information about a time interval W for the CSI report, the time interval W comprising multiple time slots; and a number (Y) of channel quality indicator (CQI) values associated with the time interval W; deriving, based on the configuration, Y CQI values, each at a corresponding time slot in the time interval W, wherein the Y CQI values satisfy a block error (BLER) probability requirement; and transmitting the CSI report including the Y CQI values, wherein $Y \geq 1$. 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.

The processor 340 is also coupled to the touchscreen 350 and the display 355. The operator of the UE 116 can use the touchscreen 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.

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).

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). 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.

FIGURE 4A is a high-level diagram of transmit path circuitry. For example, the transmit path circuitry may be used for an orthogonal frequency division multiple access (OFDMA) communication. FIGURE 4B is a high-level diagram of receive path circuitry. For example, the receive path circuitry may be used for an orthogonal frequency division multiple access (OFDMA) communication. In FIGURES 4A and 4B, for downlink communication, the transmit path circuitry

may be implemented in a base station (gNB) 102 or a relay station, and the receive path circuitry may be implemented in a user equipment (e.g., user equipment 116 of FIGURE 1). In other examples, for uplink communication, the receive path circuitry 450 may be implemented in a base station (e.g., gNB 102 of FIGURE 1) or a relay station, and the transmit path circuitry may be implemented in a user equipment (e.g., user equipment 116 of FIGURE 1).

Transmit path circuitry comprises channel coding and modulation block 405, serial-to-parallel (S-to-P) block 410, Size N Inverse Fast Fourier Transform (IFFT) block 415, parallel-to-serial (P-to-S) block 420, add cyclic prefix block 425, and up-converter (UC) 430. Receive path circuitry 450 comprises down-converter (DC) 455, remove cyclic prefix block 460, serial-to-parallel (S-to-P) block 465, Size N Fast Fourier Transform (FFT) block 470, parallel-to-serial (P-to-S) block 475, and channel decoding and demodulation block 480.

At least some of the components in FIGURES 4A 400 and 4B 450 may be implemented in software, while other components may be implemented by configurable hardware or a mixture of software and configurable hardware. In particular, it is noted that the FFT blocks and the IFFT blocks described in this disclosure document may be implemented as configurable software algorithms, where the value of Size N may be modified according to the implementation.

Furthermore, although this disclosure is directed to an embodiment that implements the Fast Fourier Transform and the Inverse Fast Fourier Transform, this is by way of illustration only and may not be construed to limit the scope of the disclosure. It may be appreciated that in an alternate embodiment of the present disclosure, the Fast Fourier Transform functions and the Inverse Fast Fourier Transform functions may easily be replaced by discrete Fourier transform (DFT) functions and inverse discrete Fourier transform (IDFT) functions, respectively. It may be appreciated that for DFT and IDFT functions, the value of the N variable may be any integer number (i.e., 1, 4, 3, 4, etc.), while for FFT and IFFT functions, the value of the N variable may be any integer number that is a power of two (i.e., 1, 2, 4, 8, 16, etc.).

In transmit path circuitry 400, channel coding and modulation block 405 receives a set of information bits, applies coding (e.g., LDPC coding) and modulates (e.g., quadrature phase shift keying (QPSK) or quadrature amplitude modulation (QAM)) the input bits to produce a sequence of frequency-domain modulation symbols. Serial-to-parallel block 410 converts (i.e., de-multiplexes) the serial modulated symbols to parallel data to produce N parallel symbol streams where N is the IFFT/FFT size used in BS 102 and UE 116. Size N IFFT block 415 then performs an IFFT operation on the N parallel symbol streams to produce time-domain output signals.

Parallel-to-serial block 420 converts (i.e., multiplexes) the parallel time-domain output symbols from Size N IFFT block 415 to produce a serial time-domain signal. Add cyclic prefix block 425 then inserts a cyclic prefix to the time-domain signal. Finally, up-converter 430 modulates (i.e., up-converts) the output of add cyclic prefix block 425 to RF frequency for transmission via a wireless channel. The signal may also be filtered at baseband before conversion to RF frequency.

The transmitted RF signal arrives at the UE 116 after passing through the wireless channel, and reverse operations to those at gNB 102 are performed. Down-converter 455 down-converts the received signal to baseband frequency and removes cyclic prefix block 460 and removes the cyclic prefix to produce the serial time-domain baseband signal. Serial-to-parallel block 465 converts the time-domain baseband signal to parallel time-domain signals. Size N FFT block 470 then performs an FFT algorithm to produce N parallel frequency-domain signals. Parallel-to-serial block 475 converts the parallel frequency-domain signals to a sequence of modulated data symbols. Channel decoding and demodulation block 480 demodulates and then decodes the modulated symbols to recover the original input data stream.

Each of gNBs 101-103 may implement a transmit path that is analogous to transmitting in the downlink to user equipment 111-116 and may implement a receive path that is analogous to receiving in the uplink from user equipment 111-116. Similarly, each one of user equipment 111-116 may implement a transmit path corresponding to the architecture for transmitting in the uplink to gNBs 101-103 and may implement a receive path corresponding to the architecture for receiving in the downlink from gNBs 101-103.

5G communication system use cases have been identified and described. Those use cases can be roughly categorized into three different groups. In one example, enhanced mobile broadband (eMBB) is determined to do with high bits/sec requirement, with less stringent latency and reliability requirements. In another example, ultra-reliable and low latency (URLL) is determined with less stringent bits/sec requirement. In yet another example, massive machine type communication (mMTC) is determined that a number of devices can be as many as 100,000 to 1 million per km2, but the reliability/throughput/latency requirement could be less stringent. This scenario may also involve power efficiency requirement as well, in that the battery consumption may be minimized as possible.

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.

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).

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.

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.

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_{sc}^{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.

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.

An UL subframe includes two slots. Each slot includes N_{symb}^{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, $N_{\mathrm{RB}} = 1$. 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 $N_{\mathrm{symb}} = 2 \cdot \left(N_{\mathrm{symb}}^{\mathrm{UL}} - 1\right) - N_{\mathrm{SRS}}$, where $N_{\mathrm{SRS}} = 1$ if a last subframe symbol is used to transmit SRS and $N_{\mathrm{SRS}} = 0$ otherwise.

FIGURE 5 illustrates a transmitter block diagram 500 for a PDSCH in a subframe according to embodiments of the present disclosure. The embodiment of the transmitter block diagram 500 illustrated in FIGURE 5 is for illustration only. One or more of the components illustrated in FIGURE 5 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 5 does not limit the scope of this disclosure to any particular implementation of the transmitter block diagram 500.

As shown in FIGURE 5, information bits 510 are encoded by encoder 520, such as a turbo encoder, and modulated by modulator 530, for example using quadrature phase shift keying (QPSK) modulation. A serial to parallel (S/P) converter 540 generates M modulation symbols that are subsequently provided to a mapper 550 to be mapped to REs selected by a transmission BW selection unit 555 for an assigned PDSCH transmission BW, unit 560 applies an Inverse fast Fourier transform (IFFT), the output is then serialized by a parallel to serial (P/S) converter 570 to create a time domain signal, filtering is applied by filter 580, and a signal transmitted 590. 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.

FIGURE 6 illustrates a receiver block diagram 600 for a PDSCH in a subframe according to embodiments of the present disclosure. The embodiment of the 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 diagram 600.

As shown in FIGURE 6, a received signal 610 is filtered by filter 620, REs 630 for an assigned reception BW are selected by BW selector 635, unit 640 applies a fast Fourier transform (FFT), and an output is serialized by a parallel-to-serial converter 650. Subsequently, a demodulator 660 coherently demodulates data symbols by applying a channel estimate obtained from a DMRS or a CRS (not shown), and a decoder 670, such as a turbo decoder, decodes the demodulated data to provide an estimate of the information data bits 680. Additional functionalities such as time-windowing, cyclic prefix removal, de-scrambling, channel estimation, and de-interleaving are not shown for brevity.

FIGURE 7 illustrates a transmitter block diagram 700 for a PUSCH in a subframe according to embodiments of the present disclosure. The embodiment of the block diagram 700 illustrated in FIGURE 7 is for illustration only. One or more of the components illustrated in FIGURE 5 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 block diagram 700.

As shown in FIGURE 7, information data bits 710 are encoded by encoder 720, such as a turbo encoder, and modulated by modulator 730. A discrete Fourier transform (DFT) unit 740 applies a DFT on the modulated data bits, REs 750 corresponding to an assigned PUSCH transmission BW are selected by transmission BW selection unit 755, unit 760 applies an IFFT and, after a cyclic prefix insertion (not shown), filtering is applied by filter 770 and a signal transmitted 780.

FIGURE 8 illustrates a receiver block diagram 800 for a PUSCH in a subframe according to embodiments of the present 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 8 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.

As shown in FIGURE 8, a received signal 810 is filtered by filter 820. Subsequently, after a cyclic prefix is removed (not shown), unit 830 applies a FFT, REs 840 corresponding to an assigned PUSCH reception BW are selected by a reception BW selector 845, unit 850 applies an inverse DFT (IDFT), a demodulator 860 coherently demodulates data symbols by applying a channel estimate obtained from a DMRS (not shown), a decoder 870, such as a turbo decoder, decodes the demodulated data to provide an estimate of the information data bits 880.

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.

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.

FIGURE 9 illustrates an example antenna blocks or arrays 900 according to embodiments of the present disclosure. The embodiment of the antenna blocks or arrays 1100 illustrated in FIGURE 9 is for illustration only. FIGURE 9 does not limit the scope of this disclosure to any particular implementation of the antenna blocks or arrays 900.

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 9. 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 901. One CSI-RS port can then correspond to one sub-array which produces a narrow analog beam through analog beamforming 905. This analog beam can be configured to sweep across a wider range of angles (920) 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 910 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.

To enable digital precoding, efficient design of CSI-RS is a crucial factor. For this reason, three types of CSI reporting mechanisms corresponding to three types of CSI-RS measurement behavior are supported, for example, "CLASS A" CSI reporting which corresponds to non-precoded CSI-RS, "CLASS B" reporting with K=1 CSI-RS resource which corresponds to UE-specific beamformed CSI-RS, and "CLASS B" reporting with K>1 CSI-RS resources which corresponds to cell-specific beamformed CSI-RS.

For non-precoded (NP) CSI-RS, a cell-specific one-to-one mapping between CSI-RS port and TXRU is utilized. Different CSI-RS ports have the same wide beam width and direction and hence generally cell wide coverage. For beamformed CSI-RS, beamforming operation, either cell-specific or UE-specific, is applied on a non-zero-power (NZP) CSI-RS resource (e.g., comprising multiple ports). At least at a given time/frequency, CSI-RS ports have narrow beam widths and hence not cell wide coverage, and at least from the gNB perspective. At least some CSI-RS port-resource combinations have different beam directions.

In scenarios where DL long-term channel statistics can be measured through UL signals at a serving eNodeB, UE-specific BF CSI-RS can be readily used. This is typically feasible when UL-DL duplex distance is sufficiently small. When this condition does not hold, however, some UE feedback is necessary for the eNodeB to obtain an estimate of DL long-term channel statistics (or any of representation thereof). To facilitate such a procedure, a first BF CSI-RS transmitted with periodicity T1 (ms) and a second NP CSI-RS transmitted with periodicity T2 (ms), where T1 $\leq$ T2. This approach is termed hybrid CSI-RS. The implementation of hybrid CSI-RS is largely dependent on the definition of CSI process and NZP CSI-RS resource.

In the 3GPP LTE specification, MIMO has been identified as an essential feature in order to achieve high system throughput requirements and it will continue to be the same in NR. One of the key components of a MIMO transmission scheme is the accurate CSI acquisition at the eNB (or TRP). For MU-MIMO, in particular, the availability of accurate CSI is necessary in order to guarantee high MU performance. For TDD systems, the CSI can be acquired using the SRS transmission relying on the channel reciprocity. For FDD systems, on the other hand, the CSI can be acquired using the CSI-RS transmission from the eNB, and CSI acquisition and feedback from the UE. In legacy FDD systems, the CSI feedback framework is 'implicit' in the form of CQI/PMI/RI derived from a codebook assuming SU transmission from the eNB. Because of the inherent SU assumption while deriving CSI, this implicit CSI feedback is inadequate for MU transmission. Since future (e.g., NR) systems are likely to be more MU-centric, this SU-MU CSI mismatch will be a bottleneck in achieving high MU performance gains. Another issue with implicit feedback is the scalability with larger number of antenna ports at the eNB. For large number of antenna ports, the codebook design for implicit feedback is quite complicated, and the designed codebook is not guaranteed to bring justifiable performance benefits in practical deployment scenarios (for example, only a small percentage gain can be shown at the most).

In 5G or NR systems, the above-mentioned CSI reporting paradigm from LTE is also supported and referred to as Type I CSI reporting. In addition to Type I, a high-resolution CSI reporting, referred to as Type II CSI reporting, is also supported to provide more accurate CSI information to gNB for use cases such as high-order MU-MIMO. The overhead of Type II CSI reporting can be an issue in practical UE implementations. One approach to reduce Type II CSI overhead is based on frequency domain (FD) compression. In Rel. 16 NR, DFT-based FD compression of the Type II CSI has been supported (referred to as Rel. 16 enhanced Type II codebook in REF8). Some of the key components for this feature includes (a) spatial domain (SD)

basis W_1, (b) FD basis W_f, and (c) coefficients $\widetilde{W}_2$ that linearly combine SD and FD basis. In a non-reciprocal FDD system, a complete CSI (comprising all components) needs to be reported by the UE. However, when reciprocity or partial reciprocity does exist between UL and DL, then some of the CSI components can be obtained based on the UL channel estimated using SRS transmission from the UE. In Rel. 16 NR, the DFT-based FD compression is extended to this partial reciprocity case (referred to as Rel. 16 enhanced Type II port selection codebook in REF8), wherein the DFT-based SD basis in W_1 is replaced with SD CSI-RS port selection, i.e., L out of $\frac{P_{CSI-RS}}{2}$ CSI-RS ports are selected (the selection is common for the two antenna polarizations or two halves of the CSI-RS ports). The CSI-RS ports in this case are beamformed in SD (assuming UL-DL channel reciprocity in angular domain), and the beamforming information can be obtained at the gNB based on UL channel estimated using SRS measurements.

It has been known in the literature that UL-DL channel reciprocity exists in both angular and delay domains if the UL-DL duplexing distance is small. Since delay in time domain transforms (or closely related to) basis vectors in frequency domain (FD), the Rel. 16 enhanced Type II port selection can be further extended to both angular and delay domains (or SD and FD). In particular, the DFT-based SD basis in W_1 and/or DFT-based FD basis in W_f can be replaced with SD and FD port selection, i.e., L CSI-RS ports are selected in SD and/or M ports are selected in FD. The CSI-RS ports in this case are beamformed in SD (assuming UL-DL channel reciprocity in angular domain) and/or FD (assuming UL-DL channel reciprocity in delay/frequency domain), and the corresponding SD and/or FD beamforming information can be obtained at the gNB based on UL channel estimated using SRS measurements. In Rel. 17 NR, such a codebook will be supported.

FIGURE 10 illustrates channel measurement with and without Doppler components 1000 according to embodiments of the present disclosure. The embodiment of the channel measurement with and without Doppler components 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 channel measurement with and without Doppler components 1000.

Now, when the UE speed is in a moderate or high-speed regime, the performance of the Rel. 15/16/17 codebooks starts to deteriorate quickly due to fast channel variations (which in turn is due to UE mobility that contributes to the Doppler component of the channel), and a one-shot nature of CSI-RS measurement and CSI reporting in Rel. 15/16/17. This limits the usefulness of

Rel. 15/16/17 codebooks to low mobility or static UEs only. For moderate or high mobility scenarios, an enhancement in CSI-RS measurement and CSI reporting is needed, which is based on the Doppler components of the channel. As described in [REF9], the Doppler components of the channel remain almost constant over a large time duration, referred to as channel stationarity time, which is significantly larger than the channel coherence time. Note that the current (Rel. 15/16/17) CSI reporting is based on the channel coherence time, which is not suitable when the channel has significant Doppler components. The Doppler components of the channel can be calculated based on measuring a reference signal (RS) burst, where the RS can be CSI-RS or SRS. When the RS is CSI-RS, the UE measures a CSI-RS burst, and use it to obtain Doppler components of the DL channel, and when RS is SRS, the gNB measures an SRS burst, and use it to obtain Doppler components of the UL channel. The obtained Doppler components can be reported by the UE using a codebook (as part of a CS report). Or the gNB can use the obtained Doppler components of the UL channel to beamform CSI-RS for CSI reporting by the UE. An illustration of channel measurement with and without Doppler components is shown in FIGURE 10. When the channel is measured with the Doppler components (e.g., based on an RS burst), the measured channel can remain close to the actual varying channel. On the other hand, when the channel is measured without the Doppler components (e.g., based on a one-shot RS), the measured channel can be far from the actual varying channel.

As described, measuring an RS burst is needed in order to obtain the Doppler components of the channel. This disclosure provides several example embodiments on obtaining the Doppler domain components or units that determine the length of the basis vectors that are used for the Doppler compression. The disclosure also describes example embodiments on signaling related to the CSI reporting format.

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.

In the present disclosure, the frequency resolution (reporting granularity) and span (reporting bandwidth) of CSI reporting can be defined in terms of frequency "subbands" and "CSI reporting band" (CRB), respectively.

A subband for CSI reporting is defined as a set of contiguous PRBs which represents the smallest frequency unit for CSI 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 reporting setting.

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

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

In terms of UE configuration, a UE can be configured with at least one CSI 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 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 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.

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.

FIGURE 11 illustrates an example antenna port layout 1100 according to embodiments of the present disclosure. The embodiment of the antenna port layout 1100 illustrated in FIGURE 11 is for illustration only. FIGURE 11 does not limit the scope of this disclosure to any particular implementation of the antenna port layout 1100.

As illustrated in FIGURE 11, 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.

As described in U.S. Patent No. 10,659,118, issued May 19, 2020, and entitled "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.

FIGURE 12 illustrates a 3D grid 1300 of the oversampled DFT beams (1st port dim., 2nd port dim., freq. dim.) in which

1st dimension is associated with the 1st port dimension,

2nd dimension is associated with the 2nd port dimension, and

3rd dimension is associated with the frequency dimension.

The basis sets for 1st and 2nd 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 oversampling factor O3. In one example, O1 = O2 = O3 = 4. 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).

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 $l = 1,..,\nu$, where ν 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

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

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

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

where

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

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

P_{CSI-RS} is a number of CSI-RS ports configured to the UE.

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),

$\boldsymbol{a}_i$ is a $2N_1N_2 \times 1$ (Eq. 1) or $N_1N_2 \times 1$ (Eq. 2) column vector, and $\boldsymbol{a}_i$ is a $N_1N_2 \times 1$ or $\frac{P_{CSIRS}}{2} \times 1$ port selection column vector if antenna ports at the gNB are co-polarized, and is a $2N_1N_2 \times 1$ or $P_{CSIRS} \times 1$ port selection column vector if antenna ports at the gNB are dual-polarized or cross-polarized, where a port selection vector is a defined as a vector which contains a value of 1 in one element and zeros elsewhere, and P_{CSIRS} is the number of CSI-RS ports configured for CSI reporting,

$\boldsymbol{b}_f$ is a $N_3 \times 1$ column vector,

$c_{l,i,f}$ is a complex coefficient associate with vectors $\boldsymbol{a}_i$ and $\boldsymbol{b}_f$.

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

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

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

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.

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).

The columns of $\boldsymbol{W}^l$ are normalized to norm one. For rank R or R layers ($\upsilon = R$), the pre-coding matrix is given by $\boldsymbol{W}^{(R)} = \frac{1}{\sqrt{R}}[\boldsymbol{W}^1 \quad \boldsymbol{W}^2 \quad \cdots \quad \boldsymbol{W}^R]$. 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.

Here L $\leq \frac{P_{CSI-RS}}{2}$ and M $\leq$ N3. 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, $\boldsymbol{b}_f = \boldsymbol{w}_f$, where the quantity $\boldsymbol{w}_f$ is given by

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

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

$$\boldsymbol{w}_f = \begin{bmatrix} y_{0,l}^{(f)} & y_{1,l}^{(f)} & \cdots & y_{N_3-1,l}^{(f)} \end{bmatrix}^T,$$

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

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

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

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.

On a high level, a precoder $\boldsymbol{W}^l$ can be described as follows.

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

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

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 ($c_{l,i,f} = p_{l,i,f}\phi_{l,i,f}$) in $\widetilde{\boldsymbol{W}}_2$ is quantized as amplitude coefficient ($p_{l,i,f}$) and phase coefficient ($\phi_{l,i,f}$). 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

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

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

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.

The UE reports the following for the quantization of the NZ coefficients in $\widetilde{\mathbf{W}}_2$

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

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

Two antenna polarization-specific reference amplitudes is used.

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

For the other polarization, reference amplitude $p_{l,i,f}^{(1)}$ is quantized to 4 bits

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

For $\{c_{l,i,f},\ (i,f) \neq (i^*,f^*)\}$:

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

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

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

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

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 $p_{l,i,f}^{(1)} = p_{l,r^*}^{(1)} = 1$. For the other polarization $r \in \{0,1\}$ and $r \neq r^*$, we have $r = \left(\left\lfloor \frac{i^*}{L} \right\rfloor + 1\right) \ mod\ 2$ and the reference amplitude $p_{l,i,f}^{(1)} = p_{l,r}^{(1)}$ is quantized (reported) using the 4-bit amplitude codebook mentioned above.

A UE can be configured to report M FD basis vectors. In one example, $M = \left\lceil p \times \frac{N_3}{R} \right\rfloor$, 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., $M = \left\lceil p \times \frac{N_3}{R} \right\rfloor$ for rank 1-2 and $M = \left\lceil v_0 \times \frac{N_3}{R} \right\rfloor$ 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 the rest of the disclosure, M is replaced with M_v to show its dependence on the rank value v, hence p is replaced with $p_v, v \in \{1,2\}$ and v_0 is replaced with $p_v, v \in \{3,4\}$.

