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(54) **MIMO OPERATIONS**

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***H04B 7/0413*** (2017.01)

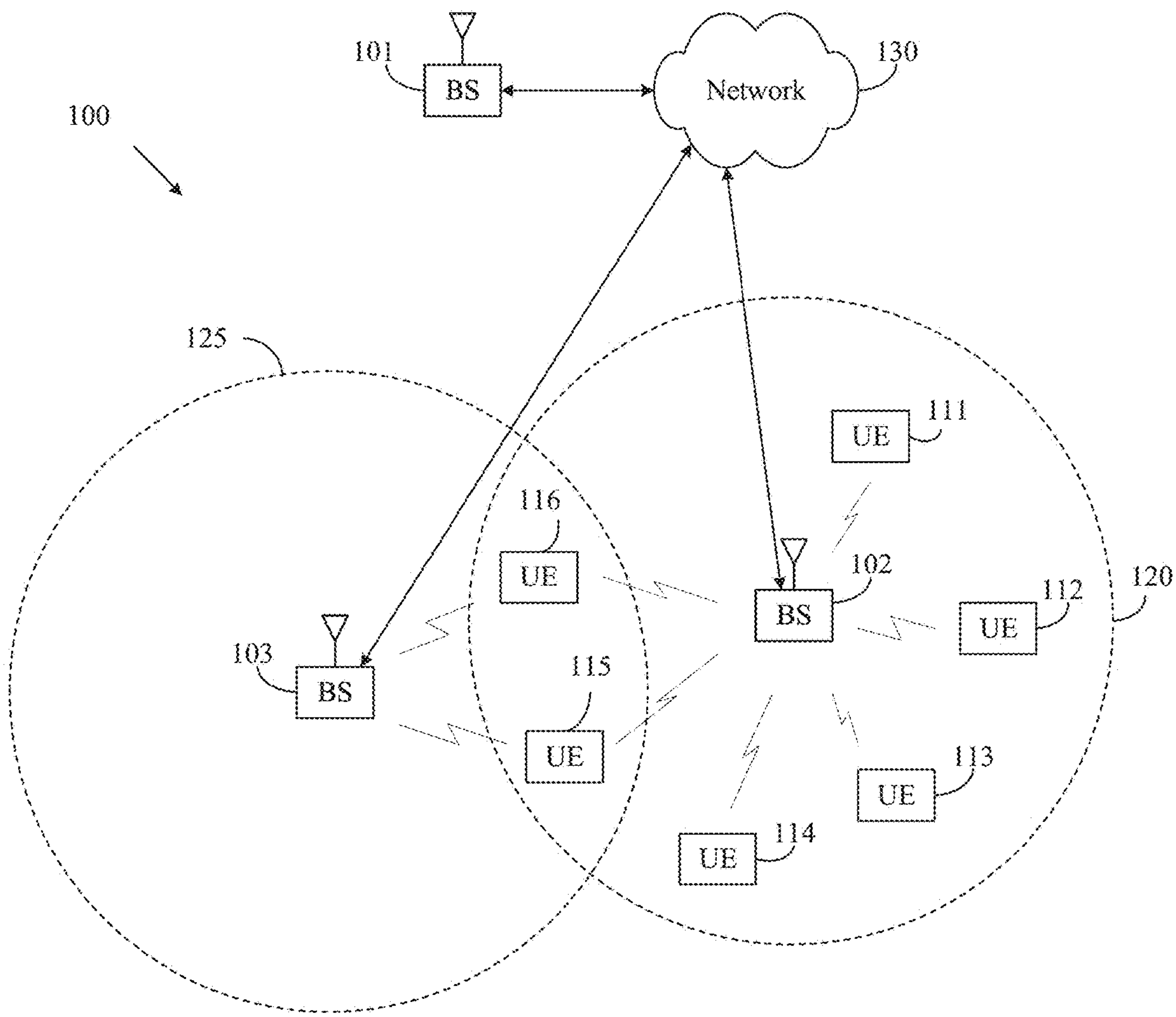
(52) **U.S. Cl.**
CPC ......... ***H04L 5/0094*** (2013.01); ***H04B 7/0413*** (2013.01)

(57) **ABSTRACT**

Apparatuses and methods for multiple-input multiple-output (MIMO) operations. A method performed by a user equipment (UE) includes receiving information about a list of multivariate transmission configuration indicator (mv-TCI) states and receiving an indication about a mv-TCI state from the list of mv-TCI states. Each of the mv-TCI states includes a TCI state ID, a quasi co-location-type (QCL-type), and a coherency type and is associated with at least one port group (PG) comprising n ports. The method further includes identifying, based on the mv-TCI state, the QCL-type, the coherency type, and the at least one PG; determining, based on the QCL-type, common channel properties; determining, based on the coherency type, a transmission hypothesis; and receiving, from the at least one PG, a downlink (DL) transmission based on the determined common channel properties and the determined transmission hypothesis.

1700

```
multivariate TCI state
{
     Id          TCI state Id
     V1          PG selection
     V2          QCL-Type or QCL-info
     .
     .
     .
     .
}
PG selection ::= ENUMERATED{DPS, NCJT, CJT, D-MIMO}
QCL-Type ::= ENUMERATED{A, B, C, D, E}
QCL-info includes QCL-Type
```