A UE can be configured to report M_v FD basis vectors in one-step from N_3 basis vectors freely (independently) for each layer $l \in \{0,1,..,v-1\}$ of a rank v CSI reporting. Alternatively, a UE can be configured to report M_v FD basis vectors in two-step as follows.

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.

In step 2, for each layer $l \in \{0,1,..,v-1\}$ of a rank v CSI reporting, M FD basis vectors are selected/reported freely (independently) from N_3' basis vectors in the InS.

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

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

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 $R = 1$.

$(p_v \text{ for } v \in \{1,2\}, p_v \text{ for } v \in \{3,4\}) \in \left\{\left(\frac{1}{2}, \frac{1}{4}\right), \left(\frac{1}{4}, \frac{1}{4}\right), \left(\frac{1}{4}, \frac{1}{8}\right)\right\}$.

$\beta \in \left\{\frac{1}{4}, \frac{1}{2}, \frac{3}{4}\right\}$.

$$\alpha \in \{1.5,2,2.5,3\}$$

$N_{ph} \in \{8,16\}$.

In another example, the set of values for these codebook parameters are as follows: $\alpha = 2$, $N_{ph} = 16$, and as in Table 1, where the values of L, β and p_v are determined by the higher layer parameter paramCombination-r17. In one example, the UE is not expected to be configured with paramCombination-r17 equal to

3, 4, 5, 6, 7, or 8 when $P_{\text{CSI-RS}} = 4$,

7 or 8 when number of CSI-RS ports $P_{\text{CSI-RS}} < 32$,

7 or 8 when higher layer parameter typeII-RI-Restriction-r17 is configured with $r_i = 1$ for any $i > 1$,

7 or 8 when $R = 2$.

The bitmap parameter typeII-RI-Restriction-r17 forms the bit sequence r_3, r_2, r_1, r_0 where r_0 is the LSB and r_3 is the MSB. When r_i is zero, $i \in \{0,1,\ldots,3\}$, PMI and RI reporting are not allowed to correspond to any precoder associated with $v = i + 1$ layers. The parameter R is configured with the higher-layer parameter numberOfPMISubbandsPerCQISubband-r17. This parameter controls the total number of precoding matrices N_3 indicated by the PMI as a function

of the number of subbands in csi-ReportingBand, the subband size configured by the higher-level parameter subbandSize and of the total number of PRBs in the bandwidth part.

Table 1

paramCombination-r17	L	p_v		β
		$v \in \{1,2\}$	$v \in \{3,4\}$	
1		1/4	1/8	
2		1/4	1/8	
3		1/4	1/8	
4		1/4	1/8	
5		1/4		
6		1/2		
7		1/4		
8		1/4		

The above-mentioned framework (equation 5) represents the precoding-matrices for multiple (N_3) FD units using a linear combination (double sum) over $2L$ SD beams and M_v FD beams. This framework can also be used to represent the precoding-matrices in time domain (TD) by replacing the FD basis matrix $\boldsymbol{W}_f$ with a TD basis matrix $\boldsymbol{W}_t$, wherein the columns of $\boldsymbol{W}_t$ comprises M_v TD beams that represent some form of delays or channel tap locations. Hence, a precoder $\boldsymbol{W}^l$ can be described as follows.

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

In one example, the M_v 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.

The abovementioned framework for CSI reporting based on space-frequency compression (equation 5) or space-time compression (equation 5A) frameworks can be extended to Doppler domain (e.g., for moderate to high mobility UEs). This disclosure focuses on a reference signal burst that can be used to obtain Doppler component(s) of the channel, which can be used to perform Doppler domain compression.

FIGURE 13 illustrates an example of a UE configured to receive a burst of non-zero power (NZP) CSI-RS resource(s) 1300 according to embodiments of the present disclosure. The embodiment of the UE configured to receive the burst of NZP CSI-RS resource(s) 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 UE configured to receive a burst of NZP CSI-RS resource(s) 1300.

In one embodiment A, as shown in FIGURE 13, a UE is configured to receive a burst (or occasions) of non-zero power (NZP) CSI-RS resource(s), referred to as CSI-RS burst (or occasions) for brevity, in B time slots, where $B \geq 1$. The B time slots can be accordingly to at least one of the following examples.

In one example, the B time slots are evenly/uniformly spaced with an inter-slot spacing d.

In one example, the B time slots can be non-uniformly spaced with inter-slot spacing $e_1 = d_1$, $e_2 = d_2 - d_1$, $e_3 = d_3 - d_2$,..., so on, where $e_i \neq e_j$ for at least one pair (i,j) with $i \neq j$.

The UE receives the CSI-RS burst, estimates the B instances of the DL channel measurements, and uses the channel estimates to obtain the Doppler component(s) of the DL channel. The CSI-RS burst can be linked to (or associated with) a single CSI reporting setting (e.g., via higher layer parameter CSI-ReportConfig), wherein the corresponding CSI report includes an information about the Doppler component(s) of the DL channel.

Let $\boldsymbol{h}_t$ be the DL channel estimate based on the CSI-RS resource(s) received in time slot $t \in \{0,1,\ldots,B-1\}$. When the DL channel estimate in slot t is a matrix $\boldsymbol{G}_t$ of size $N_{Rx} \times N_{Tx} \times N_{Sc}$, then $\boldsymbol{h}_t = vec(\boldsymbol{G}_t)$, where N_{Rx}, N_{Tx}, and N_{Sc} are number of receive (Rx) antennae at the UE, number of CSI-RS ports measured by the UE, and number of subcarriers in frequency band of the CSI-RS burst, respectively. The notation $vec(\boldsymbol{X})$ is used to denote the vectorization operation wherein the matrix $\boldsymbol{X}$ is transformed into a vector by concatenating the elements of the matrix in

an order, for example, 1 → 2 → 3 → and so on, implying that the concatenation starts from the first dimension, then moves second dimension, and continues until the last dimension. Let $\boldsymbol{H}_B = [\boldsymbol{h}_0\ \boldsymbol{h}_1 \ldots \boldsymbol{h}_{B-1}]$ be a concatenated DL channel. The Doppler component(s) of the DL channel can be obtained based on $\boldsymbol{H}_B$. For example, $\boldsymbol{H}_B$ can be represented as $\boldsymbol{C}\boldsymbol{\Phi}^H = \sum_{s=0}^{N-1} \boldsymbol{c}_s \boldsymbol{\phi}_s^H$ where $\boldsymbol{\Phi} = [\boldsymbol{\phi}_0\ \boldsymbol{\phi}_1 \ldots \boldsymbol{\phi}_{N-1}]$ is a Doppler domain (DD) basis matrix whose columns comprise basis vectors, $\boldsymbol{C} = [\boldsymbol{c}_0\ \boldsymbol{c}_1 \ldots \boldsymbol{c}_{N-1}]$ is a coefficient matrix whose columns comprise coefficient vectors, and $N < B$ is the number of DD basis vectors. Since the columns of $\boldsymbol{H}_B$ are likely to be correlated, a DD compression can be achieved when the value of N is small (compared to the value of B). In this example, the Doppler component(s) of the channel is represented by the DD basis matrix $\boldsymbol{\Phi}$ and the coefficient matrix $\boldsymbol{C}$.

FIGURE 14 illustrates an example of a UE configured to determine a value of N_4 based on the value B in a CSI-RS burst 1400 according to embodiments of the present disclosure. The embodiment of the UE configured to determine a value of N_4 based on the value B in a CSI-RS burst 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 UE configured to determine a value of N_4 based on the value B in a CSI-RS burst 1400.

Let N_4 be the length of the basis vectors $\{\boldsymbol{\phi}_s\}$, e.g., each basis vector is a length $N_4 \times 1$ column vector.

In one example, the UE can be configured to determine/report the CSI report that is valid for C additional time instances or future time instances (as described in embodiment E and F), and hence the UE can perform prediction in C time instances (for example, based on the channel measurements in B time instances), and then determine the DD/TD components of the predicted or/and measured DL channel. In this case, the UE can use the concatenated channel $\boldsymbol{H}_{B+C} = [\boldsymbol{h}_0\ \boldsymbol{h}_1 \ldots \boldsymbol{h}_{B+C-1}]$ or $\boldsymbol{H}_C = [\boldsymbol{h}_B\ \boldsymbol{h}_{B+1} \ldots \boldsymbol{h}_{B+C-1}]$ to determine the DD/TD components of the DL channel. The length of DD/TD basis vectors (N_4) can depend on B (embodiment D) or C (embodiment F) or both B and C (embodiment E).

In one example, the C additional or future time instances belong to a time window that does not include any (CSI-RS) measurement or/and is after the time slot of the CSI reference resource (as described in 5.2.2.5, TS 38.214).

In one embodiment B, a UE is configured to determine a value of N_4 based on the value B (number of CSI-RS instances in a CSI-RS burst) or/and C (number of future/additional time

instances), as described above, and determine components across which the DD compression is performed, where each component corresponds to one or multiple time instances within the CSI-RS burst or/and addition/future time instances. In one example, N_4 is fixed (e.g., $N_4 = B$ or C or $B + C$) or configured (e.g., via RRC or MAC CE or DCI) or reported by the UE (as part of the CSI report). In one example, the B or C or $B + C$ time instances can be partitioned into sub-time (ST) units (instances), where each ST unit is defined as (up to) N_{ST} contiguous time instances in the B or C or $B + C$ time instances. In this example, a component for the DD compression corresponds to a ST unit.

Three examples of the ST units are shown in FIGURE 14 for the case of B time instances. In the first example, each ST unit comprises $N_{ST} = 1$ time instance in the CSI-RS burst. In the second example, each ST unit comprises $N_{ST} = 2$ contiguous time instances in the CSI-RS burst. In the third example, each ST unit comprises $N_{ST} = 4$ contiguous time instances in the CSI-RS burst. These examples can be extended to C or $B + C$ time instances in a straight-forward manner.

The value of N_{ST} can be fixed (e.g., $N_{ST} = 1$ or 2 or 4) or indicated to the UE (e.g., via higher layer RRC or MAC CE or DCI based signaling) or reported by the UE (e.g., as part of the CSI report). The value of N_{ST} (fixed or indicated or reported) can be subject to a UE capability reporting. The value of N_{ST} can also be dependent on the value of B and/or C (e.g., one value for a range of values for B and/or C, and another value for another range of values for B and/or C).

FIGURE 15 illustrates an example of a UE configured to determine a value of N_4 with $J \geq 1$ CSI-RS bursts that occupy a frequency band and a time span 1500 according to embodiments of the present disclosure. The embodiment of the UE configured to determine a value of N_4 with $J \geq 1$ CSI-RS bursts that occupy a frequency band and a time span 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 UE configured to determine a value of N_4 with $J \geq 1$ CSI-RS bursts that occupy a frequency band and a time span 1500.

In one embodiment C, a UE is configured with $J \geq 1$ CSI-RS bursts (as illustrated earlier in the disclosure) that occupy a frequency band and a time span (duration), wherein the frequency band comprises A RBs, and the time span comprises B time instances (of CSI-RS resource(s)) or C or $B + C$ time instances, as described above. When $J > 1$, the A RBs or/and Y time instances (where $Y = B$ or C or $B + C$) can be aggregated across J CSI-RS bursts. In one example, the frequency band equals the CSI reporting band, and the time span equals the number of CSI-RS

resource instances (across J CSI-RS bursts) or the time span/window during which the CSI report is expected to be valid, both can be configured to the UE for a CSI reporting, which can be based on the DD compression.

The UE is further configured to partition (divide) the A RBs into subbands (SBs) and/or the Y time instances into sub-times (STs). The partition of A RBs can be based on a SB size value N_{SB}, which can be configured to the UE (cf. Table 5.2.1.4-2 of REF8). The partition of Y time instances can be based either a ST size value N_{ST} or an r value, as described in this disclosure (cf. embodiment B). An example is illustrated in FIGURE 15 for $Y = B$, where RB0, RB1, ..., RBA-1 comprise A RBs, $T_0, T_1, \ldots, T_{B-1}$ comprise B time instances, the SB size $N_{SB} = 4$, and the ST size $N_{ST} = 2$.

In one embodiment D, the value of N_4 depends on B. For example, $N_4 = B$, or $N_4 = B \times R_{ST}$ where $R_{ST} \geq 1$ (or $R_{ST} < 1$). So, the DD basis matrix W_d comprises N DD basis vectors $\{\boldsymbol{\phi}_s\}$, each with length $N_4 \times 1$. Here, N can be fixed or configured (e.g., via RRC, or MAC CE or DCI). Likewise, B can be fixed or configured (e.g., via RRC, or MAC CE or DCI). When configured, B can be based on the timing (slot indices) of deactivation and activation commands of the SP CSI-RS resource that is configured as the CSI-RS burst, as described in this disclosure. When configured, B can be based on the measurement window of a periodic (P) CSI-RS resource that is configured as the CSI-RS burst, as described in this disclosure.

In one example, the gNB/NW receives the CSI feedback including DD components, where the DD components include the DD basis vectors $\{\boldsymbol{\phi}_s\}$. The gNB/NW can use the CSI feedback and predict the precoding matrices for $(C = Q - N_4)$ future time slots or DD units.

In one example, the gNB/NW determines/constructs basis vectors $\{\boldsymbol{b}_s\}$, each with length $Q \times 1$ where $Q > N_4$. In one example, $Q = N_4 \times g$ where g is scaling, e.g., $g = 2$.

In one example, when $\boldsymbol{\phi}_s$ is a DFT vector with index s, then $\boldsymbol{b}_s$ can also be a DFT vector, which can be determined from $\boldsymbol{\phi}_s$.

In one example, the entries of $\boldsymbol{\phi}_s$ can be repeated g times, e.g., $[\phi_0, \phi_0, \phi_1, \phi_1, \ldots \phi_{N_4-1}, \phi_{N_4-1}]$ when $g = 2$, and the vector $\boldsymbol{b}_s$ can be the closest DFT vector of length $Q = gN_4$, where the closest DFT vector can be determined based on a metric such as max inner product value, i.e., $abs(\boldsymbol{b}_s^H \boldsymbol{\phi}_s)$.

In one example, $\boldsymbol{b}_s = [\boldsymbol{\phi}_s, \ldots \boldsymbol{\phi}_s]$ (repeated g times).

In one example, when $g = Q/N_4$ is integer, then $\boldsymbol{b}_s$ is a DFT vector with index $sg - 1$.

In this example, the rest of the components of the codebook are the same as the ones that were reported. For example, when the codebook structure is $W_1\widetilde{W}_2\left(W_f\otimes W_d\right)^H$ or $\left(W_f\otimes W_1\right)\widetilde{W}_2W_d^H$, and the CSI report includes SD basis W_1, FD basis W_f, DD basis W_d and coefficient matrix $\widetilde{W}_2$, then the gNB/NW determines/constructs the Q precoders as $W_1\widetilde{W}_2\left(W_f\otimes W_{d,pred}\right)^H$ or $\left(W_f\otimes W_1\right)\widetilde{W}_2W_{d,pred}^H$, where $W_{d,pred}$ is the predicted DD basis matrix comprising N predicted DD basis vectors $\{\boldsymbol{b}_s\}$.

In one example, the gNB/NW determines/constructs $W_2=\widetilde{W}_2\left(W_f\otimes W_d\right)^H$ and use it to determine/predict the W_2 matrices for $(C=Q-N_4)$ future time slots or DD units. Let $W_{2,pred}$ is the predicted W_2 matrix. Then, the gNB/NW determines/constructs the Q precoders as $W_1W_{2,pred}$.

In one example, the gNB/NW determines/constructs precoders $W=W_1\widetilde{W}_2\left(W_f\otimes W_d\right)^H$ or $\left(W_f\otimes W_1\right)\widetilde{W}_2W_d^H$ and use it to determine/predict the precoding matrices for $(C=Q-N_4)$ future time slots or DD units.

In one embodiment E, the value of N_4 depends on B and C (or depends on B, C, and N_{ST}), where

B = number of CSI-RS measurement instances (time slots) comprising the CSI-RS burst configured for the CSI reporting including the DD components,

C = number of additional time instances or future time slots or prediction window, and

N_{ST} is TD/DD unit size as described above.

In one example, C is length of a CSI reporting/validity window $[l,l+W_{CSI}-1]$ during which the reported CSI is expected to be valid, i.e., $W_{CSI}=C$. In one example, $l=n_{ref}$ and n_{ref} is the slot index of the CSI reference resource (5.2.2.5, TS 28.214).

In one example, $b\leq B$ and C are included in a CSI reporting/validity window $[l,l+W_{CSI}-1]$ during which the reported CSI is expected to be valid, i.e., $W_{CSI}=b+C$. In one example, $l=n_{ref}-b$ and n_{ref} is the slot index of the CSI reference resource (5.2.2.5, TS 28.214).

In one example, $N_4=T=B+C$. In one example, $N_4=T\times R_{ST}$ where $R_{ST}\geq 1$ (or $R_{ST}<1$).

In one example, $N_4=T_1=\frac{(B+C)}{N_{ST}}$. In one example, $N_4=T_1\times R_{ST}$ where $R_{ST}\geq 1$ (or $R_{ST}<1$).

In one example, $N_4 = T_2 = \frac{B}{N_{ST}} + C$. In one example, $N_4 = T_2 \times R_{ST}$ where $R_{ST} \geq 1$ (or $R_{ST} < 1$).

In one example, $N_4 = T_1 = \left\lceil \frac{(B+C)}{N_{ST}} \right\rceil$. In one example, $N_4 = T_1 \times R_{ST}$ where $R_{ST} \geq 1$ (or $R_{ST} < 1$).

In one example, $N_4 = T_2 = \left\lceil \frac{B}{N_{ST}} + C \right\rceil$ or $\left\lceil \frac{B}{N_{ST}} \right\rceil + C$. In one example, $N_4 = T_2 \times R_{ST}$ where $R_{ST} \geq 1$ (or $R_{ST} < 1$).

In one example, $N_4 = T_1 = \left\lfloor \frac{(B+C)}{N_{ST}} \right\rfloor$. In one example, $N_4 = T_1 \times R_{ST}$ where $R_{ST} \geq 1$ (or $R_{ST} < 1$).

In one example, $N_4 = T_2 = \left\lfloor \frac{B}{N_{ST}} + C \right\rfloor$ or $\left\lfloor \frac{B}{N_{ST}} \right\rfloor + C$. In one example, $N_4 = T_2 \times R_{ST}$ where $R_{ST} \geq 1$ (or $R_{ST} < 1$).

In one example, there is no measurement RS (e.g., CSI-RS or TRS or SSB) during the C time slots (window). In one example, there can be measurement RS (e.g., CSI-RS or TRS or SSB) during the C time slots (window).

The DD basis matrix W_d comprises DD basis vectors $\{\boldsymbol{\phi}_s\}$, each with length $N_4 \times 1$

In one example, the UE may not or does not need to perform any prediction (for C future slots). The UE can determine the DD basis vectors $\{\boldsymbol{\phi}_s\}$ based on the measured DL channel (H_{meas}) during B time slots (measured via the CSI-RS burst configured for CSI reporting), and a portion (or subset of entries) of the DD basis vectors that corresponds to the B CSI-RS measurements. Let $\boldsymbol{\phi}_s = [\boldsymbol{\phi}_{s,meas}, \boldsymbol{\phi}_{s,pred}]$ be a DD basis vector with a portion $\boldsymbol{\phi}_{s,meas}$ that corresponds to the B CSI-RS measurements and another portion $\boldsymbol{\phi}_{s,pred}$ that corresponds to the C future time slots. Then, $\boldsymbol{\phi}_s$ can be determined based on $\boldsymbol{\phi}_{s,meas}$ and H_{meas}. For instance, the DD basis vectors $\{\boldsymbol{\phi}_s\}$ can be determined based on a metric, e.g., max power or absolute value or max norm value $|\boldsymbol{\phi}_{s,meas}^H H_{meas}|$ or $abs(\boldsymbol{\phi}_{s,meas}^H H_{meas})$.

In one example, the UE can use the measured DL channel (H_{meas}) during B time slots (measured via the CSI-RS burst configured for CSI reporting) to predict/extrapolate the DL channel in C future time slots. The UE can then determine DD basis vectors based on the measured (H_{meas}) as well as the predicted (H_{pred}) channels. In this case, the DD basis vectors $\boldsymbol{\phi}_s$ can be determined based on $H_{agg} = [H_{meas}, H_{pred}]$. For instance, the DD basis vectors $\{\boldsymbol{\phi}_s\}$ can be

determined based on a metric, e.g., max power or absolute value or max norm value $|\boldsymbol{\phi}_s^H H_{agg}|$ or $abs(\boldsymbol{\phi}_s^H H_{agg})$.

In one example, the UE can perform the prediction based on DFT/FFT basis vectors. For example, a DFT/IFFT basis vector $F = [F_1, F_2]$ can be used to determine prediction coefficient vector as $x = F_1^H \times H_{meas}$, and then use x to predict the channel as $H_{pred} = x^H \times F_2$.

The value of B and C can be determined according to at least one of the following examples.

In one example, both B and C are fixed.

In one example, one of B and C is configured (e.g., via RRC, or MAC CE or DCI), and the other is fixed or determined based on the configured value. For example, B can be configured, and C can be fixed (e.g., $C = 10$) or determined based on B (e.g., $C = B$ or $C = t \times B$, and t can be fixed, e.g., 2).

In one example, both B and C are configured (e.g., via RRC, or MAC CE or DCI), either via two separate parameters or via a joint parameter.

In one example, one of B and C is configured (e.g., via RRC, or MAC CE or DCI), and the other is reported by UE (e.g., via UE capability reporting). For example, B can be configured, and C can be reported.

When both B and C are provided (configured) to UE, then at least one of the following examples is used.

In one example, both are configured via the same medium such as RRC, MAC CE or DCI.

In one example, one of B and C is configured via RRC, and the other via MAC CE or DCI.

In one example, one of B and C is configured via MAC CE, and the other via DCI.

When B and/or C are configured via RRC, then the configuration can be included in or a part of higher layer CSI-ResourceConfig, or higher layer CSI-ReportConfig.

When B and/or C are configured via MAC CE, then the configuration can be included in or a part of CSI trigger state that can be activated/deactivated via MAC CE.

When B and/or C are configured via DCI, then the configuration can be included in or a part of CSI trigger state that can be triggered by DCI.

In one example, one or both of B and N_4 are configured and C is determined based on B and N_4, e.g., $C = N_4 - B$. The value of B and N_4 can be determined according to at least one of the following examples.

In one example, both B and N_4 are fixed.

In one example, one of B and N_4 is configured (e.g., via RRC, or MAC CE or DCI), and the other is fixed or determined based on the configured value. For example, B can be configured, and N_4 can be fixed (e.g., $N_4 = 10$) or determined based on B (e.g., $N_4 = t \times B$, and t can be fixed, e.g., 2).

In one example, both B and N_4 are configured (e.g., via RRC, or MAC CE or DCI), either via two separate parameters or via a joint parameter.

In one example, one of B and N_4 is configured (e.g., via RRC, or MAC CE or DCI), and the other is reported by UE (e.g., via UE capability reporting). For example, B can be configured, and N_4 can be reported.

When both B and N_4 are provided (configured) to UE, then at least one of the following examples is used.

In one example, both are configured via the same medium such as RRC, MAC CE or DCI.

In one example, one of B and N_4 is configured via RRC, and the other via MAC CE or DCI.

In one example, one of B and N_4 is configured via MAC CE, and the other via DCI.

When B and/or N_4 are configured via RRC, then the configuration can be included in or a part of higher layer CSI-ResourceConfig, or higher layer CSI-ReportConfig.

When B and/or N_4 are configured via MAC CE, then the configuration can be included in or a part of CSI trigger state that can be activated/deactivated via MAC CE.

When B and/or N_4 are configured via DCI, then the configuration can be included in or a part of CSI trigger state that can be triggered by DCI.

The UE is configured to determine/report the CSI report including a PMI, where the PMI indicates SD basis vectors, FD basis vectors, DD basis vectors, and coefficients associated with triples of (SD, FD, DD) basis vectors. The coefficient reporting can be similar to Rel. 16 Type II codebook i.e., an indication of non-zero coefficients (e.g., via bitmap), SCI, reference amplitude, amplitude and phase of NZ coefficients.

The CSI report can also include CQI, where the CQI reporting can be configured to be according to at least one of the following examples.

In one example, CQI is reported using both the measurement window or time instances (B), and the prediction or future time instances (C), i.e., T_{B+C}.

In one example, CQI is reported using only the measurement window or time instances (B), i.e., T_B.

In one example, CQI is reported using only the prediction or future time instances (C), i.e., T_C.

The number of CQIs reported in TD/DD can be configured to be according to at least one of the following examples.

In one example, only one CQI is reported for the entire T_x TD/DD units, where x belongs to $\{B, C, B + C\}$. That is, the time granularity of CQI reporting is WT (as described later in this disclosure).

When CQI reporting across SBs (the frequency granularity of CQI) is WB, then only one CQI is reported for both CSI reporting band (across SBs) and time window T_x.

When CQI reporting across SBs (the frequency granularity of CQI) is per SB, then one CQI is reported for each SB, and the reported value remains the same for the time window T_x. When the multiple CQIs are reported in a differential manner, then a reference CQI value (for differential CQI reporting) is also reported.

In one example, multiple CQIs are reported for the entire T_x TD/DD units, where x belongs to $\{B, C, B + C\}$. That is, the time granularity of CQI reporting is ST (as described later in this disclosure). In one example, the number for CQI = 2. In one example, the number of CQI is N_4. In one example, the number of CQI is $N_4 + 1$ (where plus 1 is due for the reference CQI in TD).

When CQI reporting across SBs (the frequency granularity of CQI) is WB, then multiple CQIs in TD remains the same for all SBs.

When CQI reporting across SBs (the frequency granularity of CQI) is per SB, then multiple CQIs in TD are reported for each SB. When the multiple CQIs are reported in a differential manner, then a reference CQI value (for differential CQI reporting) is also reported or two reference CQI values (one for TD, another for FD) are also reported.

In one embodiment F, the value of N_4 depends on C (or depends on C, and N_{ST}), where

C = number of additional time instances or future time slots or prediction window, and

N_{ST} is TD/DD unit size as described above.

In one example, $N_4 = T = C$. In one example, $N_4 = T \times R_{ST}$ where $R_{ST} \geq 1$ (or $R_{ST} < 1$).

In one example, $N_4 = T_1 = \frac{C}{N_{ST}}$. In one example, $N_4 = T_1 \times R_{ST}$ where $R_{ST} \geq 1$ (or $R_{ST} < 1$).

In one example, $N_4 = T_1 = \left\lceil \frac{C}{N_{ST}} \right\rceil$. In one example, $N_4 = T_1 \times R_{ST}$ where $R_{ST} \geq 1$ (or $R_{ST} < 1$).

In one example, $N_4 = T_1 = \left\lfloor \frac{C}{N_{ST}} \right\rfloor$. In one example, $N_4 = T_1 \times R_{ST}$ where $R_{ST} \geq 1$ (or $R_{ST} < 1$).

In one example, there is no measurement RS (e.g., CSI-RS or TRS or SSB) during the C time slots (window). In one example, there can be measurement RS (e.g., CSI-RS or TRS or SSB) during the C time slots (window).

The DD basis matrix W_d comprises DD basis vectors $\{\boldsymbol{\phi}_s\}$, each with length $N_4 \times 1$.

In one example, the UE may not or does not need to perform any prediction (for C future slots). The UE can determine the DD basis vectors $\{\boldsymbol{\phi}_s\}$ based on the measured DL channel (H_{meas}) during B time slots (measured via the CSI-RS burst configured for CSI reporting).

In one example, the UE can use the measured DL channel (H_{meas}) during B time slots (measured via the CSI-RS burst configured for CSI reporting) to predict/extrapolate the DL channel in C future time slots. The UE can then determine DD basis vectors based on the predicted (H_{pred}) channels. For instance, the DD basis vectors $\{\boldsymbol{\phi}_s\}$ can be determined based on a metric, e.g., max power or absolute value or max norm value $|\boldsymbol{\phi}_s^H H_{pred}|$ or $abs(\boldsymbol{\phi}_s^H H_{pred})$.

In one example, the UE can perform the prediction based on DFT/FFT basis vectors. For example, a DFT/IFFT basis vector $F = [F_1, F_2]$ can be used to determine prediction coefficient vector as $x = F_1^H \times H_{meas}$, and then use x to predict the channel as $H_{pred} = x^H \times F_2$.

The value of C can be determined according to at least one of the following examples.

In one example, C is fixed.

In one example, C is configured (e.g., via RRC, or MAC CE or DCI).

In one example, C is reported by UE (e.g., via UE capability reporting).

When C is configured via RRC, then the configuration can be included in or a part of higher layer CSI-ResourceConfig, or higher layer CSI-ReportConfig.

When C is configured via MAC CE, then the configuration can be included in or a part of CSI trigger state that can be activated/deactivated via MAC CE.

When C is configured via DCI, then the configuration can be included in or a part of CSI trigger state that can be triggered by DCI.

In one example, N_4 is configured and C is determined based on N_4. The value of C and N_4 can be determined according to at least one of the following examples.

In one example, both C and N_4 are fixed.

In one example, one of C and N_4 is configured (e.g., via RRC, or MAC CE or DCI), and the other is fixed or determined based on the configured value. For example, C can be configured, and N_4 can be fixed (e.g., $N_4 = 10$) or determined based on C (e.g., $N_4 = t \times C$, and t can be fixed, e.g., 2).

In one example, both C and N_4 are configured (e.g., via RRC, or MAC CE or DCI), either via two separate parameters or via a joint parameter.

In one example, one of C and N_4 is configured (e.g., via RRC, or MAC CE or DCI), and the other is reported by UE (e.g., via UE capability reporting). For example, C can be configured, and N_4 can be reported.

When both C and N_4 are provided (configured) to UE, then at least one of the following examples is used.

In one example, both are configured via the same medium such as RRC, MAC CE or DCI.

In one example, one of C and N_4 is configured via RRC, and the other via MAC CE or DCI.

In one example, one of C and N_4 is configured via MAC CE, and the other via DCI.

When C or/and N_4 are configured via RRC, then the configuration can be included in or a part of higher layer CSI-ResourceConfig, or higher layer CSI-ReportConfig.

When C or/and N_4 are configured via MAC CE, then the configuration can be included in or a part of CSI trigger state that can be activated/deactivated via MAC CE.

When C or/and N_4 are configured via DCI, then the configuration can be included in or a part of CSI trigger state that can be triggered by DCI.

The UE is configured to determine/report the CSI report including a PMI, where the PMI indicates SD basis vectors, FD basis vectors, DD basis vectors, and coefficients associated with triples of (SD, FD, DD) basis vectors. The coefficient reporting can be similar to Rel. 16 Type II codebook i.e., an indication of non-zero coefficients (e.g., via bitmap), SCI, reference amplitude, amplitude and phase of NZ coefficients.

In the rest of the disclosure, the signaling/configuration related to the (time or/and frequency) granularity of (components of) the CSI reporting (based on the DD compression) is discussed, where the 'granularity' of a quantity refers to the number of values of the quantity is

reported in the CSI reported. For example, when the quantity is CQI, then the granularity of the CQI can correspond to one (i.e., only one CQI value is reported) or multiple (i.e., multiple CQI values are reported).

In one embodiment I.1, the frequency granularity (i.e., the granularity in FD) of a component, say X, of the CSI report is determined/configured according to at least one of the following examples.

In one example I.1.1, the frequency granularity is wideband (WB), i.e., one (single) wideband X is reported for each codeword for the entire CSI reporting band (comprising A RBs).

In one example I.1.2, the frequency granularity is subband (SB) i.e., multiple X values are reported, one for each codeword is reported for each SB in the CSI reporting band.

In one example I.1.3, the frequency granularity is subband (SB) w.r.t. to a WB reference, i.e., it is a combination of WB and SB (or differential SB w.r.t. WB). As reference, one (single) wideband X reported for each codeword for the entire CSI reporting band. As differential, one X for each codeword is reported for each subband in the CSI reporting band. For each SB index s, a SB differential X is defined as: SB offset level (s) = SB X index (s) - WB X index. An example of the mapping from the 2-bit SB differential X values to the offset level is shown in Table 2.

Table 2: Mapping and differential X value to offset level

differential ***X*** value	Offset level
0	0
1	1
2	≥ 2
3	≤ -1

In one example, the component X in this embodiment can only be CQI. In one example, the component X in this embodiment can be CQI or PMI. In one example, the component X in this embodiment can be CQI or RI. In one example, the component X in this embodiment can be CQI or PMI or RI.

In one example, the frequency granularity of the component X is determined by the UE and this information is reported by the UE, e.g., as part of the CSI report or UE capability information. In one example, the frequency granularity of the component X is configured to the

UE, e.g., via RRC, MAC-CE, or DCI, and the configuration can be subject to the UE capability reported by the UE.

The partitioning of A RBs into SBs is performed when the frequency granularity is according to Example I.1.2 or I.1.3. For some components X (e.g., PMI), each SB can be partitioned further into (up to) R parts, similar to the PMI reporting based on the Rel. 16 enhanced Type II codebook. The value of R can belong to $\{1,2,N_{SB}\}$. The value of R can be configured (e.g., via higher layer), which can be subject to the UE capability reporting. In one example, the support for $R = 1$ is mandatory (hence, doesn't require additional signaling from the UE), and the support of $R > 1$ is optional (hence, requires additional signaling if the UE supports it). Examples of two R values, $R = 1,2$ are illustrated in FIGURE 15, where when $R = 1$, SBs are not partitioned (i.e., 4 RBs form a SB), and when $R = 2$, each SB is partitioned into two parts (i.e., 4 RBs form a SB, which is partitioned into 2 parts, each with 2 RBs). When $R > 1$, a total of N_3 quantities of X are reported (e.g., via the PMI when X=PMI), one for each FD unit/component, where $N_3 = R \times N_{SB}^{tot}$ when each SB is partitioned into R parts, and $N_3 = R \times (N_{SB}^{tot} - 2) + P + Q$ in general, where N_{SB}^{tot} is the total number of SBs, P is number of parts of the first SB, Q is number of parts of the last SB, and $P, Q \in \{1, \dots R\}$.

In one embodiment I.2, the time granularity (i.e., the granularity in TD) of a component, say X, of the CSI report is determined/configured according to at least one of the following examples.

In one example I.2.1, the time granularity is wide-time (WT), i.e., one (single) wide-time X is reported for each codeword for the entire time span (duration) comprising B or C or $B + C$ time instances.

In one example I.2.2, the time granularity is subtime (ST) i.e., multiple X values are reported, one for each codeword is reported for each ST in the entire time span.

In one example I.2.3, the time granularity is subtime (ST) w.r.t. to a WT reference, i.e., it is a combination of WT and ST (or differential ST w.r.t. WT). As reference, one (single) wide time X reported for each codeword for the entire time span. As differential, one X for each codeword is reported for each subtime in the entire time span. For each ST index t, a ST differential X is defined as: ST offset level (t) = ST X index (t) - WT X index. An example of the mapping from the 2-bit ST differential X values to the offset level is shown in Table 2.

In one example, the component X in this embodiment can only be CQI. In one example, the component X in this embodiment can be CQI or PMI. In one example, the component X in this embodiment can be CQI or RI. In one example, the component X in this embodiment can be CQI or PMI or RI.

In one example, the time granularity of the component X is determined by the UE and this information is reported by the UE, e.g., as part of the CSI report or UE capability information. In one example, the time granularity of the component X is configured to the UE, e.g., via RRC, MAC-CE, or DCI, and the configuration can be subject to the UE capability reported by the UE.

The partitioning of B or C or $B + C$ time instances into STs is performed when the time granularity is according to Example I.2.2 or I.2.3. For some components X (e.g., PMI), each ST can be partitioned further into (up to) R_{ST} parts, similar to the PMI reporting based on the Rel. 16 enhanced Type II codebook. The value of R_{ST} can belong to $\{1,2, N_{ST}\}$. The value of R_{ST} can be configured (e.g., via higher layer), which can be subject to the UE capability reporting. In one example, the support for $R_{ST} = 1$ is mandatory (hence, doesn't require additional signaling from the UE), and the support of $R_{ST} > 1$ is optional (hence, requires additional signaling if the UE supports it). Examples of two R_{ST} values, $R_{ST} = 1,2$ are illustrated in FIGURE 15 for B time instances, where when $R_{ST} = 1$, STs are not partitioned (i.e., 2 time instances form a ST), and when $R_{ST} = 2$, each ST is partitioned into two parts (2 time instances form a ST, which is partitioned into 2 parts, each with 1 time instance). When $R_{ST} > 1$, a total of N_4 quantities of X are reported (via the PMI when X=PMI), one for each ST unit/component, where $N_4 = R_{ST} \times N_{ST}^{tot}$ when each ST is partitioned into R_{ST} parts, and $N_4 = R_{ST} \times (N_{ST}^{tot} - 2) + P_{ST} + Q_{ST}$ in general, where N_{ST}^{tot} is the total number of STs, P_{ST} is number of parts of the first ST, Q_{ST} is number of parts of the last ST, and $P_{ST}, Q_{ST} \in \{1, \ldots R_{ST}\}$.

In one embodiment I.3, the frequency and time granularities (i.e., granularity in FD and TD) of a component, say X, of the CSI report is according to at least one of the following examples.

In one example I.3.1, both frequency and time granularities are fixed, hence there is no need for any signaling or configuration. In particular, the frequency and time granularities are fixed to example I.1.a and example I.2.b, respectively, where (a, b) is one of (1,1), (1,2), (1,3), (2,1), (2,2), (2,3), (3,1), (3,2), and (3,3).

In one example I.3.2, the frequency granularity is signaled/configured (e.g., RRC, MAC-CE, or DCI), and the time granularity is fixed. In particular, the frequency granularity is

signaled/configured from example I.1.1 through I.1.3, and the time granularity is fixed to one of example I.2.1 through I.2.3.

In one example I.3.3, the time granularity is signaled/configured (e.g., RRC, MAC-CE, or DCI), and the frequency granularity is fixed. In particular, the time granularity is signaled/configured from example I.2.1 through I.2.3, and the frequency granularity is fixed to one of example I.1.1 through I.1.3.

In one example I.3.4, both frequency and time granularities are signaled/configured (e.g., RRC, MAC-CE, or DCI). In particular, the frequency granularity is signaled/configured from example I.1.1 through I.1.3, and the time granularity is signaled/configured from example I.2.1 through I.2.3. The signaling/configuration of the frequency and time granularities can be separate (i.e., via two separate parameters or configurations), or joint (i.e., via one parameter or configuration).

In one example, the component X in this embodiment can only be CQI. In one example, the component X in this embodiment can be CQI or PMI. In one example, the component X in this embodiment can be CQI or RI. In one example, the component X in this embodiment can be CQI or PMI or RI.

In one example, the frequency and time granularities of the component X are determined by the UE and this information is reported by the UE, e.g., as part of the CSI report or UE capability information. In one example, the frequency and time granularities of the component X are configured to the UE, e.g., via RRC, MAC-CE, or DCI, and the configuration can be subject to the UE capability reported by the UE. In one example, one of the frequency and time granularities is determined by the UE and this information is reported by the UE, e.g., as part of the CSI report or UE capability information, and the other of the frequency and time granularities is configured to the UE, e.g., via RRC, MAC-CE, or DCI.

The partitioning of A RBs into SBs is performed when the frequency granularity is according to Example I.1.2 or I.1.3, the details as in embodiment I.1. Likewise, the partitioning of B or C or $B + C$ time instances into STs is performed when the time granularity is according to Example I.2.2 or I.2.3, the details as in embodiment I.2.

FIGURE 16 illustrates an example of the time and frequency granularities of reporting X 1600 according to embodiments of the present disclosure. The embodiment of the time and frequency granularities of reporting X 1600 illustrated in FIGURE 16 is for illustration only.

FIGURE 16 does not limit the scope of this disclosure to any particular implementation of the time and frequency granularities of reporting X 1600.

An illustration of the time and frequency granularities of reporting X is shown in FIGURE 16, wherein four examples are shown: when the reporting format is (WB, WT), only one value for X is reported for the whole CSI band and for entire time span; when the reporting format is (WB, ST), four values for X are reported, each value is for the whole CSI band and a specific ST; when the reporting format is (SB, WT), 8 values for X are reported, each value is for a specific SB and the entire time span; when the reporting format is (SB, ST), 32 values for X are reported, each value is for a specific SB and a specific ST.

In one embodiment I.4, the frequency and time granularities of two components, say X_1 and X_2, of the CSI report is according to at least one of the following examples.

In one example I.4.1, the frequency and time granularities for both X_1 and X_2 are fixed, hence there is no need for any signaling or configuration. In particular, the frequency and time granularities for both X_1 and X_2 are fixed according to example I.3.1 with $(a, b) = (a_1, b_1)$ and $(a, b) = (a_2, b_2)$ for X_1 and X_2, respectively. In one example, $(a_1, b_1) = (a_2, b_2)$. In one example, $a_1 = a_2$ but b_1 and b_2 can be the same or different. In one example, $b_1 = b_2$ but a_1 and a_2 can be the same or different. In one example, both a_1 and a_2, and b_1 and b_2 can be the same or different.

In one example I.4.2, the frequency and time granularities for X_1 are signaled/configured (e.g., RRC, MAC-CE, or DCI), and the frequency and time granularities for X_2 are fixed (i.e., signaling/configuration is only for X_1). In particular, the frequency and time granularities for X_1 is signaled/configured from example I.3.2 through I.3.4, and the frequency and time granularities for X_2 are fixed according to example I.3.1.

In one example I.4.3, the frequency and time granularities for X_2 are signaled/configured (e.g., RRC, MAC-CE, or DCI), and the frequency and time granularities for X_1 are fixed (i.e., signaling/configuration is only for X_2). In particular, the frequency and time granularities for X_2 is signaled/configured from example I.3.2 through I.3.4, and the frequency and time granularities for X_1 are fixed according to example I.3.1.

In one example I.4.4, the frequency and time granularities for both X_1 and X_2 are signaled/configured (e.g., RRC, MAC-CE, or DCI). In particular, the frequency and time granularities for both X_1 and X_2 are signaled/configured from example I.3.2 through I.3.4. In one example, the frequency and time granularities for both X_1 and X_2 are the same, hence, the

one/same example from example I.3.2 through I.3.4 is used. In one example, the frequency and time granularities for both X_1 and X_2 can be the same or different, hence two examples, each from example I.3.2 through I.3.4 is used, one for X_1 and another for X_2 . Also, the signaling/configuration of the frequency and time granularities for X_1 and X_2 can be separate (i.e., via two separate parameters or configurations), or joint (i.e., via one parameter or configuration).

In one example, the two components (X_1 and X_2) in this embodiment can only be X_1 = PMI and X_2 = CQI. In one example, two components (X_1 and X_2) in this embodiment can be (X_1, X_2) = (PMI, CQI), or (PMI, RI), or (RI, CQI).

In one example, the frequency and time granularities of the components X_1 and X_2 are determined by the UE and this information is reported by the UE, e.g., as part of the CSI report or UE capability information. In one example, the frequency and time granularities of the components X_1 and X_2 are configured to the UE, e.g., via RRC, MAC-CE, or DCI, and the configuration can be subject to the UE capability reported by the UE. In one example, one of the frequency and time granularities of component X_i (i = 1,2) is determined by the UE and this information is reported by the UE, e.g., as part of the CSI report or UE capability information, and the other of the frequency and time granularities of component X_i (i = 1,2) is configured to the UE, e.g., via RRC, MAC-CE, or DCI.