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


FIG. 1

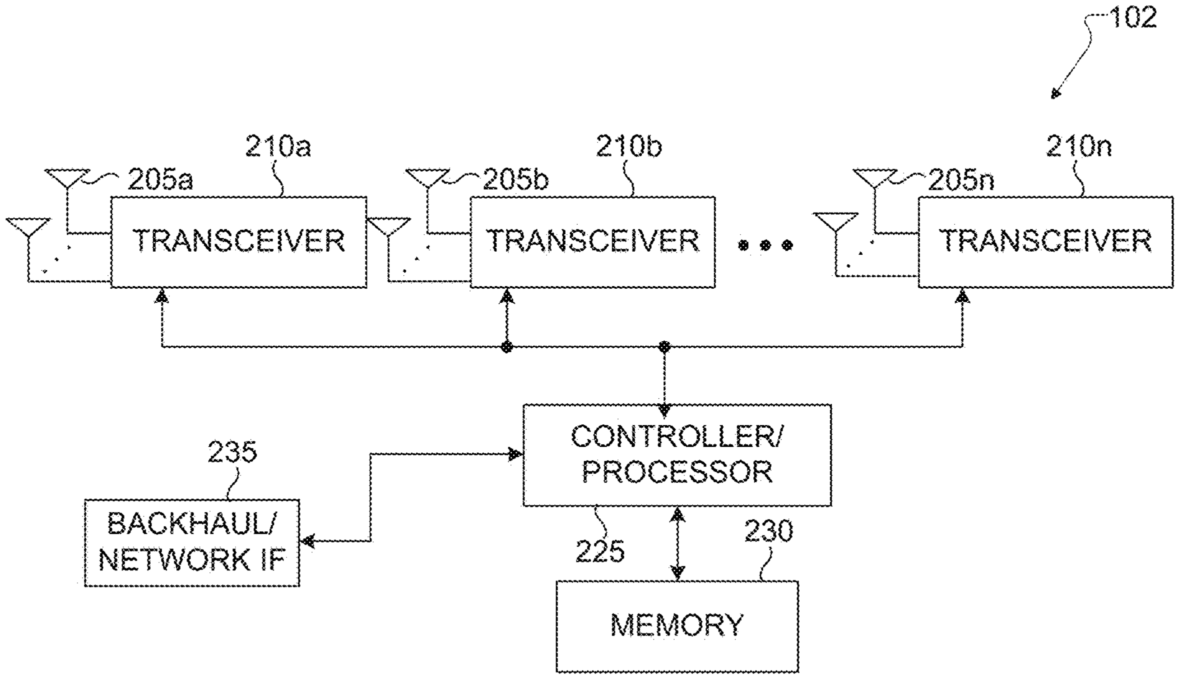

102
210a
205a
TRANSCEIVER
210b
205b
TRANSCEIVER
210n
205n
TRANSCEIVER
235
BACKHAUL/
NETWORK IF
CONTROLLER/
PROCESSOR
225
230
MEMORY

FIG. 2

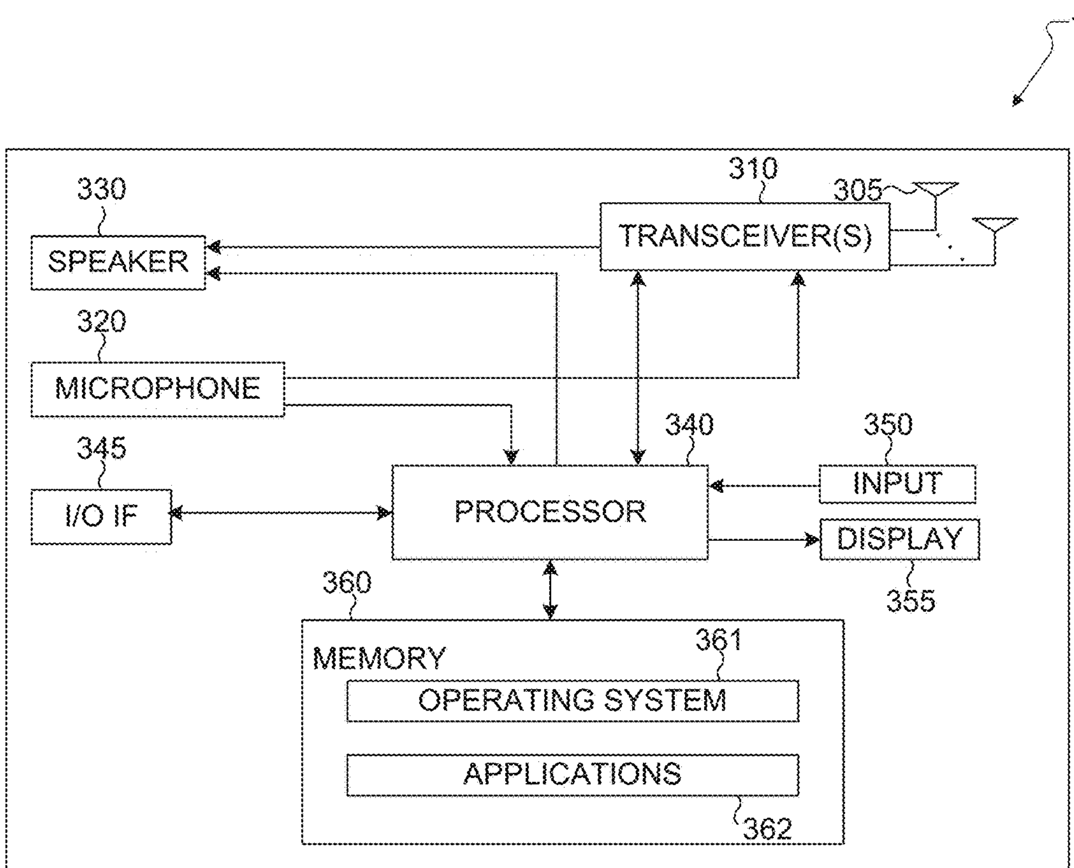

116
330
SPEAKER
310
305
TRANSCEIVER(S)
320
MICROPHONE
345
I/O IF
340
PROCESSOR
350
INPUT
DISPLAY
355
360
MEMORY
361
OPERATING SYSTEM
APPLICATIONS
362

FIG. 3

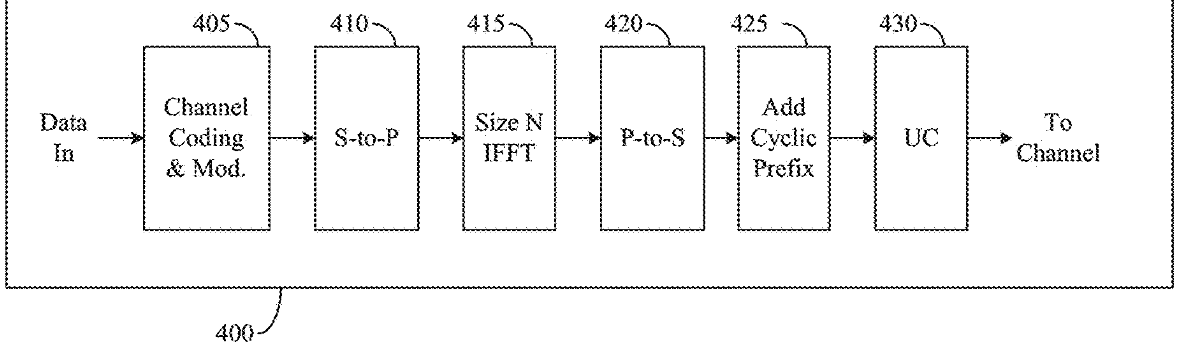

405
410
415
420
425
430
Data In
Channel Coding & Mod.
S-to-P
Size N IFFT
P-to-S
Add Cyclic Prefix
UC
To Channel
400