In one embodiment I.5, when the frequency and time granularities of CQI reporting is signaled/configured (e.g., RRC, MAC-CE, or DCI) as described in example I.3.4, the signaling/configuration can be according to at least one of the following examples.

In one example I.5.1, the signaling is separate via two separate parameters, for example, using a first parameter cqiFormatIndicator or cqiFrequencyFormatIndicator indicating a value from {wideband, subband} for frequency granularity, and using a second parameter cqiFormatIndicator2 or cqiTimeFormatIndicator indicating a value from {wide-time, sub-time} for time granularity.

In one example I.5.2, the signaling is joint via one parameter, for example, using a joint parameter cqiFormatIndicator indicating a pair of values from {(wideband, wide-time), (wideband, sub-time), (subband, wide-time), (subband, sub-time)} for (frequency, time) granularity pair.

In one embodiment I.6, when the frequency and time granularities of PMI reporting is signaled/configured (e.g., RRC, MAC-CE, or DCI) as described in example I.3.4, the signaling/configuration can be according to at least one of the following examples.

In one example I.6.1, the signaling is separate via two separate parameters, for example, using a first parameter pmiFormatIndicator or pmiFrequencyFormatIndicator indicating a value from {wideband, subband} for frequency granularity, and using a second parameter pmiFormatIndicator2 or pmiTimeFormatIndicator indicating a value from {wide-time, sub-time} for time granularity.

In one example I.6.2, the signaling is joint via one parameter, for example, using a joint parameter pmiFormatIndicator indicating a pair of values from {(wideband, wide-time), (wideband, sub-time), (subband, wide-time), (subband, sub-time)} for (frequency, time) granularity pair.

In one embodiment I.7, when the frequency and time granularities of both CQI and PMI reporting are signaled/configured (e.g., RRC, MAC-CE, or DCI) as described in example I.3.4, the signaling/configuration can be according to at least one of the following examples.

In one example I.7.1, the signaling/configuration is common for both PMI and CQI and indicates the same time and frequency granularities for PMI and CQI.

In one example I.7.1.1, the signaling is separate via two separate parameters, for example, using a first parameter FormatIndicator or frequencyFormatIndicator indicating a value from {wideband, subband} for frequency granularity, and using a second parameter formatIndicator2 or timeFormatIndicator indicating a value from {wide-time, sub-time} for time granularity.

In one example I.7.1.2, the signaling is joint via one parameter, for example, using a joint parameter formatIndicator indicating a pair of values from {(wideband, wide-time), (wideband, sub-time), (subband, wide-time), (subband, sub-time)} for (frequency, time) granularity pair.

In one example I.7.2, the signaling/configuration of the time granularity is common for PMI and CQI and indicates the same time granularity for PMI and CQI; and the signaling/configuration of the frequency granularity is separate for PMI and CQI.

In one example I.7.2.1, the signaling is via 3 parameters (p1,p2,p3)

p1=timeFormatIndicator indicating a value from {wide-time, sub-time} for time granularity,

p2=pmiFrequencyFormatIndicator indicating a value from {wideband, subband} for frequency granularity of PMI,

p3=cqiFrequencyFormatIndicator indicating a value from {wideband, subband} for frequency granularity of CQI.

In one example I.7.2.2, the signaling is via 2 parameters (p1,p2) which are according to one of the following examples.

In one example, p1 indicates a pair (timeFormatIndicator, cqiFrequencyFormatIndicator), and p2=pmiFrequencyFormatIndicator.

In one example, p1 indicates a pair (timeFormatIndicator, pmiFrequencyFormatIndicator), and p2=cqiFrequencyFormatIndicator.

In one example, p1 indicates a pair (pmiFrequencyFormatIndicator, cqiFrequencyFormatIndicator), and p3=timeFormatIndicator.

In one example I.7.2.3, the signaling is via 1 parameter p indicating a triple (timeFormatIndicator, pmiFrequencyFormatIndicator, cqiFrequencyFormatIndicator).

In one example I.7.3, the signaling/configuration of the frequency granularity is common for PMI and CQI and indicates the same frequency granularity for PMI and CQI; and the signaling/configuration of the time granularity is separate for PMI and CQI.

In one example I.7.3.1, the signaling is via 3 parameters (p1,p2,p3)

p1=frequencyFormatIndicator indicating a value from {wideband, subband} for frequency granularity,

p2=pmiTimeFormatIndicator indicating a value from {wide-time, sub-time} for time granularity of PMI,

p3=cqiTimeFormatIndicator indicating a value from {wide-time, sub-time} for time granularity of CQI.

In one example I.7.3.2, the signaling is via 2 parameters (p1,p2) which are according to one of the following examples.

In one example, p1 indicates a pair (frequencyFormatIndicator, pmiTimeFormatIndicator), and p2= cqiTimeFormatIndicator.

In one example, p1 indicates a pair (frequencyFormatIndicator, cqiTimeFormatIndicator), and p2= pmiTimeFormatIndicator.

In one example, p1 indicates a pair (pmiTimeFormatIndicator, cqiTimeFormatIndicator), and p3= frequencyFormatIndicator.

In one example I.7.3.3, the signaling is via 1 parameter p indicating a triple (frequencyFormatIndicator, pmiTimeFormatIndicator, cqiTimeFormatIndicator).

In one example I.7.4, the signaling/configuration is separate for PMI and CQI. For CQI, it is according to one of example I.5.1 and I.5.2, and for PMI, it is according to one of example I.6.1

and I.6.2. Let a=pmiTimeFormatIndicator indicating a value from {wide-time, sub-time} for time granularity of PMI, b=cqiTimeFormatIndicator indicating a value from {wide-time, sub-time} for time granularity of CQI, c=pmiFrequencyFormatIndicator indicating a value from {wideband, subband} for frequency granularity of PMI, d=cqiFrequencyFormatIndicator indicating a value from {wideband, subband} for frequency granularity of CQI.

In one example I.7.4.1, the signaling is via 4 parameters (p1,p2,p3,p4): p1=a, p2=b, p3=c, p4=d.

In one example I.7.4.2, the signaling is via 3 parameters (p1,p2,p3) parameters, which are according to one of the following examples.

In one example, p1 indicates a pair (a,b), p2=c, and p3=d.

In one example, p1 indicates a pair (a,c), p2=b, and p3=d.

In one example, p1 indicates a pair (a,d), p2=b, and p3=c.

In one example, p1 indicates a pair (b,c), p2=a, and p3=d.

In one example, p1 indicates a pair (b,d), p2=a, and p3=c.

In one example, p1 indicates a pair (c,d), p2=a, and p3=b.

In one example I.7.4.3, the signaling is via 2 parameters (p1,p2) parameters, which are according to one of the following examples.

In one example, p1 indicates a triple (a,b,c), and p2=d.

In one example, p1 indicates a triple (a,b,d), and p2=c.

In one example, p1 indicates a triple (b,c,d), and p2=a.

In one example, p1 indicates a triple (a,c,d), and p2=b.

In one example I.7.4.4, the signaling is via p indicates a tuple (a,b,c,d).

The frequency and time granularities are not separate (decoupled), they are rather coupled, e.g., as a two-dimensional (2D) granularity, namely frequency-time (F-T) or time-frequency (T-F) granularity. The CSI reporting band comprising A RBs and the time span (duration) comprising B time instances comprise the (2D) F-T measurement window.

FIGURE 17 illustrates an example of the F-T granularity 1700 according to embodiments of the present disclosure. The embodiment of the F-T granularity 1700 illustrated in FIGURE 17 is for illustration only. FIGURE 17 does not limit the scope of this disclosure to any particular implementation of F-T granularity 1700.

In one embodiment II.1, the F-T granularity of a component, say X, of the CSI report is according to at least one of the following examples.

In one example II.1.1, the F-T granularity is widebandAndTime (WBT), i.e., one (single) X is reported for each codeword for the entire 2D F-T measurement window.

In one example II.1.2, the T-F granularity is subbandAndTime (SBT) i.e., multiple X values are reported, one for each codeword is reported for each SBT in the 2D F-T measurement window.

In one example II.1.3, the F-T granularity is subbandAndTime (SBT) w.r.t. to a WBT reference, i.e., it is a combination of WBT and SBT (or differential SBT w.r.t. WBT). As reference, one (single) wideband X reported for each codeword for the entire 2D F-T measurement window. As differential, one X for each codeword is reported for each SBT in the 2D F-T measurement window. For each SBT index s, a SBT differential X is defined as: SBT offset level (s) = SBT X index (s) - WBT X index. An example of the mapping from the 2-bit SBT differential X values to the offset level is shown in Table 2.

In examples II.1.2 and II.1.3, the F-T measurement window is partitioned into multiple units, say subbandAndTime (SBT) units. The size of a SBT unit depends on the number of RBs and time instances comprising an SBT. An illustration of the F-T granularity is shown in FIGURE 17, wherein six examples are shown: when the reporting format is WBT, only one value for X is reported for the entire 2D F-T measurement window; when the reporting format is SBT, multiple values for X are reported, one for each SBT. Five examples of SBTs with different sizes are shown.

In one example, an SBT unit corresponds to a regular shape (e.g., as shown in FIGURE 17). The size of an SBT unit can be fixed, or configured (e.g., via RRC, MAC-CE, or DCI), or reported by the UE (e.g., as part of CSI report or UE capability reporting).

In one example, an SBT unit corresponds to a pattern, which can be irregular in shape. The SBT pattern can be fixed, or configured (e.g., via RRC, MAC-CE, or DCI), or reported by the UE (e.g., as part of CSI report or UE capability reporting).

In one example, an SBT unit corresponds to a regular shape or a pattern (which can be irregular in shape). The size or pattern of an SBT unit can be fixed, or configured (e.g., via RRC, MAC-CE, or DCI), or reported by the UE (e.g., as part of CSI report or UE capability reporting).

In one embodiment II.2, the F-T granularity of a component, say X, of the CSI report is according to at least one of the following examples.

In one example II.2.1, the F-T granularity is fixed, hence there is no need for any signaling or configuration. In particular, the F-T granularity is fixed to example II.1.a, where a is one of 1, 2, or 3.

In one example II.2.2, the F-T granularity is signaled/configured (e.g., RRC, MAC-CE, or DCI). In particular, it is signaled/configured from example II.1.1 through II.1.3.

In one example, the component X in this embodiment can only be CQI. In one example, the component X in this embodiment can be CQI or PMI. In one example, the component X in this embodiment can be CQI or RI. In one example, the component X in this embodiment can be CQI or PMI or RI.

In one example, the F-T granularity of the component X is determined by the UE and this information is reported by the UE, e.g., as part of the CSI report or UE capability information. In one example, the F-T granularity of the component X is configured to the UE, e.g., via RRC, MAC-CE, or DCI, and the configuration can be subject to the UE capability reported by the UE.

In one embodiment II.3, the F-T granularities of two components, say X_1 and X_2, of the CSI report is according to at least one of the following examples.

In one example II.3.1, the F-T granularities for both X_1 and X_2 are fixed, hence there is no need for any signaling or configuration. In particular, the F-T granularities for both X_1 and X_2 are fixed according to example II.2.1 with $a = a_1$ and $a = a_2$ for X_1 and X_2, respectively. In one example, $a_1 = a_2$. In one example, a_1 and a_2 can be the same or different.

In one example II.3.2, the F-T granularity for X_1 is signaled/configured (e.g., RRC, MAC-CE, or DCI), and the F-T granularity for X_2 are fixed (i.e., signaling/configuration is only for X_1). In particular, the F-T granularity for X_1 is signaled/configured according to example II.2.2, and the F-T granularity for X_2 is fixed according to example II.2.1.

In one example II.3.3, the F-T granularity for X_2 is signaled/configured (e.g., RRC, MAC-CE, or DCI), and the F-T granularity for X_1 are fixed (i.e., signaling/configuration is only for X_2). In particular, the F-T granularity for X_2 is signaled/configured according to example II.2.2, and the F-T granularity for X_1 is fixed according to example II.2.1.

In one example II.3.4, the F-T granularities for both X_1 and X_2 are signaled/configured (e.g., RRC, MAC-CE, or DCI). In particular, the F-T granularities for both X_1 and X_2 are signaled/configured according to example II.2.2. In one example, the F-T granularities for both X_1 and X_2 are the same, hence, the one/same/single configuration is used/sufficient. In one example, the F-T granularities for both X_1 and X_2 can be the same or different, hence two configurations, one for X_1 and another for X_2, is used/needed. Also, the signaling/configuration of the F-T

granularities for X_1 and X_2 can be separate (i.e., via two separate parameters or configurations), or joint (i.e., via one parameter or configuration).

In one example, the two components (X_1 and X_2) in this embodiment can only be X_1 = PMI and X_2 = CQI. In one example, two components (X_1 and X_2) in this embodiment can be (X_1, X_2) = (PMI, CQI), or (PMI, RI), or (RI, CQI).

In one example, the F-T granularity of the components X_1 and X_2 are determined by the UE and this information is reported by the UE, e.g., as part of the CSI report or UE capability information. In one example, the F-T granularity of the components X_1 and X_2 are configured to the UE, e.g., via RRC, MAC-CE, or DCI, and the configuration can be subject to the UE capability reported by the UE. In one example, the F-T granularity of one of components X_i $(i = 1,2)$ is determined by the UE and this information is reported by the UE, e.g., as part of the CSI report or UE capability information, and the F-T granularity of another of components X_i $(i = 1,2)$ is configured to the UE, e.g., via RRC, MAC-CE, or DCI.

In one embodiment II.4, the F-T granularities of at least one of CQI and PMI is signaled/configured according to at least one of the following examples.

In one example II.4.1, when the F-T granularity of CQI reporting is signaled/configured (e.g., RRC, MAC-CE, or DCI) as described in example II.2.2, the signaling/configuration can be via a parameter, for example, parameter cqiFormatIndicator, indicating a value from {WBT, SBT}.

In one example II.4.2, when the F-T granularity of PMI reporting is signaled/configured (e.g., RRC, MAC-CE, or DCI) as described in example II.2.2, the signaling/configuration can be via a parameter, for example, parameter pmiFormatIndicator, indicating a value from {WBT, SBT}.

In one example II.4.3, when the F-T granularities of both CQI and PMI reporting are signaled/configured (e.g., RRC, MAC-CE, or DCI) as described in example II.2.2, the signaling/configuration can be according to at least one of the following examples.

In one example II.4.3.1, the F-T granularities of CQI and PMI are the same, hence the signaling/configuration is common for both PMI and CQI and indicates the same/one/single F-T granularity that is used common for both PMI and CQI. For example, the signaling is via one parameter, for example, parameter formatIndicator indicating a value from {WBT, SBT}.

In one example II.4.3.2, the F-T granularities of PMI and CQI are separate (can be the same or different), and the signaling/configuration is via 2 parameters (p1,p2), where p1 =

pmiFormatIndicator indicating a value from {WBT, SBT} for the F-T granularity of PMI, and p2= cqiFormatIndicator indicating a value from {WBT, SBT} for the F-T granularity of CQI.

In one example II.4.3.3, the F-T granularities of PMI and CQI are separate (can be the same or different) and the signaling/configuration is via 1 parameter p indicating a pair (pmiFormatIndicator, cqiFormatIndicator).

In one embodiment III.1, the granularity of RI reporting (included in the CSI reporting based on the codebook with Doppler component as described in this disclosure) is according to at least one of the following examples.

In one example III.1.1, RI is not reported, and the CSI report (including components such as PMI and CQI) corresponds to a rank value, which can be fixed (e.g., rank 1), or configured (e.g., via higher layer signaling such as RI-restriction or rank-restriction).

In one example III.1.2, a single RI value is reported, and the rest of the CSI components (such as PMI and CQI) are conditioned on (or according to) the rank value indicated via the reported RI value. The set of allowed or candidate rank values for RI reporting can be fixed (e.g., rank 1-2 or 1-4), or configured (e.g., via higher layer signaling such as RI-restriction or rank-restriction).

In one example III.1.3, multiple RI values are reported, and for each rank value (indicated via one of the multiple RI values), the rest of the CSI components (such as PMI and CQI) are reported, i.e., the CSI report includes $\{(r, C_r), r \in R\}$, where R is the set of rank values indicated via the multiple RI values, r is a rank value included in the set R, and C_r is CSI components (such as PMI and CQI) conditioned on rank r. The set R can be determined based on a set S, which is the set of allowed or candidate rank values for RI reporting, and it can be fixed (e.g., rank 1-2 or 1-4), or configured (e.g., via higher layer signaling such as RI-restriction or rank-restriction).

In one example III.1.3.1, the multiple RI values correspond to rank values potentially varying in time domain (e.g., across STs) and fixed in frequency domain (e.g., across SBs). Let n_t is the number of rank values reported via the multiple RI values. Then, the B or C or $B + C$ time instances can be partitioned into n_t time-domain (TD) parts, and one rank value is reported for each TD part. Note that the rank value is fixed within each TD part (i.e., for all SBs and STs within each TD part).

In one example III.1.3.2, the multiple RI values correspond to rank values potentially varying in frequency domain (e.g., across SBs) and fixed in time domain (e.g., across STs). Let n_f is the number of rank values reported via the multiple RI values. Then, the A frequency instances

can be partitioned into n_f frequency-domain (FD) parts, and one rank value is reported for each FD part. Note that the rank value is fixed within each FD part (i.e., for all STs and SBs within each FD part).

In one example III.1.3.3, the multiple RI values correspond to rank values potentially varying in both frequency domain (e.g., across SBs) and time domain (e.g., across STs). Then, the A frequency instances, and B or C or $B + C$ time instances can be partitioned into $n_t n_f$ TD-FD parts, and one rank value is reported for each TD-FD part. Note that the rank value is fixed within each TD-FD part (i.e., for all SBs and STs within each TD-FD part).

In one example, when multiple RI values are reported, the RI reporting can be differential with respect to a reference RI value. As reference, one RI value is reported. As differential, one RI value is reported for each part, where a part is as explained in example III.1.3. For each part index p, a differential RI is defined as: RI offset level (p) = RI index (p) – reference RI index. An example of the mapping from the 2-bit differential RI values to the RI offset level is shown in Table 2.

In one embodiment III.2, the granularity of RI reporting can be fixed (e.g., to example III.1.1 or III.1.2). Or it is signaled/configured (e.g., RRC, MAC-CE, or DCI). The configuration can include an information on whether RI reporting is according to example III.1.1 or example III.1.2 or example III.1.3. When the configuration allows RI reporting according to multiple of examples III.1.1 through example III.1.3, then the reporting format (or granularity) of RI reporting can be further configured, e.g., via a parameter riFormatIndicator.

In one example III.2.1, the granularity of RI reporting is signaled/configured to be one of example III.1.a and III.1.b, where (a,b) = one of (1,2), (1,3), (2,3).

In one example III.2.2, the granularity of RI reporting is signaled/configured to be one of example III.1.1, example III.1.2, and example III.1.3.

In one example III.2.3, the granularity of RI reporting is signaled/configured according to example III.2.1 or III.2.2 subject to UE capability reported by the UE. For example, whether the UE supports multiple RI reporting (example III.1.3) can be reported by the UE in its capability reporting, and only when the UE reports being capable of reporting multiple RI values, it can be configured with such RI reporting (by the NW.gNB).

FIGURE 18 illustrates a timing relation between CSI-RS occasion, CSI reference resource, and CSI report 1800 according to embodiments of the present disclosure. The embodiment of the timing relation between CSI-RS occasion, CSI reference resource, and CSI report 1800 is for illustration only. FIGURE 18 does not limit the scope of this disclosure to any particular

implementation of the timing relation between CSI-RS occasion, CSI reference resource, and CSI report 1800.

The block error (BLER) probability requirement for CQI reporting as defined in Section 5.2.2.1 of TS 38.214 is as follows. The UE shall derive for each CQI value reported in uplink slot on the highest CQI index which satisfies the following condition:

A single PDSCH transport block with a combination of modulation scheme, target code rate and transport block size corresponding to the CQI index, and occupying a group of downlink physical resource blocks termed the CSI reference resource, could be received with a transport block error probability not exceeding:

0.1, if the higher layer parameter cqi-Table in CSI-ReportConfig configures 'table1' (corresponding to Table 5.2.2.1-2, TS 38.214), or 'table2' (corresponding to Table 5.2.2.1-3, TS 38.214), or if the higher layer parameter cqi-Table in CSI-ReportConfig configures 'table4-r17' (corresponding to Table 5.2.2.1-5, TS 38.214), or

0.00001, if the higher layer parameter cqi-Table in CSI-ReportConfig configures 'table3' (corresponding to Table 5.2.2.1-4, TS 38.214).

The time slot of the CSI reference resource is $n_{ref} < n$. The CQI value is derived based on CSI-RS measurement occasions/window/interval $[k, k + W_{meas} - 1]$ prior to the CSI reference resource. An illustration of timing relation between CSI-RS occasion, CSI reference resource, and CSI report is provided in FIGURE 18.

In one embodiment IV.1, when the UE configured to report a CSI report that includes CQI reporting based on (or conditioned on) the PMI that indicates TD/DD components of the channel (as described in this disclosure), and when $W_{CSI} > 1$, i.e., the CSI reporting/validity window $[l, l + W_{CSI} - 1]$ comprises multiple time slots or TD/DD units, then the CQI reporting and the corresponding BLER requirements are according to at least one of the following examples.

In one example IV.1.1, the UE is configured to report one CQI value for entire time span W_{CSI} (i.e., WT as described earlier), and the BLER requirement is the same (one value), e.g., as in legacy Rel.15 NR specification (e.g., 0.1 or 0.00001).

In one example IV.1.1.1, the CQI is expected to meet the BLER requirement at a time slot s within the W_{SCI} time slots, where the BLER requirement is the same as Rel.15 NR specification (i.e., 0.1 or 0.00001 as described above).