FIG. 4A

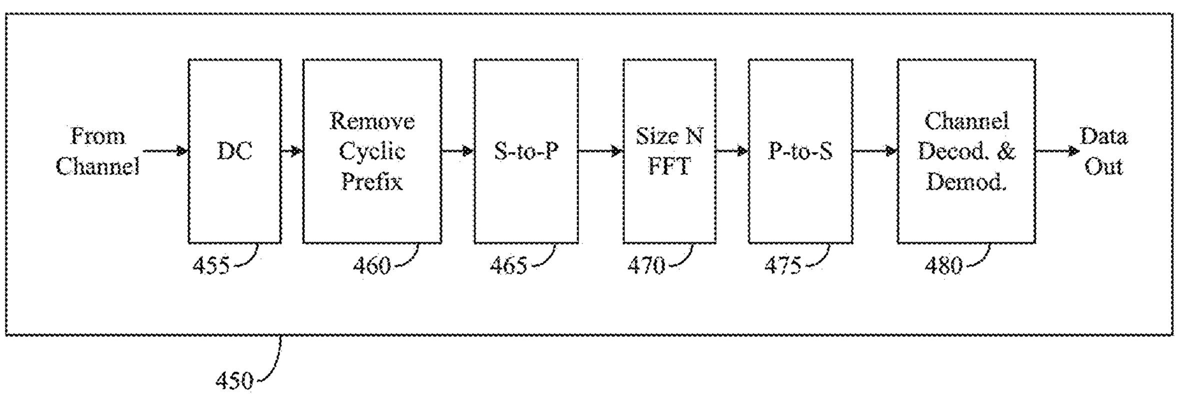

From Channel
DC
Remove Cyclic Prefix
S-to-P
Size N FFT
P-to-S
Channel Decod. & Demod.
Data Out
455
460
465
470
475
480
450

FIG. 4B

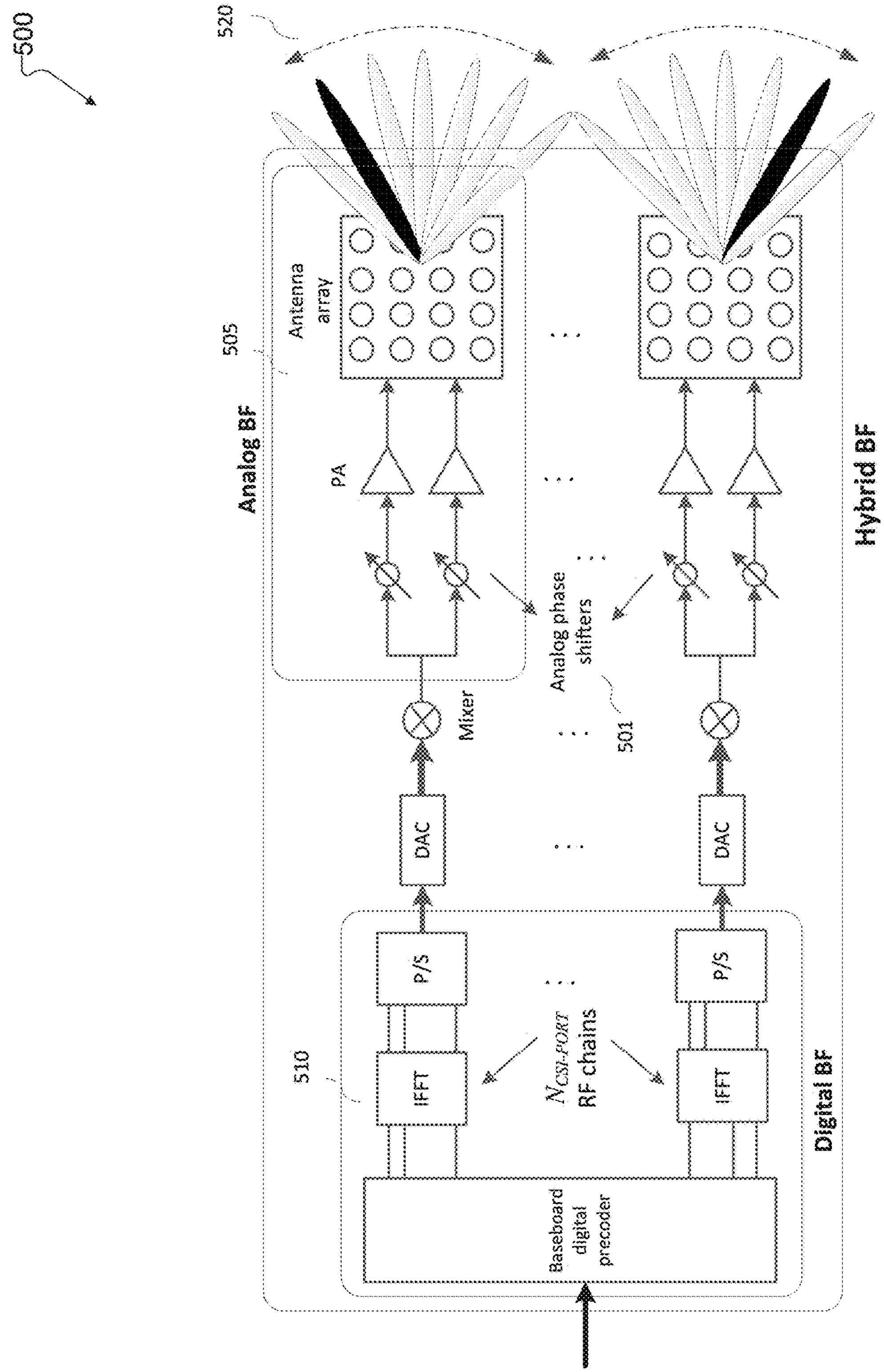

500
520
505
Analog BF
Antenna array
PA
Hybrid BF
Analog phase shifters
501
Mixer
DAC
P/S
IFFT
510
$N_{CSI\text{-}PORT}$ RF chains
Digital BF
Baseboard digital precoder