In one example, s is fixed. In one example, $s = n_{ref}$ (same as Rel.15 NR specification). In one example, $s = l + W_{CSI} - 1$. In one example, $s = n_{ref}$ when the codebook doesn't include TD/DD components (e.g., Rel.15/16/17 NR codebooks), and $s = l + W_{CSI} - 1$ for when the codebook includes TD/DD components (e.g., new codebook as described in this disclosure).

In one example, s is configured, e.g., from $\{n_{ref}, l + W_{CSI} - 1\}$ (2 values) or from the whole CSI reporting/validity window (W_{CSI} values).

In one example IV.1.1.2, the CQI is expected to meet the BLER requirement for all slots in W_{CSI}. For instance, the reported CQI is expected to meet a maximum of 0.1 (or 0.00001) BLER value during the whole CSI reporting window.

In one example IV.1.2, the UE is configured to report one CQI value for entire time span W_{CSI} (i.e., WT as described earlier), and the BLER requirement depends on the slot index in which the CQI is derived.

In one example IV.1.2.1, the BLER requirement is 0.1 for the reference slot n_{ref}, and the BLER requirement is $v > 0.1$ for a future slot (after n_{ref}), i.e., $n_f = l + W_{CSI} - 1 > n_{ref}$. In one example, v is fixed (e.g., 0.15 or 0.2). In one example, v is configured (e.g., via RRC).

In one example IV.1.2.2, the BLER requirement is $u < 0.1$ for the reference slot n_{ref}, and 0.1 for a future slot (after n_{ref}), i.e., $n_f = l + W_{CSI} - 1 > n_{ref}$. In one example, u is fixed (e.g., 0.05 or 0.01). In one example, u is configured (e.g., via RRC).

In one example IV.1.3, the UE is configured to report multiple (Y) CQI values (or multiple CQI values per SB in case of SB CQI reporting) which are for entire time span W_{CSI} (i.e., ST as described earlier), and the BLER requirement is the same (one value), e.g., as in legacy Rel.15 NR specification (e.g., 0.1 or 0.00001). In one example, Y is fixed. In one example, $Y = 2$. In one example, Y is determined based on TD/DD unit size (similar to SB size) or/and the value of B or C or $B + C$ as described above. In one example, Y is configured (e.g., via RRC). The CSI reporting/validity window can be partitioned into Y parts (referred to as ST above, similar to SB), and one CQI value (or one CQI value per SB in case of SB CQI reporting) is determined for each part. Let $W_{SCI,y}$ be the number of time slots associated with the y-th part.

In one example IV.1.3.1, for y-th part, the CQI is expected to meet the BLER requirement at a time slot s_y within the $W_{SCI,y}$ time slots associated with the y-th part $[l_y, l_y + W_{CSI,y} - 1]$, where the BLER requirement is the same as Rel.15 NR specification (i.e. 0.1 or 0.00001 as described above).

In one example, s_y is fixed. In one example, $s_y = l_y$ (same as Rel.15 NR specification). In one example, $s_y = l_y + W_{CSI,y} - 1$.

In one example, s_y is configured, e.g., from $\{l_y, l_y + W_{CSI,y} - 1\}$ (2 values) or from the whole CSI reporting/validity window for y-th part ($W_{CSI,y}$ values).

In example IV.1.3.2, for y-th part, the CQI is expected to meet the BLER requirement for all slots in $W_{CSI,y}$. For instance, the reported CQI is expected to meet a maximum of 0.1 (or 0.00001) BLER value during the whole CSI reporting window for y-th part.

In one example IV.1.4, the UE is configured to report multiple (Y) CQI values (or multiple CQI values per SB in case of SB CQI reporting) which are for entire time span W_{CSI} (i.e., ST as described earlier), and the BLER requirement depends on the slot index in which the CQI is derived. In one example, Y is fixed. In one example, $Y = 2$. In one example, Y is determined based on TD/DD unit size (similar to SB size) or/and the value of B or C or $B + C$ as described above. In one example, Y is configured (e.g., via RRC). The CSI reporting/validity window can be partitioned into Y parts (referred to as ST above, similar to SB), and one CQI value (or one CQI value per SB in case of SB CQI reporting) is determined for each part. Let $W_{SCI,y}$ be the number of time slots associated with the y-th part.

In one example IV.1.4.1, for y-th part, the BLER requirement is 0.1 for the slot l_y, and the BLER requirement is $v > 0.1$ for a future slot, i.e., $l_y + W_{CSI,y} - 1$. In one example, v is fixed (e.g., 0.15 or 0.2). In one example, v is configured (e.g., via RRC).

In one example IV.1.4.2, the BLER requirement is $u < 0.1$ for the slot l_y, and 0.1 for a future i.e., $l_y + W_{CSI,y} - 1$. In one example, u is fixed (e.g., 0.05 or 0.01). In one example, u is configured (e.g., via RRC).

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

FIGURE 19 illustrates a flow chart of a method 1900 for operating a UE, as may be performed by a UE such as UE 116, according to embodiments of the present disclosure. The embodiment of the method 1900 illustrated in FIGURE 19 is for illustration only. FIGURE 19 does not limit the scope of this disclosure to any particular implementation.

As illustrated in FIGURE 19, the method 1900 begins at step 1902. In step 1902, the UE (e.g., 111-116 as illustrated in FIGURE 1) receives a configuration about a CSI report, the configuration including information about a time interval W for the CSI report, the time interval

W comprising multiple time slots; and a number (Y) of CQI values associated with the time interval W.

In step 1904, the UE derives, based on the configuration, the Y CQI values, each of the Y CQI values at a corresponding time slot in the time interval W, wherein the Y CQI values satisfy a BLER probability requirement.

In step 1906, the UE transmits the CSI report including the Y CQI values, wherein $Y \geq 1$.

In one embodiment, the time interval W includes C time slots, $[l, l + C - 1]$, no earlier than a time slot n_{ref} of a CSI reference resource, and the C time slots don't include a non-zero power CSI reference signal (NZP CSI-RS) resource for channel measurement.

In one embodiment, the time interval W includes $B + C$ time slots, the B time slots, $[k, k + B - 1]$, is no later than a time slot n_{ref} of a CSI reference resource, and includes at least one non-zero power CSI reference signal (NZP CSI-RS) resource for channel measurement, and the C time slots, $[l, l + C - 1]$, is no earlier than the time slot n_{ref} of the CSI reference resource, and do not include a NZP CSI-RS resource for channel measurement.

In one embodiment, $Y = 1$ and a CQI value is derived at a time slot s in the time interval W, where $s > n_{ref}$ and n_{ref} is the time slot of the CSI reference resource.

In one embodiment, $Y > 1$, the time interval W comprises Y parts, $W_1, \ldots W_Y$, and for each part $y \in \{1, \ldots, Y\}$, one CQI value is derived at a time slot s_y in the part W_y.

In one embodiment, either $s_y > n_{ref}$ for all y, or $s_1 = n_{ref}$ and $s_y > n_{ref}$ for $y > 1$.

In one embodiment, the configuration includes information about a CSI reference signal (CSI-RS) burst comprising $B \geq 1$ time instances of CSI-RS transmission, and the UE is configured to: measure the CSI-RS burst, and determine, based on the measurement of the CSI-RS burst, a pre-coding matrix indicator (PMI) and the Y CQI values, where the PMI indicates precoding matrices for time slots in the time interval W, and the Y CQI values are conditioned on the PMI, when the frequency domain (FD) granularity for the CQI is wideband, the Y CQI values are for a CSI reporting band, and when the FD granularity for the CQI is subband, the Y CQI values are determined for each subband (SB) in the CSI reporting band.

FIGURE 20 illustrates a flow chart of another method 2000, as may be performed by a base station (BS) such as BS 102, according to embodiments of the present disclosure. The embodiment of the method 2000 illustrated in FIGURE 20 is for illustration only. FIGURE 20 does not limit the scope of this disclosure to any particular implementation.

As illustrated in FIGURE 20, the method 2000 begins at step 2002. In step 2002, the BS (e.g., 101-103 as illustrated in FIGURE 1), generates a configuration about a channel state information (CSI) report, the configuration including information about a time interval W for the CSI report, the time interval W comprising multiple time slots; and a number (Y) of channel quality indicator (CQI) values associated with the time interval W.

In step 2004, the BS transmits the configuration.

In step 2006, the BS receives the CSI report, wherein: the CSI report includes the Y CQI values, the Y CQI values are based on the configuration, each Y CQI value is at a corresponding time slot in the time interval W, the Y CQI values satisfy a block error (BLER) probability requirement, and $Y \geq 1$.

In one embodiment, the time interval W includes C time slots, $[l, l + C - 1]$, no earlier than a time slot n_{ref} of a CSI reference resource, and the C time slots don't include a non-zero power CSI reference signal (NZP CSI-RS) resource for channel measurement.

In one embodiment, the time interval W includes $B + C$ time slots, the B time slots, $[k, k + B - 1]$, is no later than a time slot n_{ref} of a CSI reference resource, and includes at least one non-zero power CSI reference signal (NZP CSI-RS) resource for channel measurement, and the C time slots, $[l, l + C - 1]$, is no earlier than the time slot n_{ref} of the CSI reference resource, and do not include a NZP CSI-RS resource for channel measurement.

In one embodiment, $Y = 1$ and a CQI value is based on a time slot s in the time interval W, where $s > n_{ref}$ and n_{ref} is the time slot of the CSI reference resource.

In one embodiment, $Y > 1$, the time interval W comprises Y parts, $W_1, \ldots W_Y$, and for each part $y \in \{1, \ldots, Y\}$, one CQI value is based on a time slot s_y in the part W_y.

In one embodiment, either $s_y > n_{ref}$ for all y, or $s_1 = n_{ref}$ and $s_y > n_{ref}$ for $y > 1$.

The above flowcharts illustrate example methods that can be implemented in accordance with the principles of the present 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.

Although the present disclosure has been described with an exemplary embodiment, various changes and modifications may be suggested to one skilled in the art. It is intended that the present 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.

【CLAIMS】

【Claim 1】

A user equipment (UE) comprising:

a transceiver configured to:

receive a configuration about a channel state information (CSI) report, the configuration including information about:

a time interval W for the CSI report, the time interval W comprising multiple time slots; and

a number (Y) of channel quality indicator (CQI) values associated with the time interval W; and

a processor operably coupled to the transceiver, the processor configured to:

derive, based on the configuration, the Y CQI values, each of the Y CQI values at a corresponding time slot in the time interval W, wherein:

the Y CQI values satisfy a block error (BLER) probability requirement,

the transceiver is configured to transmit the CSI report including the Y CQI values, and

$Y \geq 1$.

【Claim 2】

The UE of Claim 1, wherein:

the time interval W includes C time slots, $[l, l + C - 1]$, no earlier than a time slot n_{ref} of a CSI reference resource, and

the C time slots don't include a non-zero power CSI reference signal (NZP CSI-RS) resource for channel measurement.

【Claim 3】

The UE of Claim 1, wherein:

the time interval W includes $B + C$ time slots,

the B time slots, $[k, k + B - 1]$, is no later than a time slot n_{ref} of a CSI reference resource, and includes at least one non-zero power CSI reference signal (NZP CSI-RS) resource for channel measurement, and

the C time slots, $[l, l + C - 1]$, is no earlier than the time slot n_{ref} of the CSI reference resource, and do not include a NZP CSI-RS resource for channel measurement.

【Claim 4】

The UE of Claim 1, wherein $Y = 1$ and a CQI value is derived at a time slot s in the time interval W, where $s > n_{ref}$ and n_{ref} is the time slot of the CSI reference resource.

【Claim 5】

The UE of Claim 1, wherein:

$Y > 1$,

the time interval W comprises Y parts, $W_1, \ldots W_Y$, and

for each part $y \in \{1, \ldots, Y\}$, one CQI value is derived at a time slot s_y in the part W_y.

【Claim 6】

The UE of Claim 5, wherein:

either $s_y > n_{ref}$ for all y, or

$s_1 = n_{ref}$ and $s_y > n_{ref}$ for $y > 1$.

【Claim 7】

The UE of Claim 1, wherein:

the configuration includes information about a CSI reference signal (CSI-RS) burst comprising $B \geq 1$ time instances of CSI-RS transmission, and

the processor is further configured to:

measure the CSI-RS burst, and

determine, based on the measurement of the CSI-RS burst, a pre-coding matrix indicator (PMI) and the Y CQI values,

where the PMI indicates precoding matrices for time slots in the time interval W, and the Y CQI values are conditioned on the PMI,

when the frequency domain (FD) granularity for the CQI is wideband, the Y CQI values are for a CSI reporting band, and

when the FD granularity for the CQI is subband (SB), the Y CQI values are determined for each SB in the CSI reporting band.

【Claim 8】

A base station (BS) comprising:

a processor configured to generate a configuration about a channel state information (CSI) report, the configuration including information about:

a time interval W for the CSI report, the time interval W comprising multiple time slots; and

a number (Y) of channel quality indicator (CQI) values associated with the time interval W; and

a transceiver operably coupled to the processor, the transceiver configured to:

transmit the configuration; and

receive the CSI report, wherein:

the CSI report includes the Y CQI values,

the Y CQI values are based on the configuration,

each of the Y CQI values is at a corresponding time slot in the time interval W,

the Y CQI values satisfy a block error (BLER) probability requirement, and

$Y \geq 1$.

【Claim 9】

The BS of Claim 8, wherein:

the time interval W includes $B + C$ time slots,

the B time slots, $[k, k + B - 1]$, is no later than a time slot n_{ref} of a CSI reference resource, and includes at least one non-zero power CSI reference signal (NZP CSI-RS) resource for channel measurement, and

the C time slots, $[l, l + C - 1]$, is no earlier than the time slot n_{ref} of the CSI reference resource, and do not include a NZP CSI-RS resource for channel measurement.

【Claim 10】

The BS of Claim 8, wherein $Y = 1$ and a CQI value is based on a time slot s in the time interval W, where $s > n_{ref}$ and n_{ref} is the time slot of the CSI reference resource.

【Claim 11】

The BS of Claim 8, wherein:

$Y > 1$,

the time interval W comprises Y parts, $W_1, \ldots W_Y$, and

for each part $y \in \{1, \ldots, Y\}$, one CQI value is based on a time slot s_y in the part W_y,

wherein:

either $s_y > n_{ref}$ for all y, or

$s_1 = n_{ref}$ and $s_y > n_{ref}$ for $y > 1$.

【Claim 12】

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:

a time interval W for the CSI report, the time interval W comprising multiple time slots; and

a number (Y) of channel quality indicator (CQI) values associated with the time interval W;

deriving, based on the configuration, Y CQI values, each of the Y CQI values at a corresponding time slot in the time interval W, wherein the Y CQI values satisfy a block error (BLER) probability requirement; and

transmitting the CSI report including the Y CQI values,

wherein $Y \geq 1$.

【Claim 13】

The method of Claim 12, wherein:

the time interval W includes $B + C$ time slots,

the B time slots, $[k, k + B - 1]$, is no later than a time slot n_{ref} of a CSI reference resource, and includes at least one non-zero power CSI reference signal (NZP CSI-RS) resource for channel measurement, and

the C time slots, $[l, l + C - 1]$, is no earlier than the time slot n_{ref} of the CSI reference resource, and do not include a NZP CSI-RS resource for channel measurement,

wherein the configuration includes information about a CSI reference signal (CSI-RS) burst comprising $B \geq 1$ time instances of CSI-RS transmission, and

the method further comprises:

measuring the CSI-RS burst, and

determining, based on the measurement of the CSI-RS burst, a pre-coding matrix indicator (PMI) and the Y CQI values,

where the PMI indicates precoding matrices for time slots in the time interval W, and the Y CQI values are conditioned on the PMI,

when the frequency domain (FD) granularity for the CQI is wideband, the Y CQI values are for a CSI reporting band, and

when the FD granularity for the CQI is subband (SB), the Y CQI values are determined for each SB in the CSI reporting band.

【Claim 14】

The method of Claim 12, wherein:

based on $Y = 1$, a CQI value is derived at a time slot s in the time interval W, where $s > n_{ref}$ and n_{ref} is the time slot of the CSI reference resource,

based on $Y > 1$, the time interval W comprises Y parts, $W_1, \ldots W_Y$, and

for each part $y \in \{1, \ldots, Y\}$, one CQI value is derived at a time slot s_y in the part W_y,

wherein:

either $s_y > n_{ref}$ for all y, or

$s_1 = n_{ref}$ and $s_y > n_{ref}$ for $y > 1$.

【Claim 15】

A method for operating a base station (BS), the method comprising:

generating a configuration about a channel state information (CSI) report, the configuration including information about:

a time interval W for the CSI report, the time interval W comprising multiple time slots; and

a number (Y) of channel quality indicator (CQI) values associated with the time interval W; and

transmitting the configuration; and

receiving the CSI report, wherein:

the CSI report includes the Y CQI values,

the Y CQI values are based on the configuration,

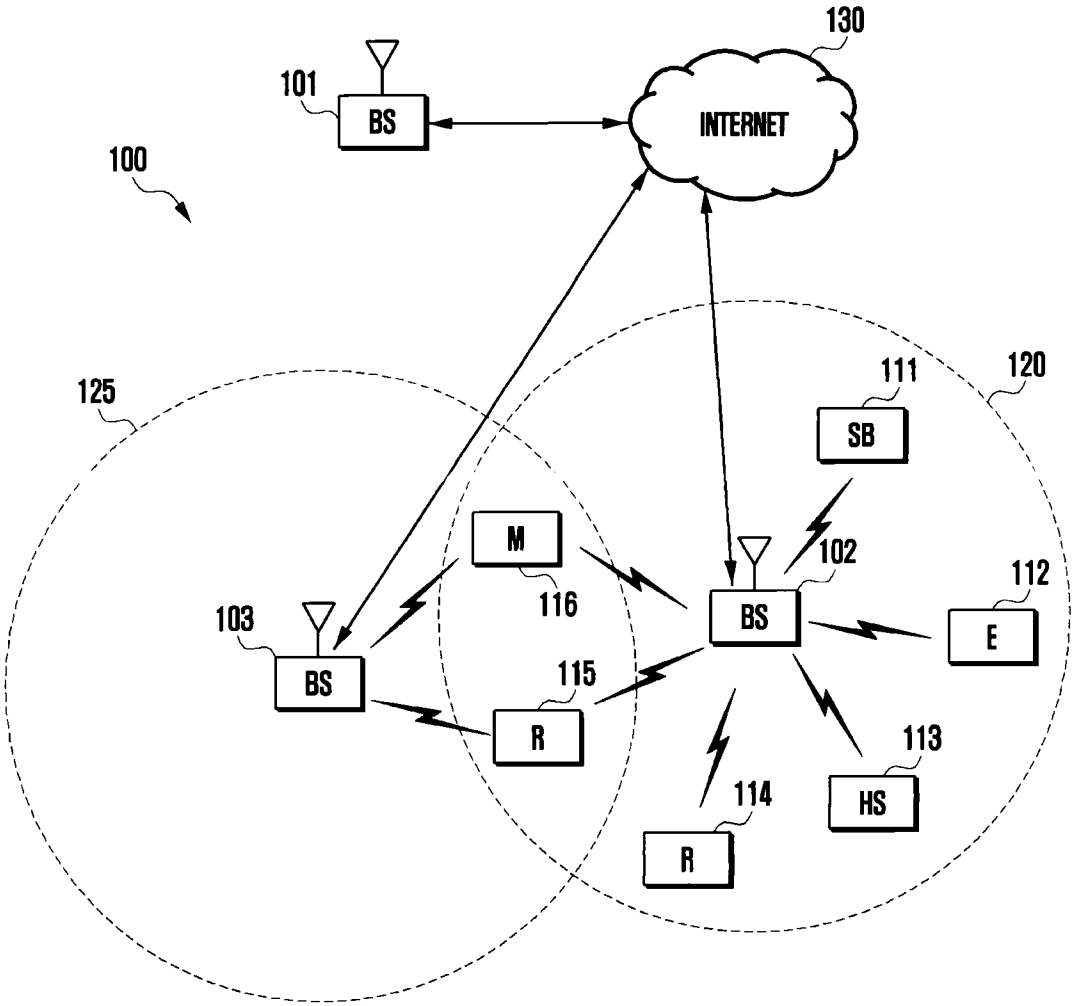
each of the Y CQI values is at a corresponding time slot in the time interval W,

the Y CQI values satisfy a block error (BLER) probability requirement, and

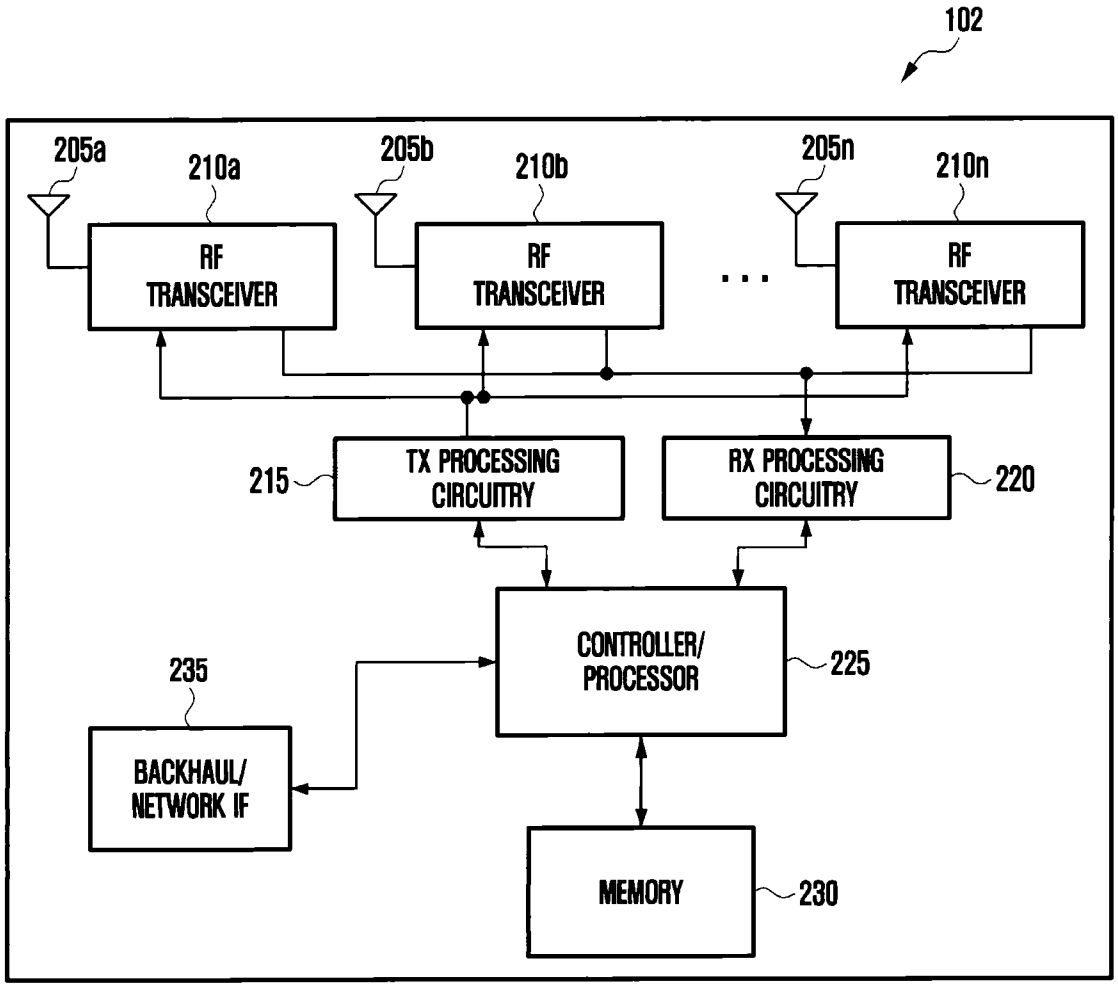
$Y \geq 1$.