FIG. 5

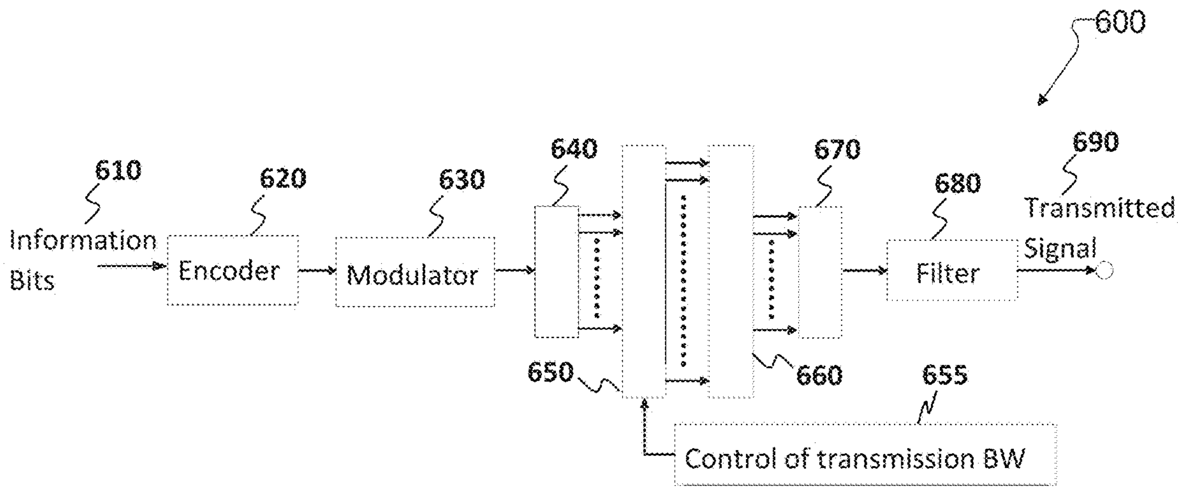



FIG. 6

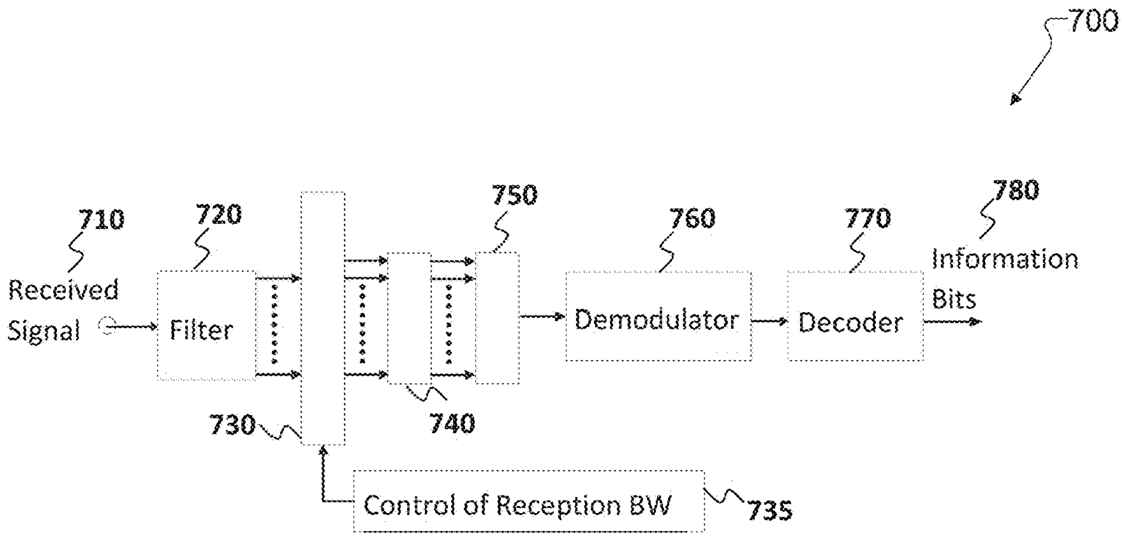



FIG. 7

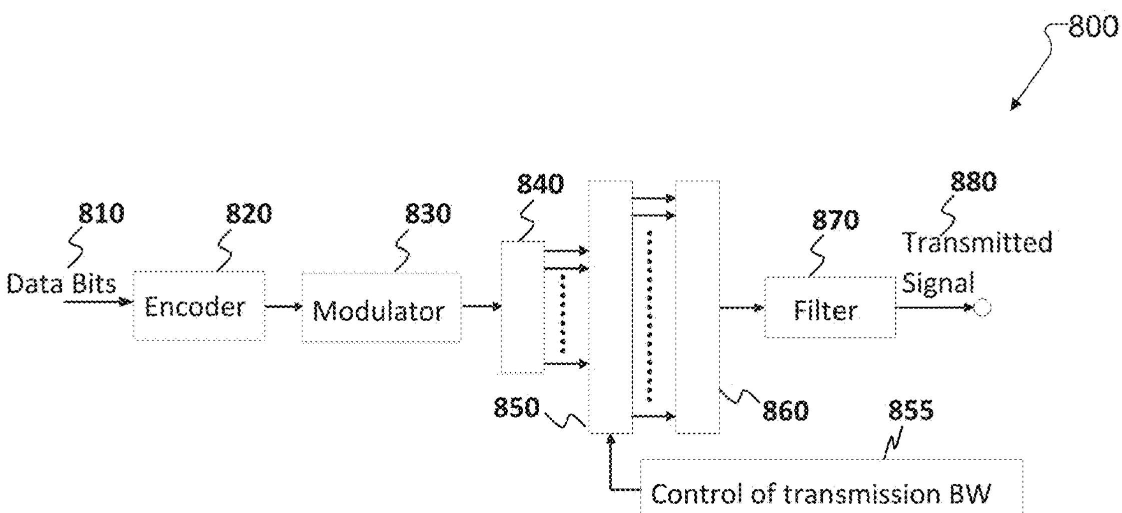



FIG. 8

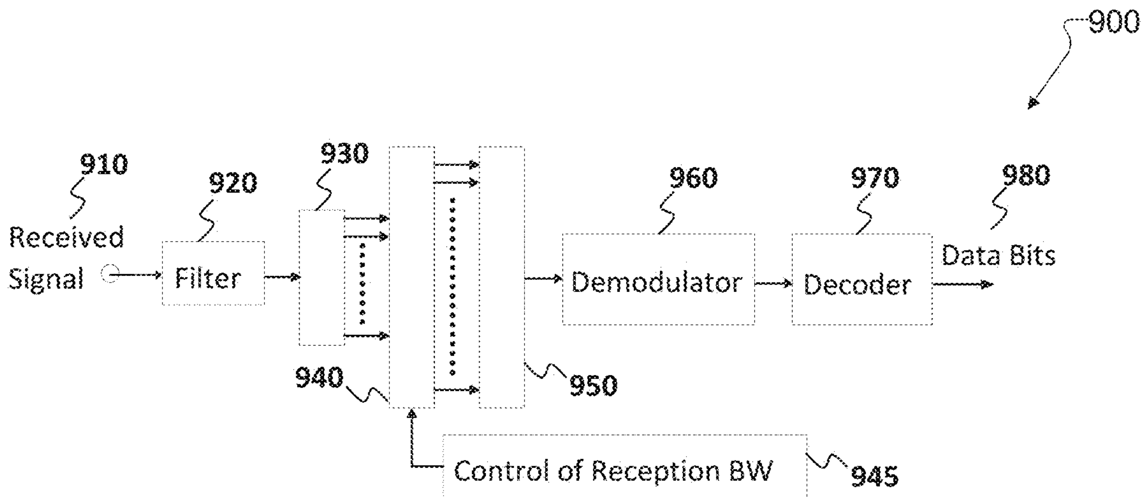

900
910
Received Signal
920
Filter
930
940
950
960
Demodulator
970
Decoder
980
Data Bits
Control of Reception BW
945

FIG. 9

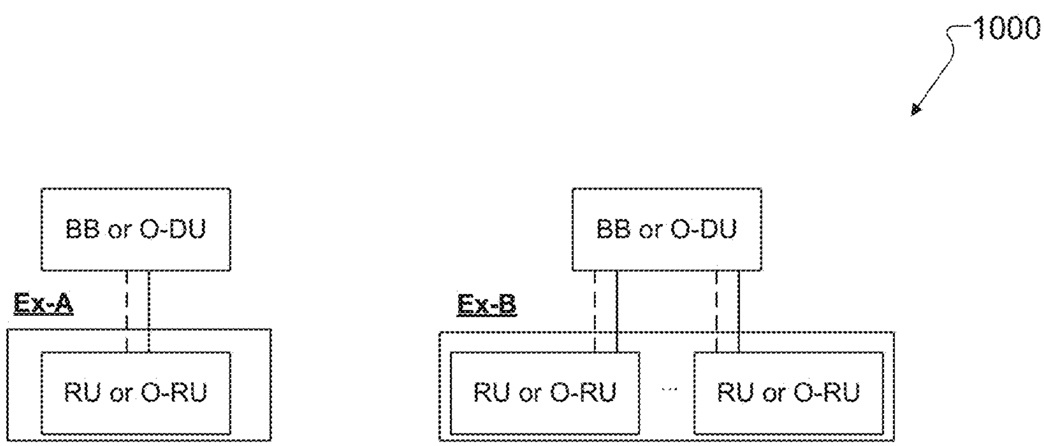

1000
BB or O-DU
Ex-A
RU or O-RU
BB or O-DU
Ex-B
RU or O-RU
...
RU or O-RU

FIG. 10

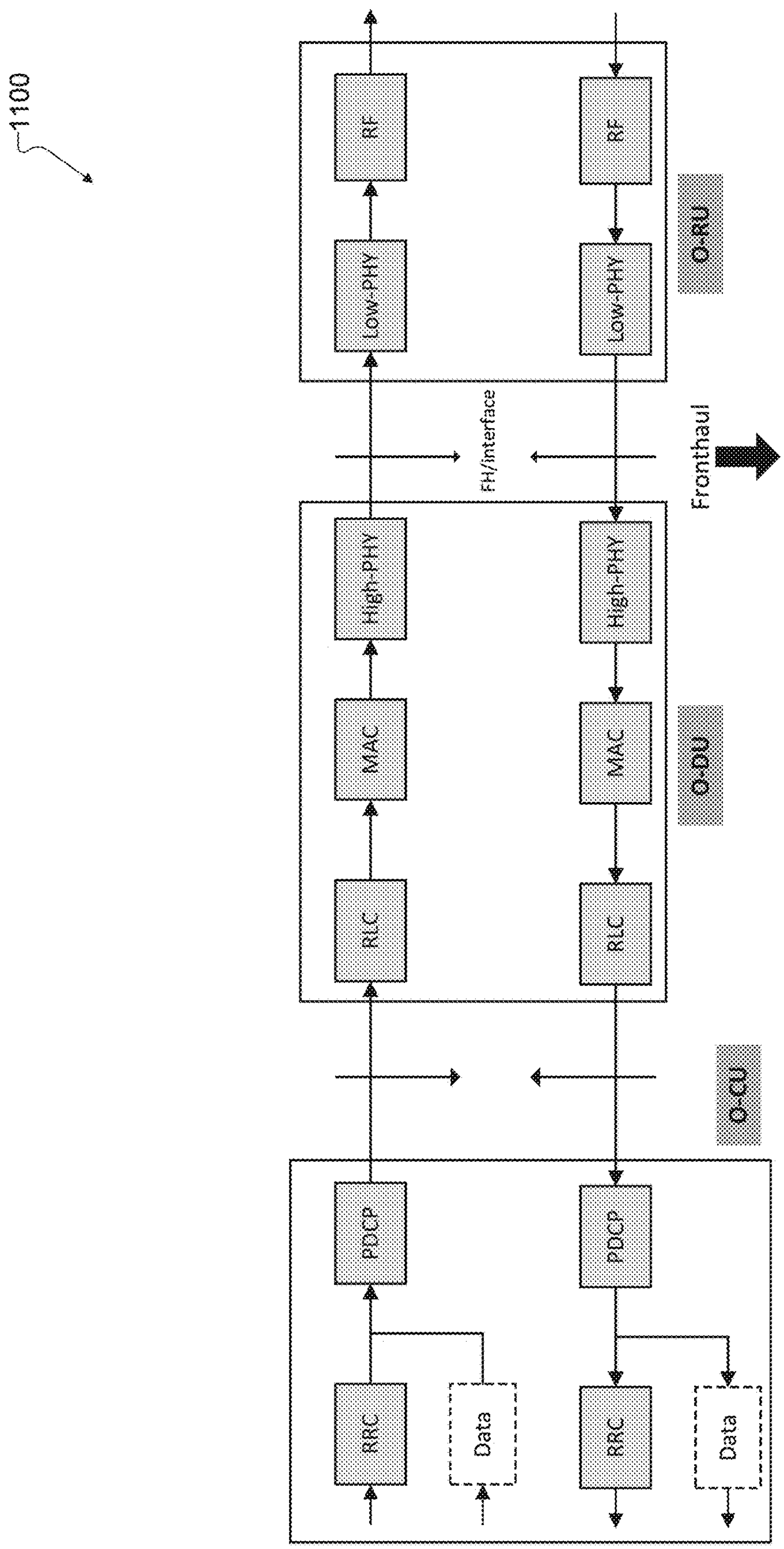