【DRAWINGS】

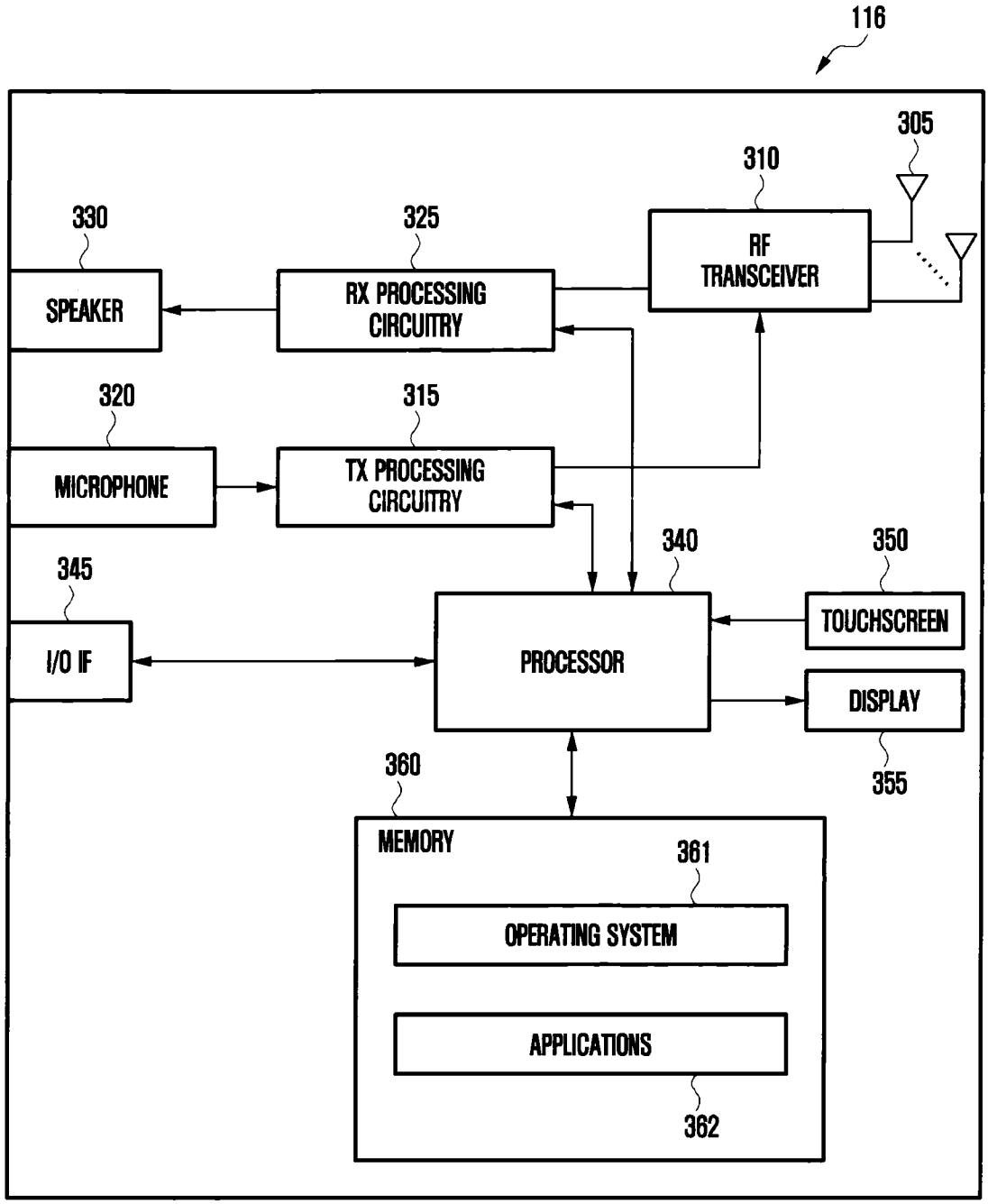
【Figure 1】



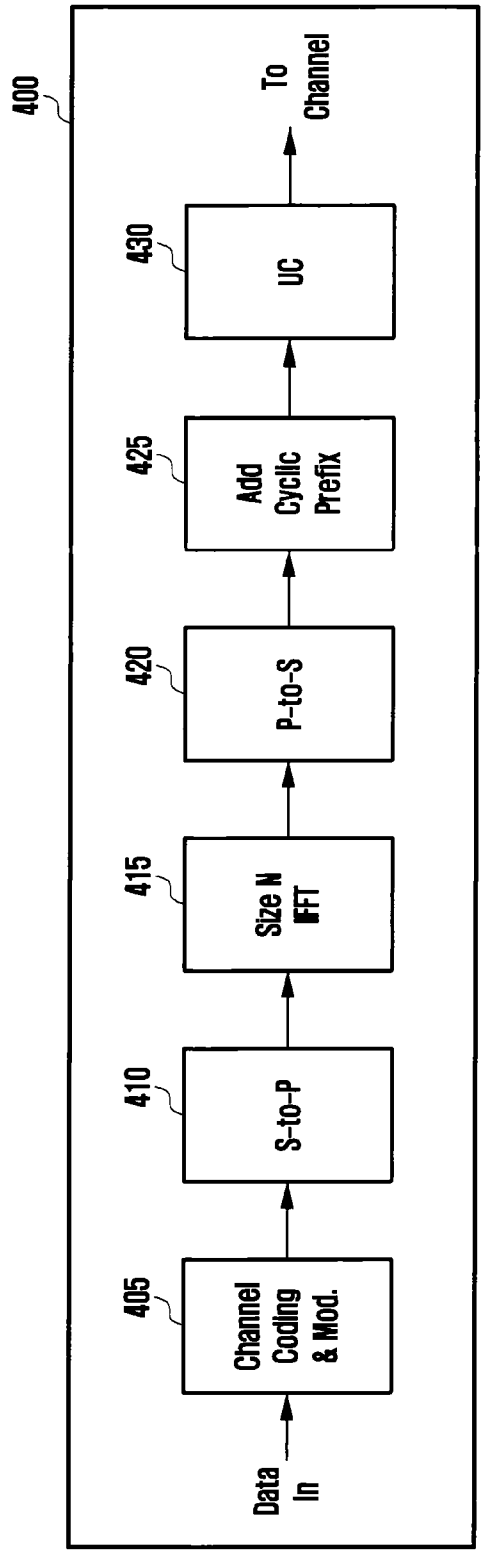
【Figure 2】


102
205a
210a
205b
210b
205n
210n
RF TRANSCEIVER
RF TRANSCEIVER
RF TRANSCEIVER
TX PROCESSING CIRCUITRY
215
RX PROCESSING CIRCUITRY
220
CONTROLLER/ PROCESSOR
225
235
BACKHAUL/ NETWORK IF
MEMORY
230

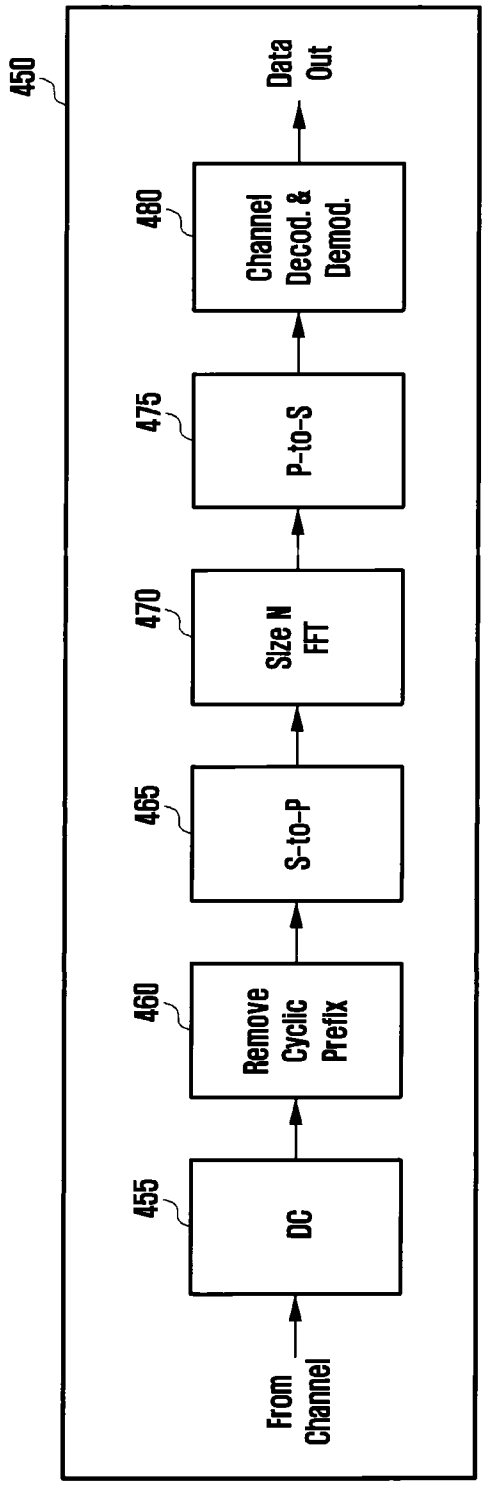
【Figure 3】


116
305
310
330
325
RF TRANSCEIVER
SPEAKER
RX PROCESSING CIRCUITRY
320
315
MICROPHONE
TX PROCESSING CIRCUITRY
340
350
345
TOUCHSCREEN
I/O IF
PROCESSOR
DISPLAY
355
360
MEMORY
361
OPERATING SYSTEM
APPLICATIONS
362

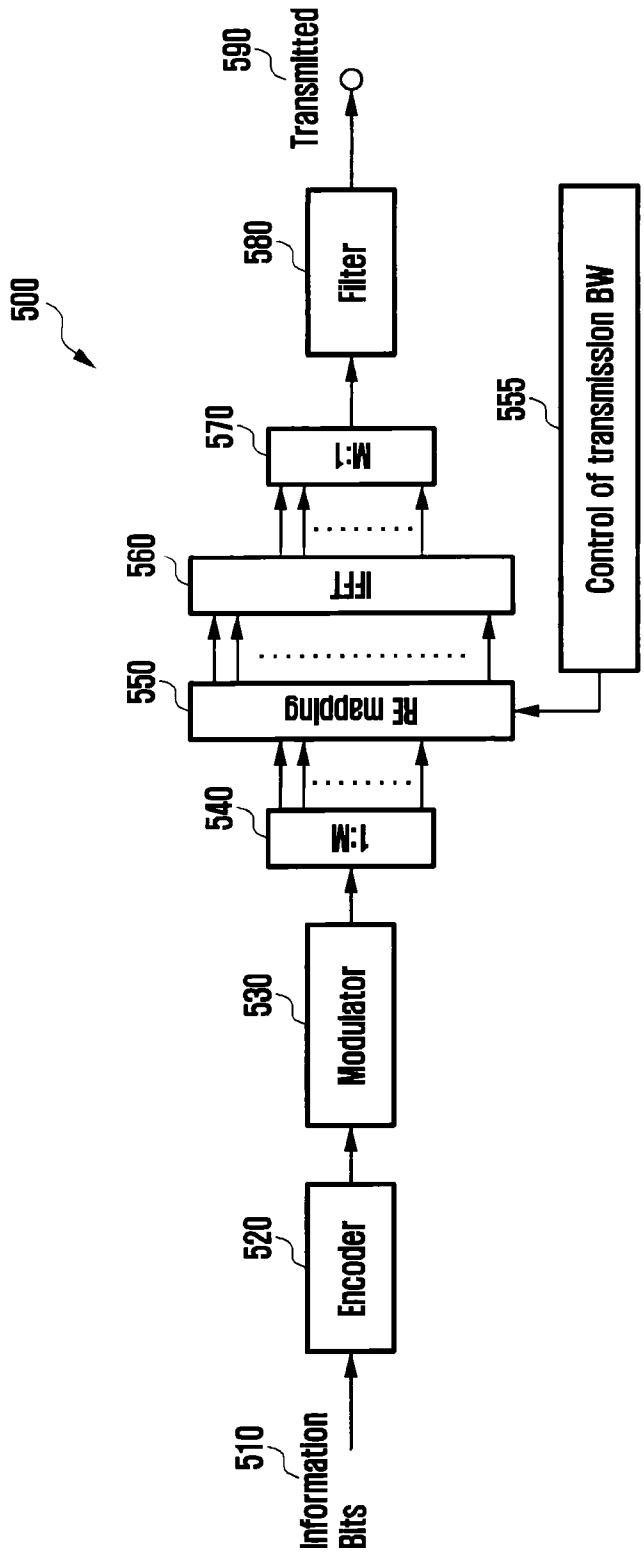
【Figure 4A】


400
Data In
405
Channel Coding & Mod.
410
S-to-P
415
Size N IFFT
420
P-to-S
425
Add Cyclic Prefix
430
UC
To Channel

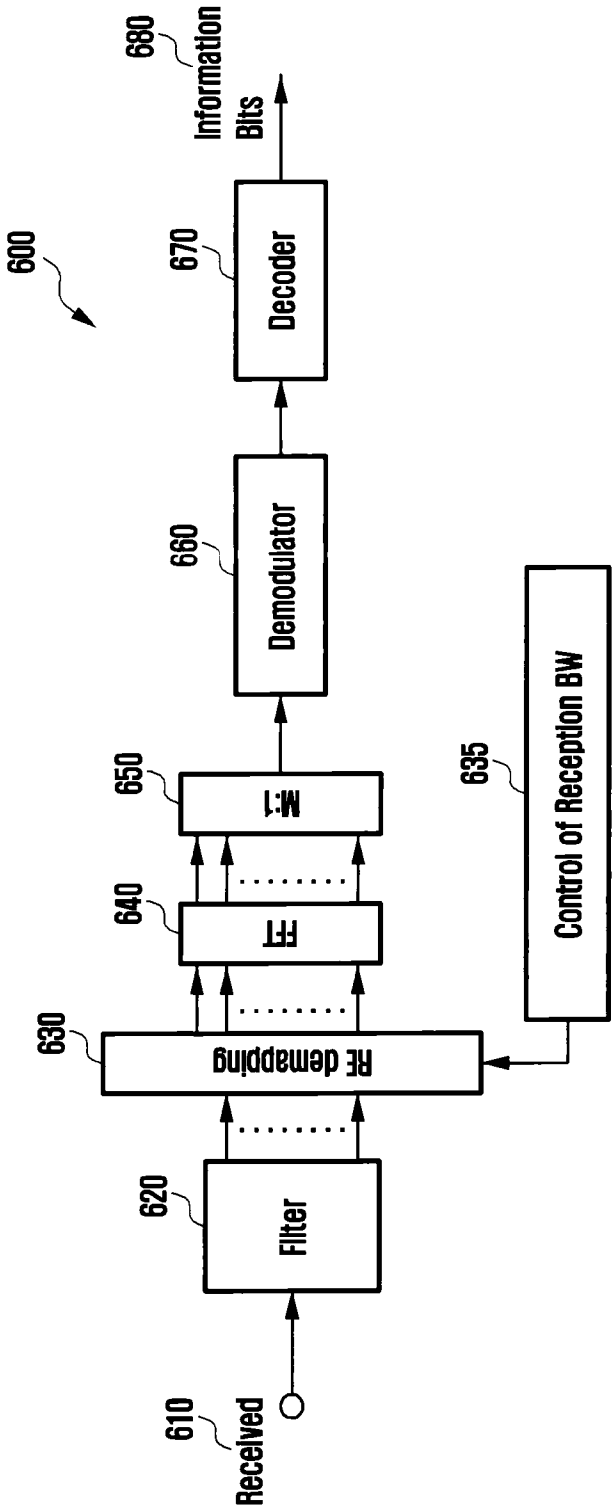
【Figure 4B】


450
Data Out
480
Channel Decod. & Demod.
475
P-to-S
470
Size N FFT
465
S-to-P
460
Remove Cyclic Prefix
455
DC
From Channel

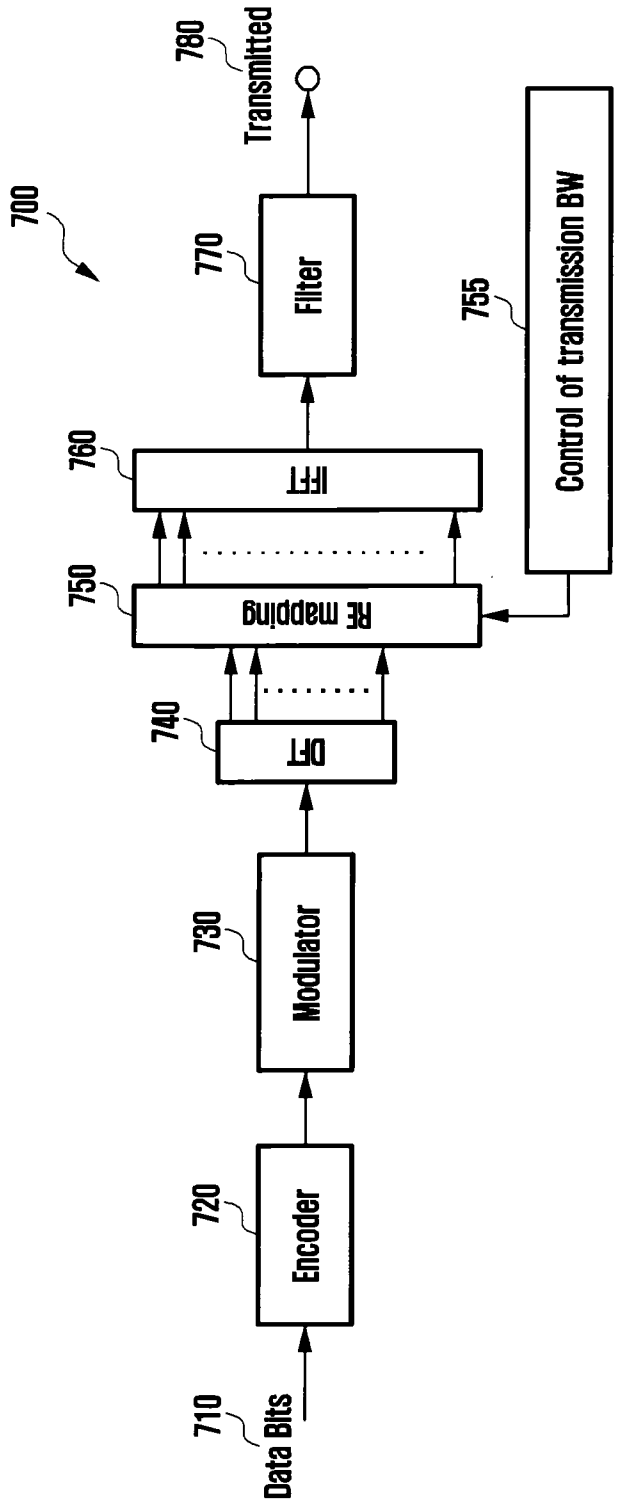
【Figure 5】


500
510
Information Bits
520
Encoder
530
Modulator
540
1:M
550
RE mapping
560
IFFT
570
M:1
580
Filter
590
Transmitted
555
Control of transmission BW

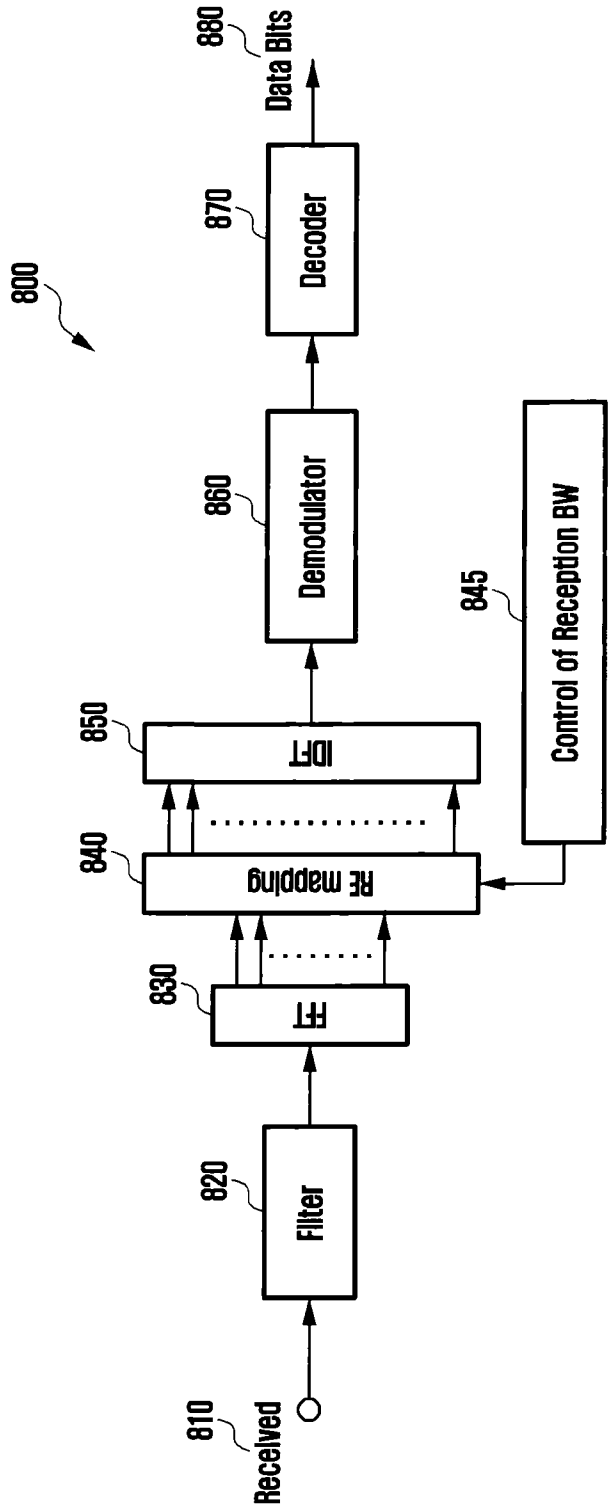
【Figure 6】


600
610
Received
620
Filter
630
RE demapping
635
Control of Reception BW
640
FFT
650
M:1
660
Demodulator
670
Decoder
680
Information Bits

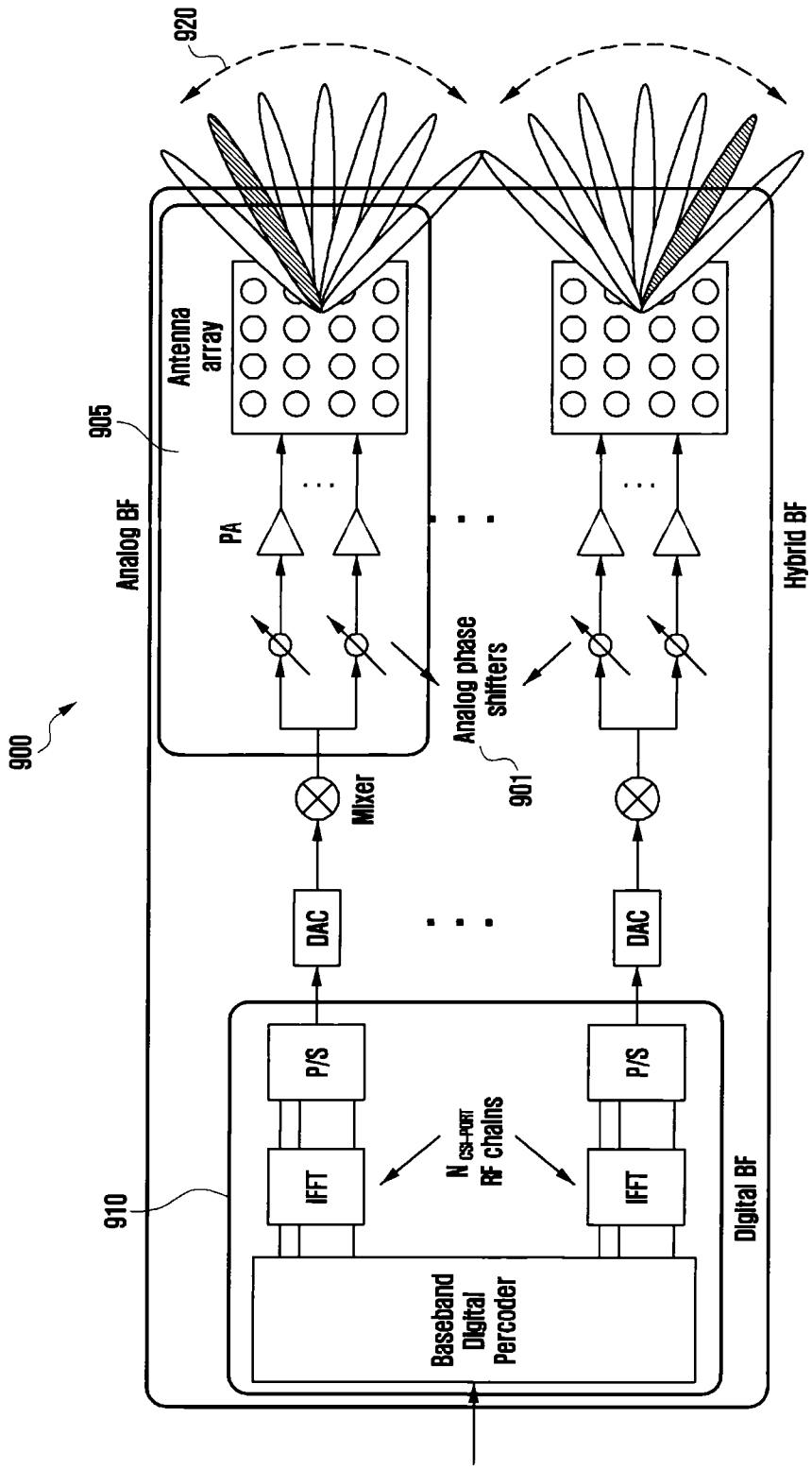
【Figure 7】


700
710
Data Bits
720
Encoder
730
Modulator
740
DFT
750
RE mapping
760
IFFT
770
Filter
780
Transmitted
755
Control of transmission BW

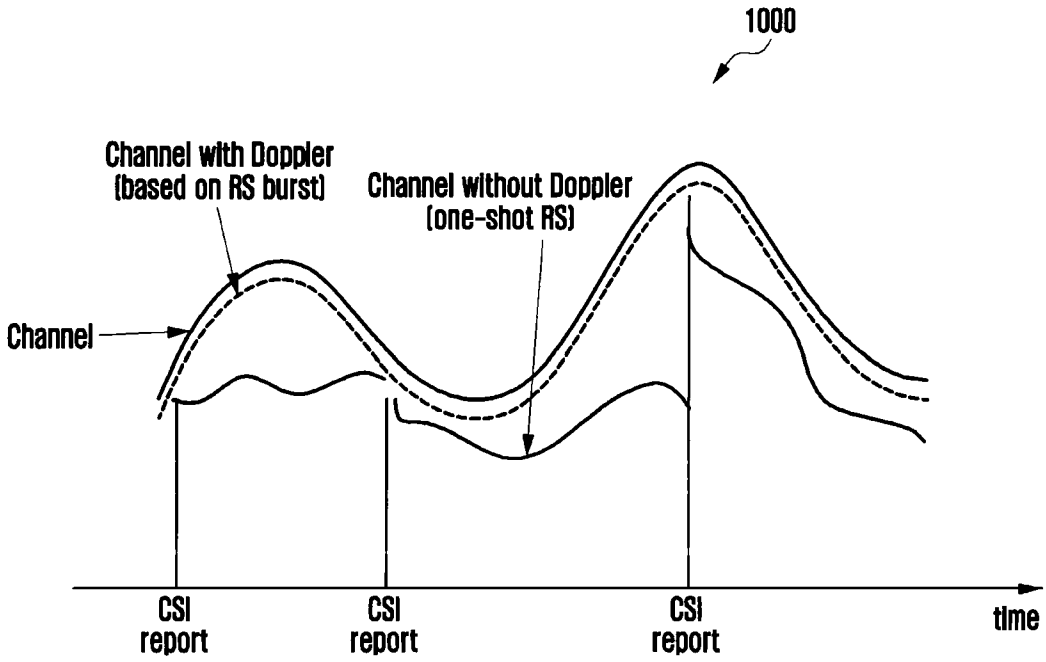
【Figure 8】


800
810
Received
820
Filter
830
FFT
840
RE mapping
845
Control of Reception BW
850
IDFT
860
Demodulator
870
Decoder
880
Data Bits

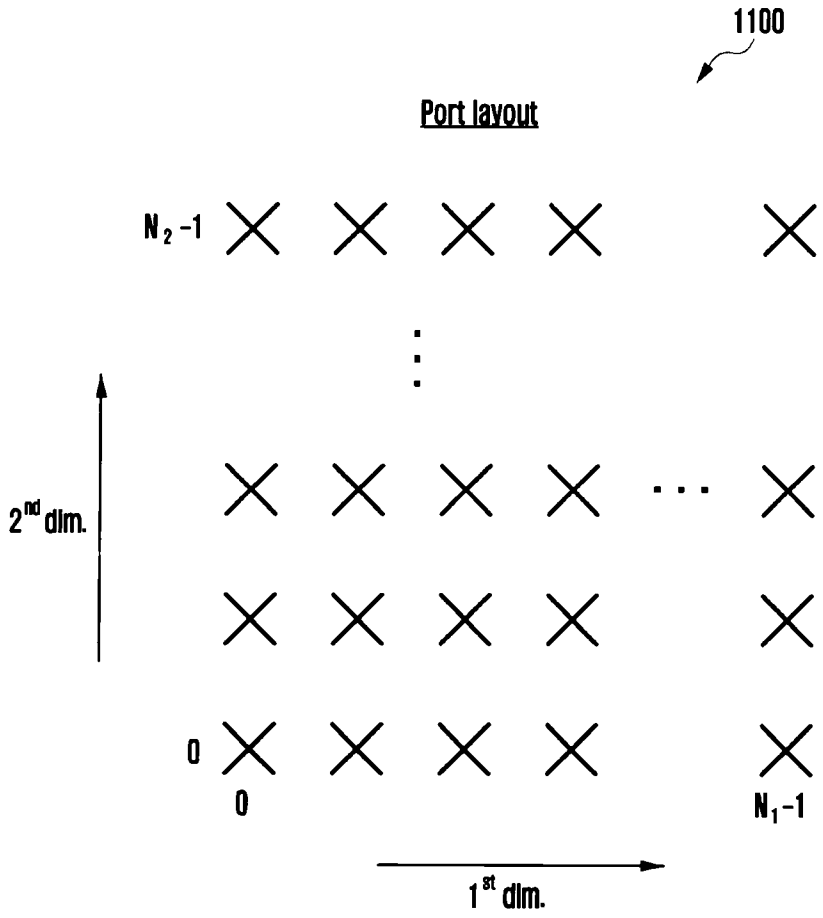
【Figure 9】


920
905
Antenna array
Analog BF
PA
Analog phase shifters
901
Hybrid BF
900
Mixer
DAC
DAC
910
P/S
P/S
IFFT
IFFT
N CSI-PORT RF chains
Digital BF
Baseband Digital Percoder

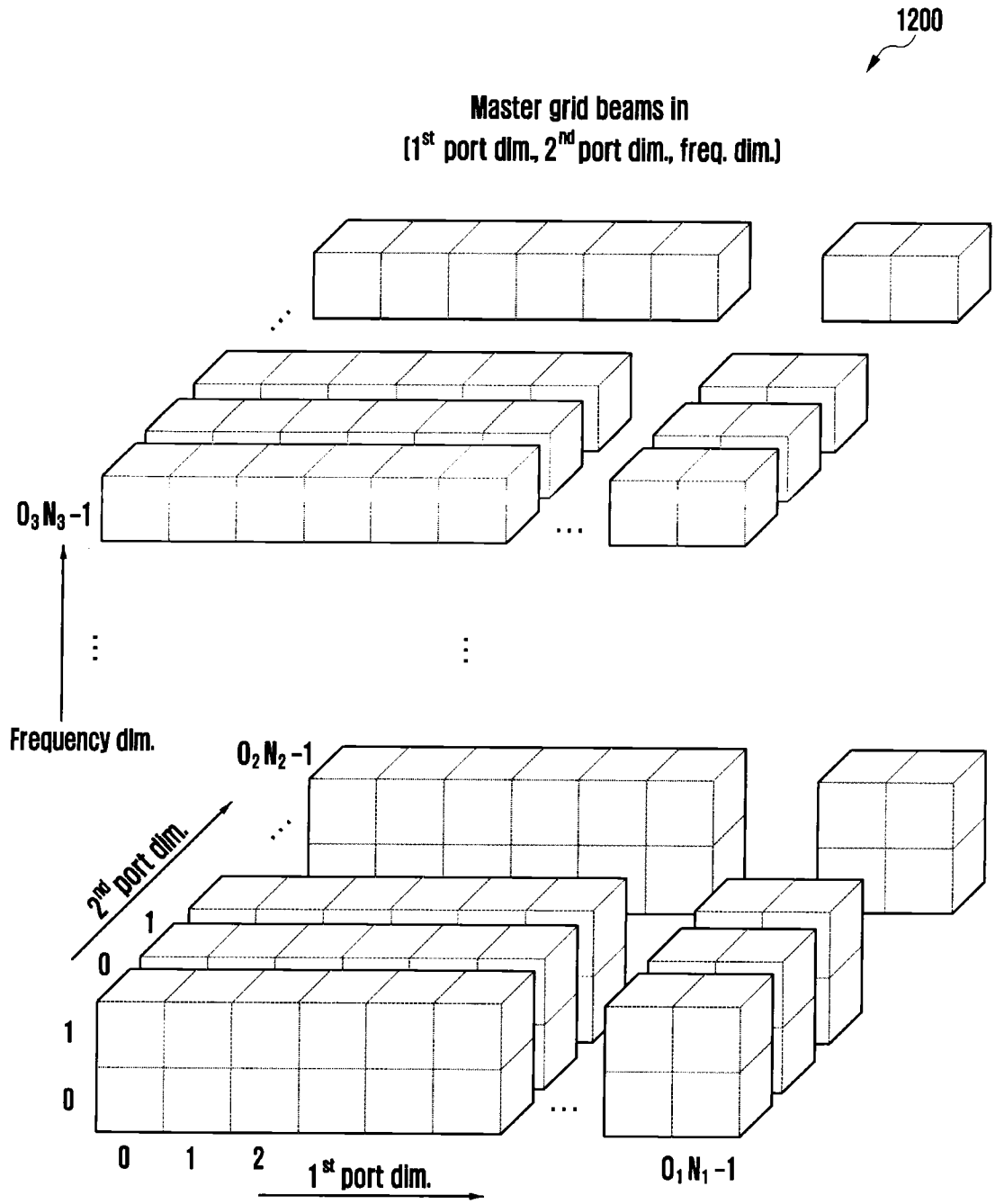
【Figure 10】


1000
Channel with Doppler
(based on RS burst)
Channel without Doppler
(one-shot RS)
Channel
CSI
report
CSI
report
CSI
report
time

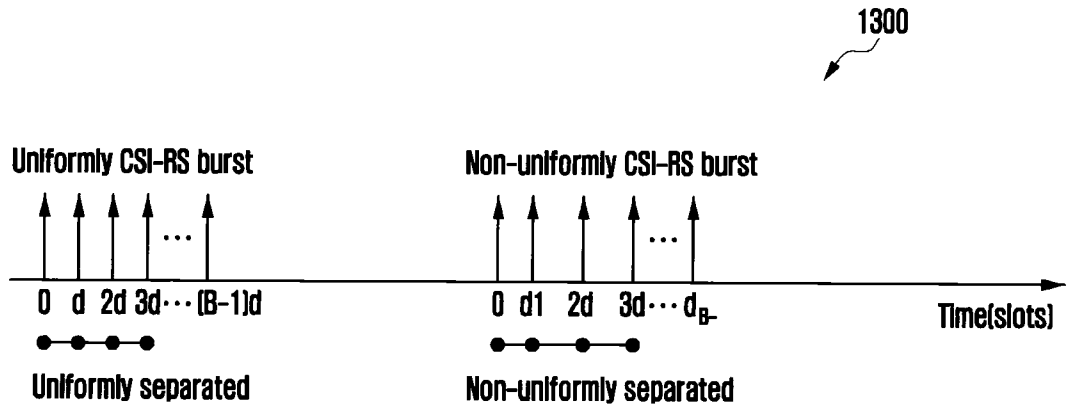
【Figure 11】



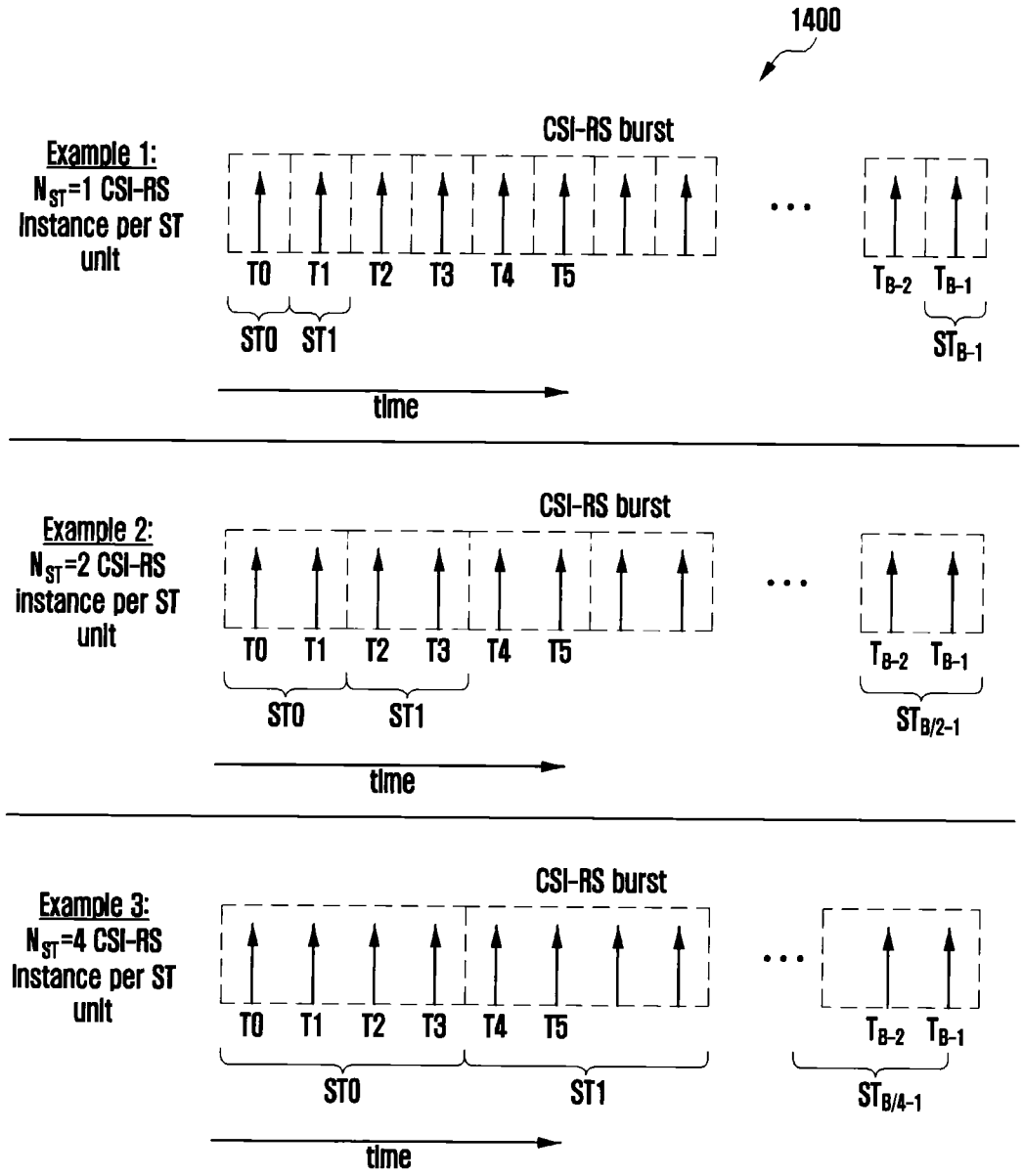
【Figure 12】


1200
Master grid 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
1st port dim.
O1N1-1

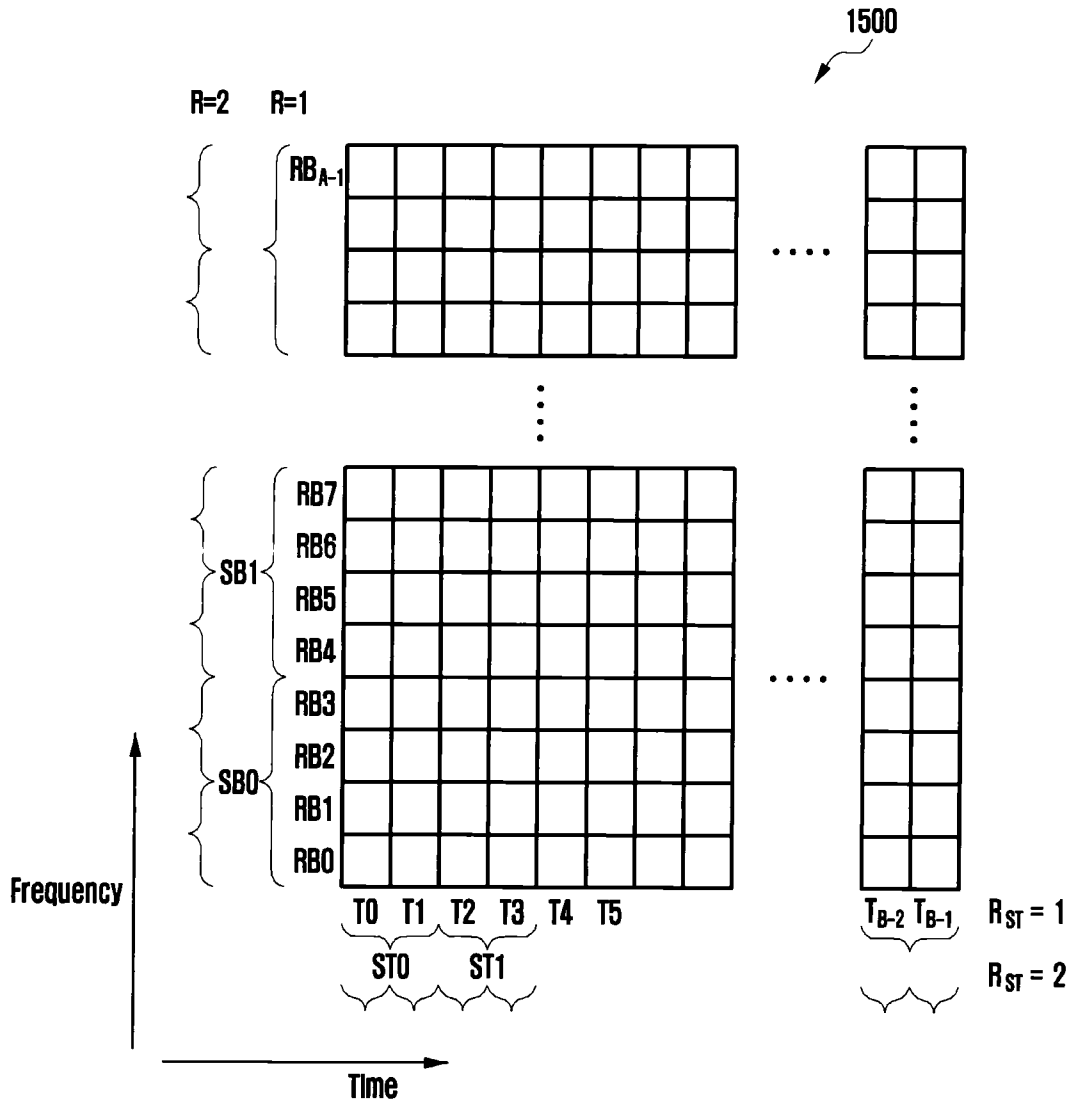
【Figure 13】


1300
Uniformly CSI-RS burst
Non-uniformly CSI-RS burst
0 d 2d 3d··· (B-1)d
0 d1 2d 3d··· dB-
Time(slots)
Uniformly separated
Non-uniformly separated