1100
RF
Low-PHY
O-RU
FH/interface
Fronthaul
High-PHY
MAC
RLC
O-DU
O-CU
PDCP
RRC
Data

FIG. 11

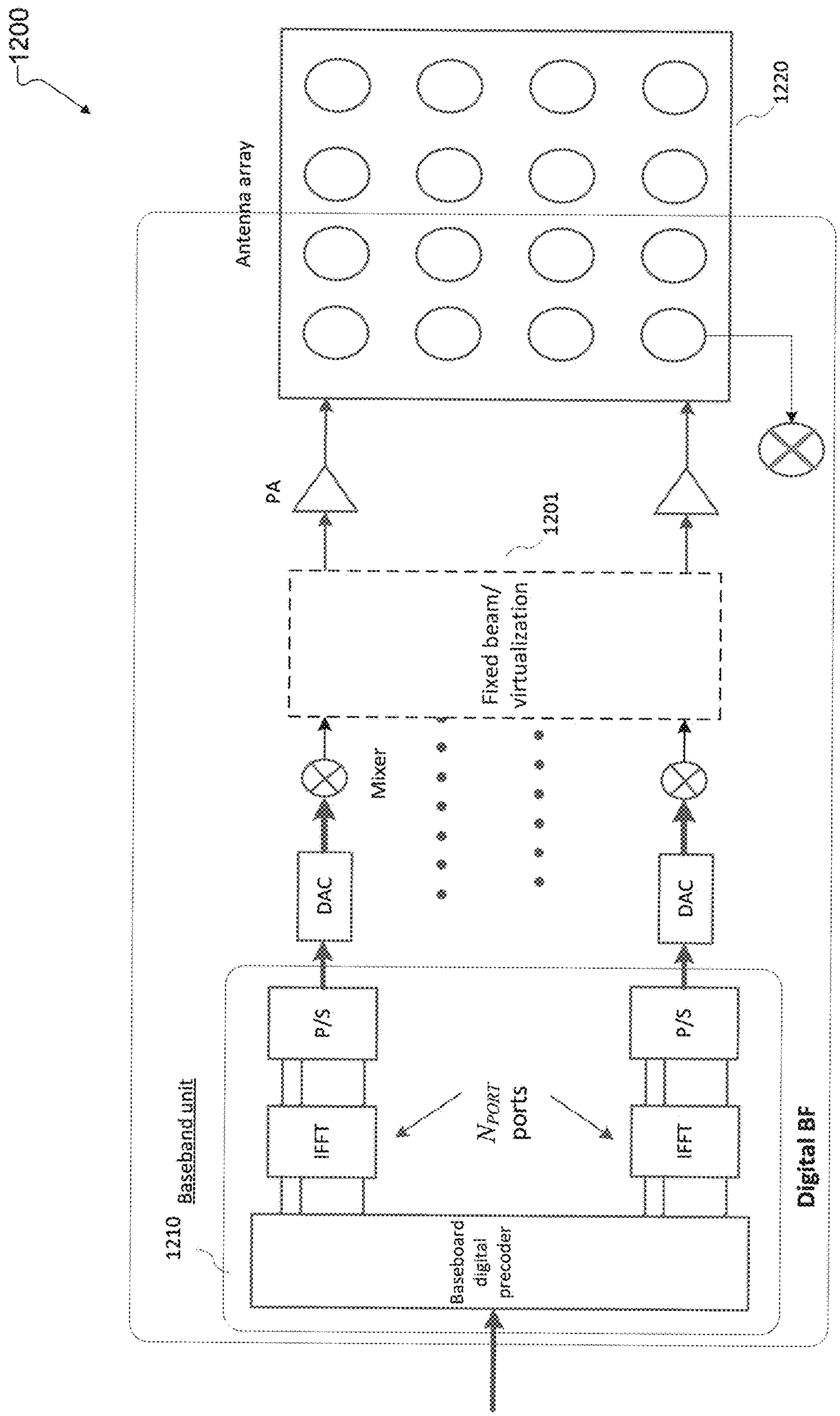
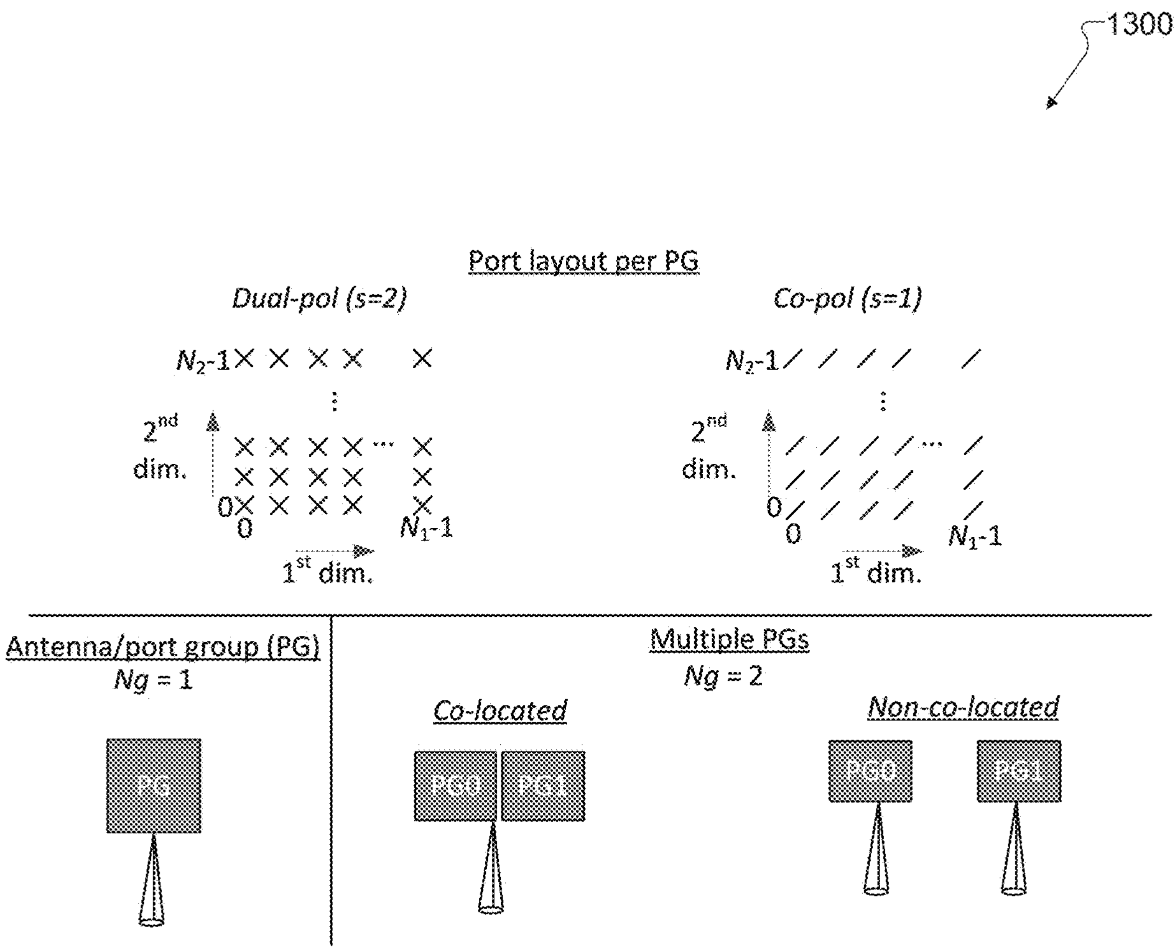