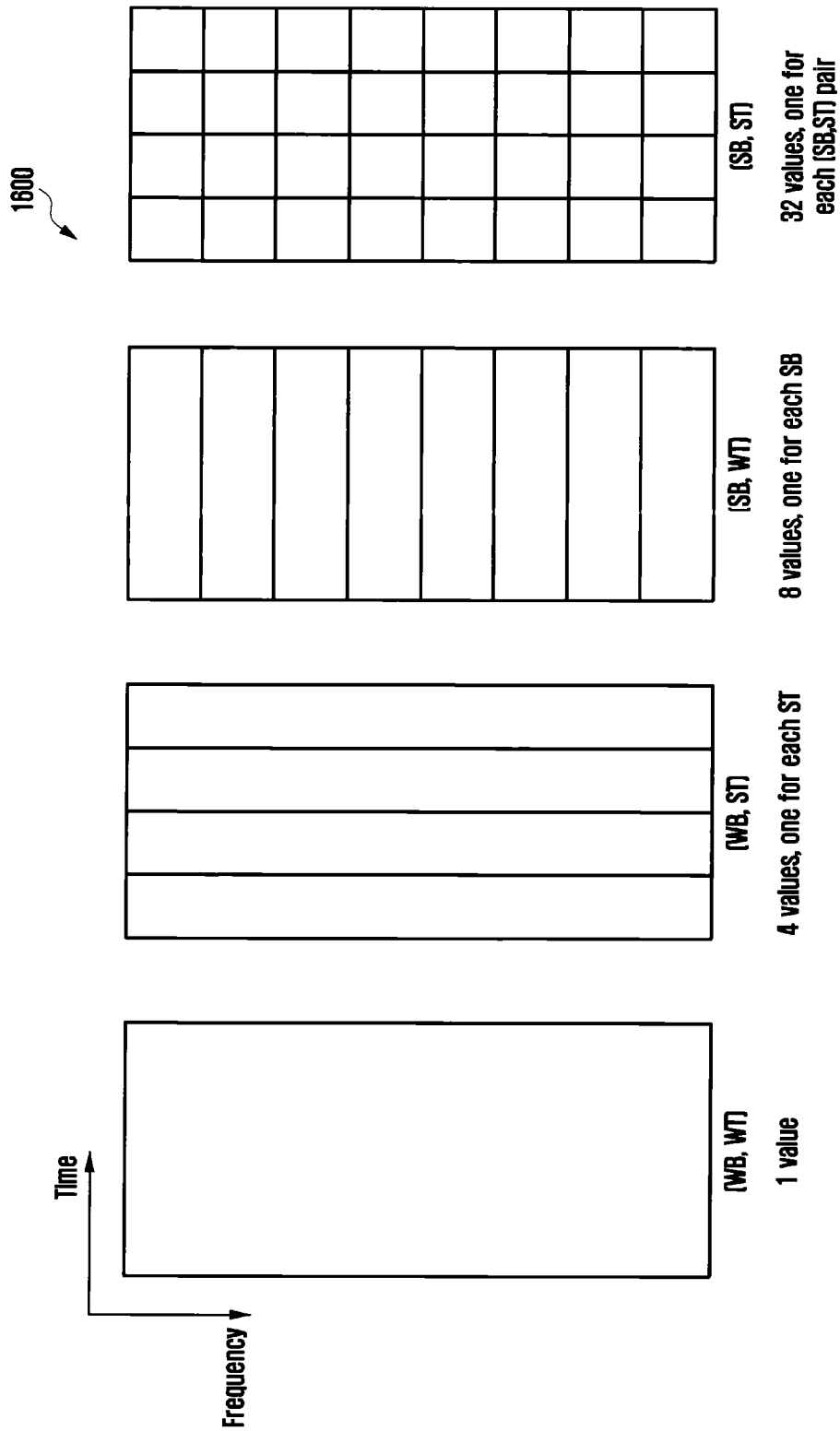
【Figure 14】


1400
Example 1:
N_{ST}=1 CSI-RS instance per ST unit
CSI-RS burst
T0 T1 T2 T3 T4 T5
T_{B-2} T_{B-1}
ST0 ST1
ST_{B-1}
time
Example 2:
N_{ST}=2 CSI-RS instance per ST unit
CSI-RS burst
T0 T1 T2 T3 T4 T5
T_{B-2} T_{B-1}
ST0 ST1
$ST_{B/2-1}$
time
Example 3:
N_{ST}=4 CSI-RS instance per ST unit
CSI-RS burst
T0 T1 T2 T3 T4 T5
T_{B-2} T_{B-1}
ST0 ST1
$ST_{B/4-1}$
time

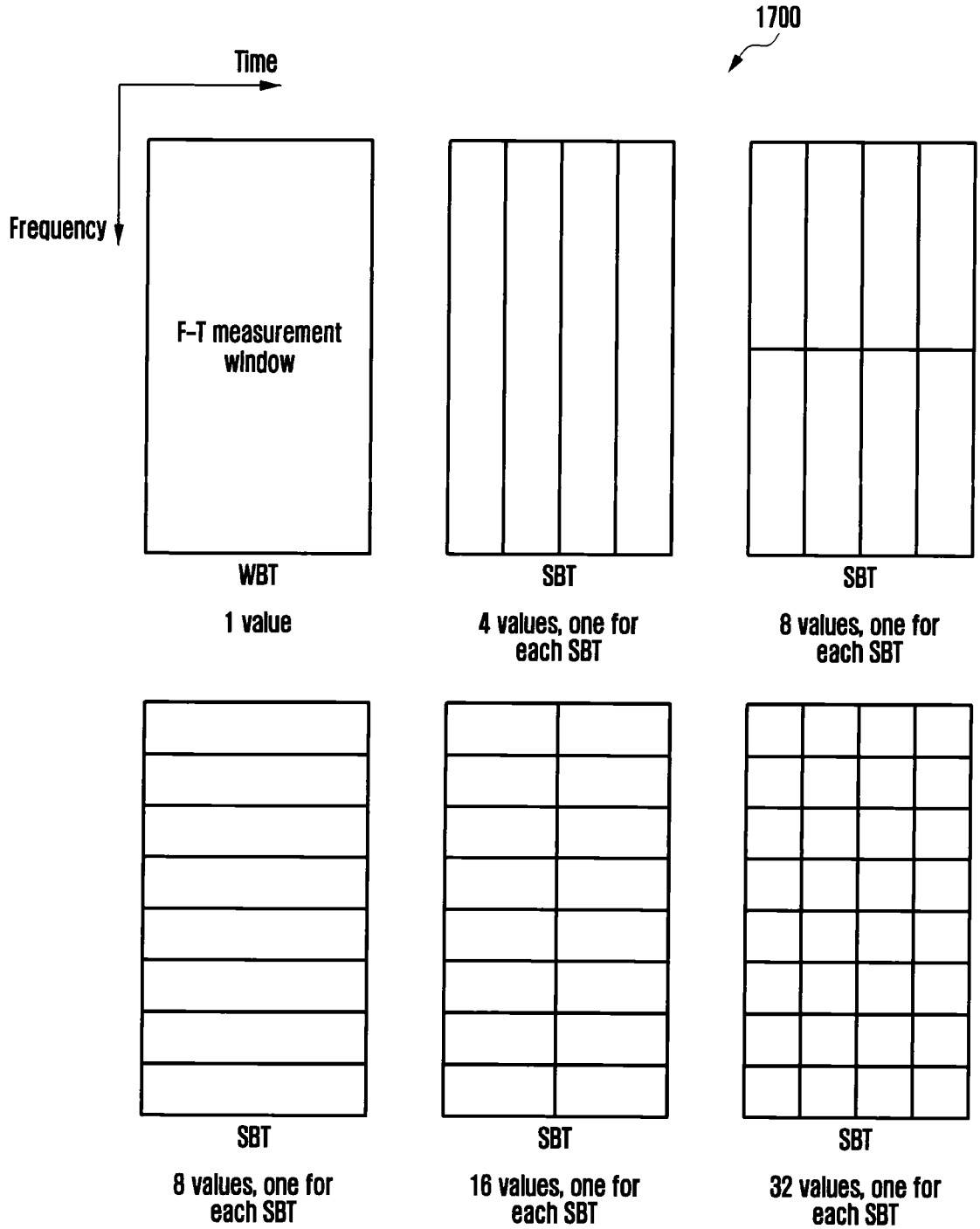
【Figure 15】


1500
R=2
R=1
RB$_{A-1}$
RB7
RB6
RB5
RB4
RB3
RB2
RB1
RB0
SB1
SB0
T0 T1 T2 T3 T4 T5
T$_{B-2}$ T$_{B-1}$
ST0 ST1
R$_{ST}$ = 1
R$_{ST}$ = 2
Frequency
Time

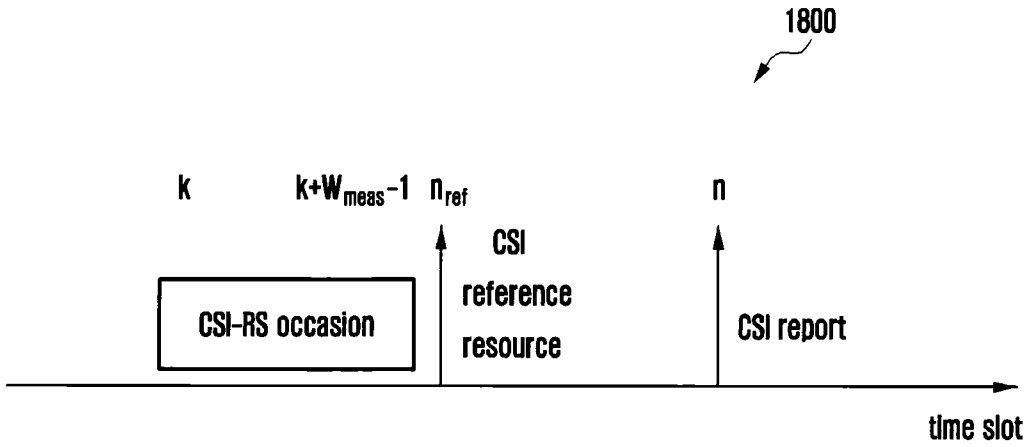
【Figure 16】


1600
(SB, ST)
32 values, one for each (SB,ST) pair
(SB, WT)
8 values, one for each SB
(WB, ST)
4 values, one for each ST
(WB, WT)
1 value
Time
Frequency

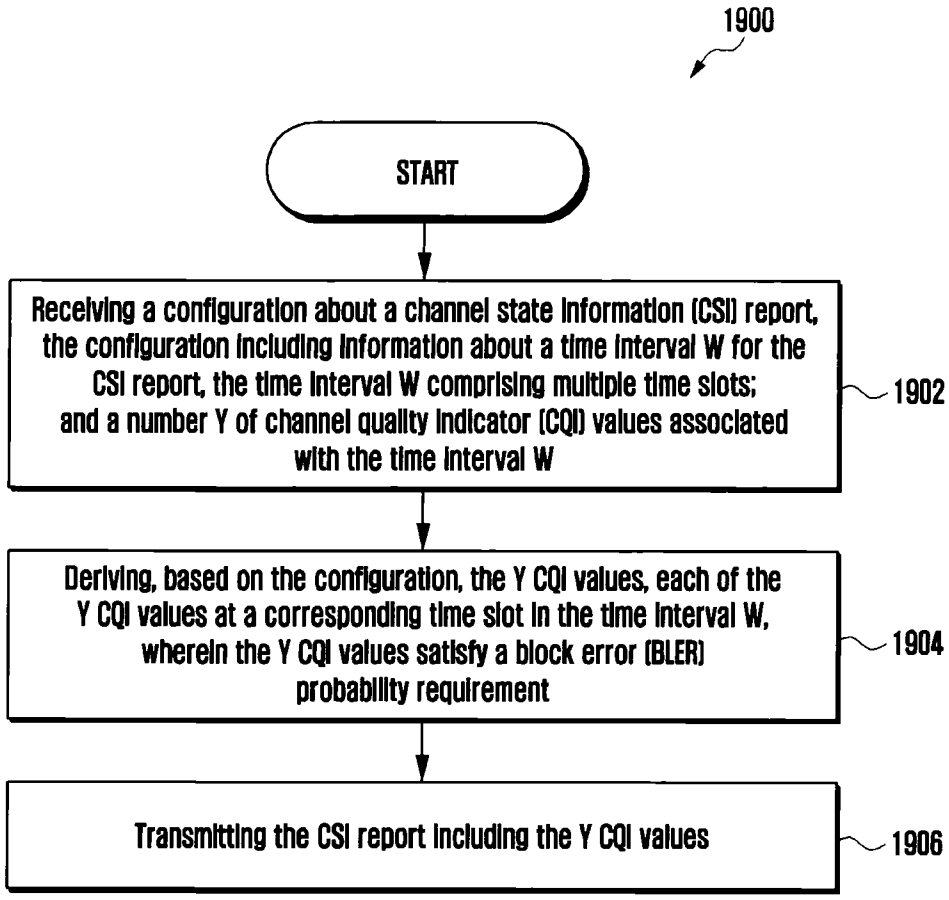
【Figure 17】


1700
Time
Frequency
F-T measurement window
WBT
1 value
SBT
4 values, one for each SBT
SBT
8 values, one for each SBT
SBT
8 values, one for each SBT
SBT
16 values, one for each SBT
SBT
32 values, one for each SBT

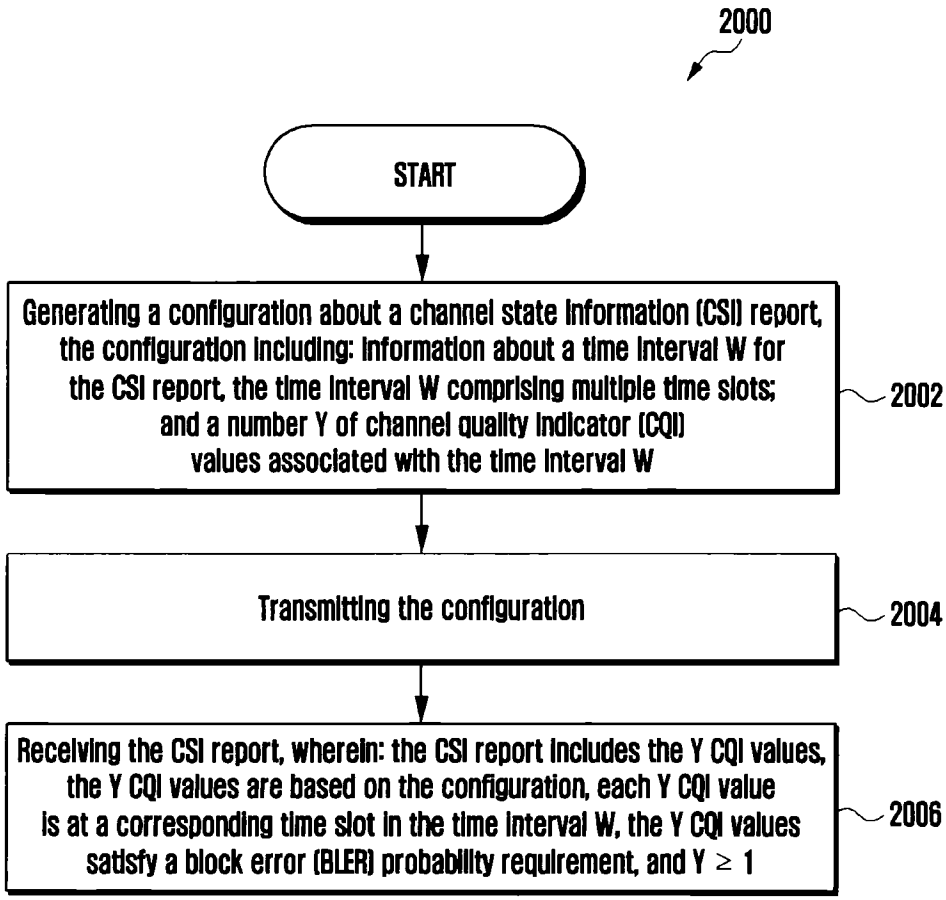
【Figure 18】



【Figure 19】



【Figure 20】


2000
START
Generating a configuration about a channel state information (CSI) report, the configuration including: information about a time interval W for the CSI report, the time interval W comprising multiple time slots; and a number Y of channel quality indicator (CQI) values associated with the time interval W
2002
Transmitting the configuration
2004
Receiving the CSI report, wherein: the CSI report includes the Y CQI values, the Y CQI values are based on the configuration, each Y CQI value is at a corresponding time slot in the time interval W, the Y CQI values satisfy a block error (BLER) probability requirement, and Y ≥ 1
2006

INTERNATIONAL SEARCH REPORT

International application No.
PCT/KR2022/008440

A. CLASSIFICATION OF SUBJECT MATTER

H04B 7/06(2006.01)i; **H04W 72/04**(2009.01)i; **H04L 5/00**(2006.01)i; **H04L 1/00**(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04B 7/06(2006.01); H04B 17/309(2014.01); H04B 7/0456(2017.01); H04L 1/00(2006.01); H04L 5/00(2006.01); H04W 4/00(2009.01); H04W 72/04(2009.01)

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: channel state information (CSI) report, time interval, CSI-RS burst, time slot

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2021-079322 A1 (TELEFONAKTIEBOLAGET LM ERICSSON (PUBL)) 29 April 2021 (2021-04-29) paragraphs [0142]-[0143], [0154]; and figures 5-6, 9	1-15
Y	WO 2021-008450 A1 (QUALCOMM INCORPORATED) 21 January 2021 (2021-01-21) paragraphs [0013], [0084]-[0085], [0088], [0146]; and figure 4	1-15
A	US 2021-0143885 A1 (FRAUNHOFER-GESELLSCHAFT ZUR FöRDERUNG DER ANGEWANDTEN FORSCHUNG E.V.) 13 May 2021 (2021-05-13) paragraphs [0231]-[0273]; and figures 4-7	1-15
A	WO 2021-035396 A1 (QUALCOMM INCORPORATED) 04 March 2021 (2021-03-04) paragraphs [0092]-[0136]; and figures 21-23	1-15
A	US 2020-0221456 A1 (LG ELECTRONICS INC.) 09 July 2020 (2020-07-09) paragraphs [0098]-[0130]; and figures 8-9	1-15

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

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"D" document cited by the applicant in the international application
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 September 2022	**30 September 2022**

Name and mailing address of the ISA/KR	Authorized officer
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2022/008440

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		WO 2021-008007 A1	21 January 2021
US 2021-0143885 A1	13 May 2021	CN 112514276 A	16 March 2021
		EP 3576312 A1	04 December 2019
		EP 3804157 A1	14 April 2021
		JP 2021-525988 A	27 September 2021
		KR 10-2021-0014698 A	09 February 2021
		WO 2019-229152 A1	05 December 2019
WO 2021-035396 A1	04 March 2021	None	
US 2020-0221456 A1	09 July 2020	CN 110945808 A	31 March 2020
		EP 3657705 A1	27 May 2020
		EP 3657705 A4	14 April 2021
		WO 2019-017679 A1	24 January 2019