1200
Antenna array
1220
PA
1201
Fixed beam/
virtualization
Mixer
DAC
DAC
Baseband unit
P/S
P/S
IFFT
IFFT
$N_{PORT}$ ports
1210
Baseboard
digital
precoder
Digital BF

FIG. 12



1300
Port layout per PG
Dual-pol (s=2)
Co-pol (s=1)
N2-1
2nd dim.
0
0
N1-1
1st dim.
Antenna/port group (PG)
Ng = 1
PG
Multiple PGs
Ng = 2
Co-located
PG0
PG1
Non-co-located
PG0
PG1


FIG. 13

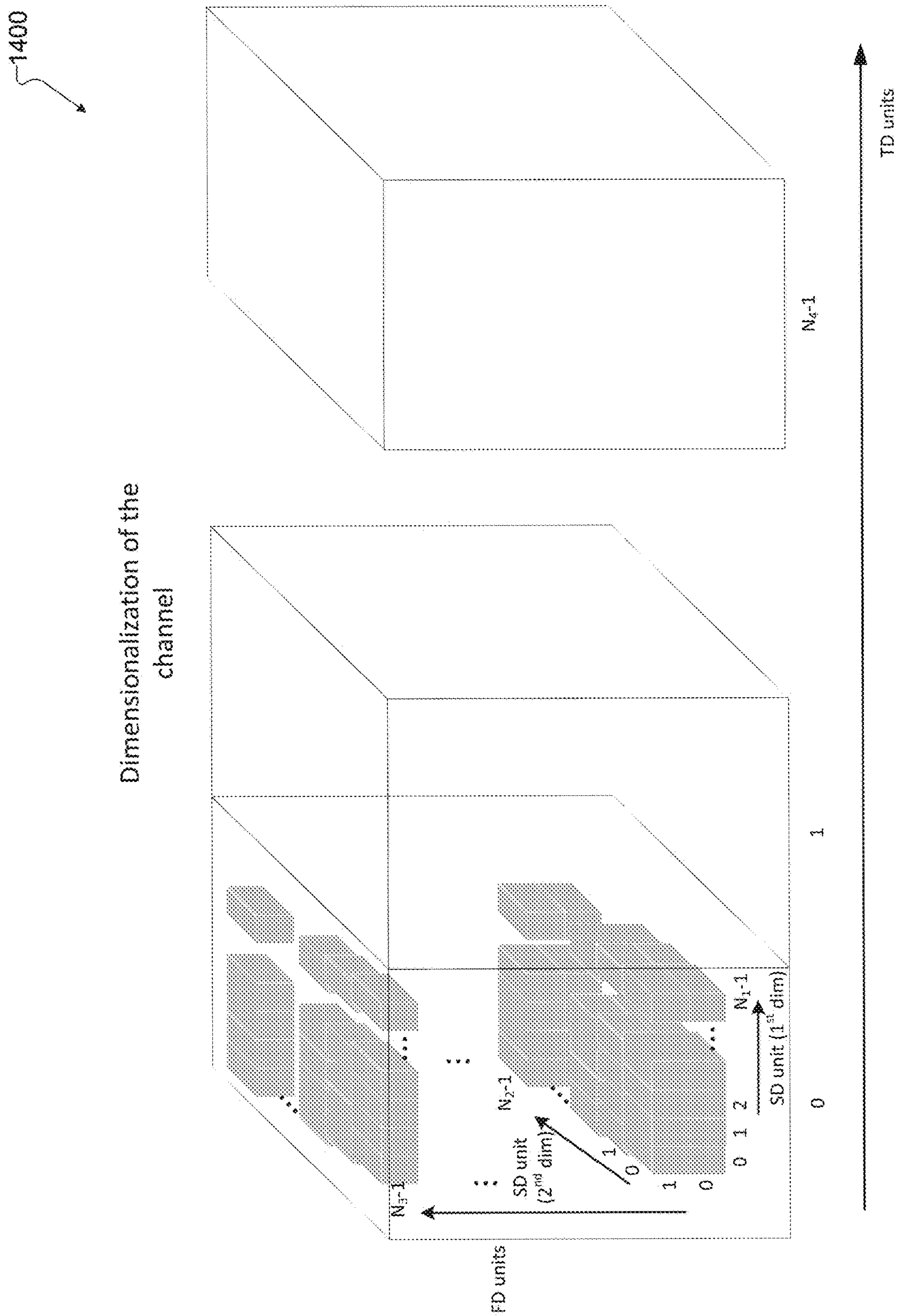

1400
Dimensionalization of the channel
FD units
$N_3$-1
SD unit ($2^{nd}$ dim)
$N_2$-1
SD unit ($1^{st}$ dim)
$N_1$-1
0 1 2
0
1
$N_4$-1
TD units

FIG. 14

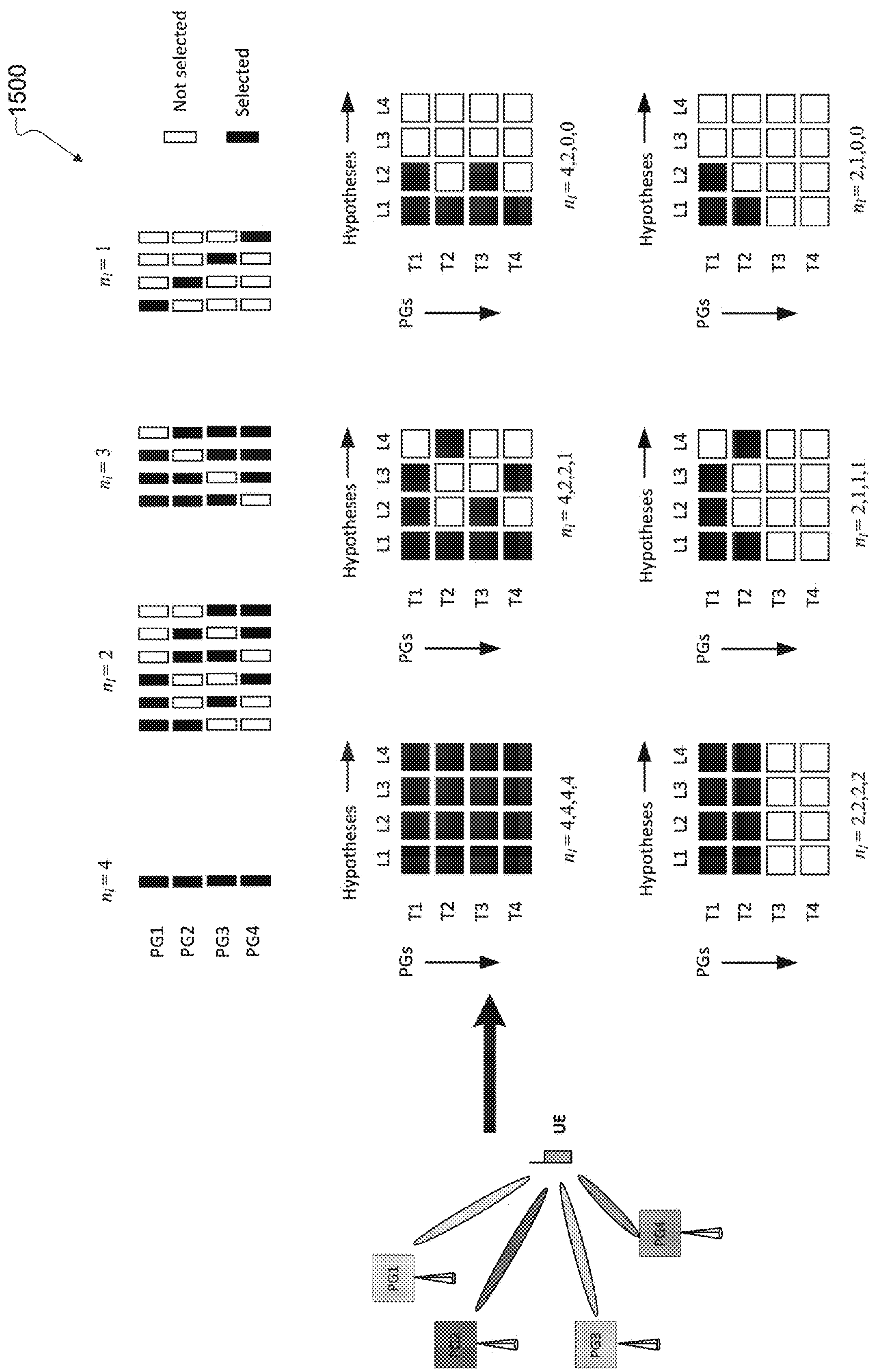

1500
Not selected
Selected
$n_l = 4$
$n_l = 2$
$n_l = 3$
$n_l = 1$
PG1
PG2
PG3
PG4
Hypotheses
L1
L2
L3
L4
PGs
T1
T2
T3
T4
$n_l = 4,4,4,4$
$n_l = 4,2,2,1$
$n_l = 4,2,0,0$
$n_l = 2,2,2,2$
$n_l = 2,1,1,1$
$n_l = 2,1,0,0$
UE

FIG. 15

1600

```
multivariate TCI state
{
     Id          TCI state Id
     V1          PG selection
     V2          QCL-Type or QCL-info
     V3          coherencyType
     .
     .
}
PG selection ::= ENUMERATED{DPS, NCJT, CJT, D-MIMO}
QCL-Type ::= ENUMERATED{A, B, C, D}
CoherenceType ::= ENUMERATED{FC, PC, NC}
QCL-info includes QCL-Type
```

FIG. 16

1700

```
multivariate TCI state
{
     Id          TCI state Id
     V1          PG selection
     V2          QCL-Type or QCL-info
     .
     .
     .
     .
}
PG selection ::= ENUMERATED{DPS, NCJT, CJT, D-MIMO}
QCL-Type ::= ENUMERATED{A, B, C, D, E}
QCL-info includes QCL-Type
```

FIG. 17

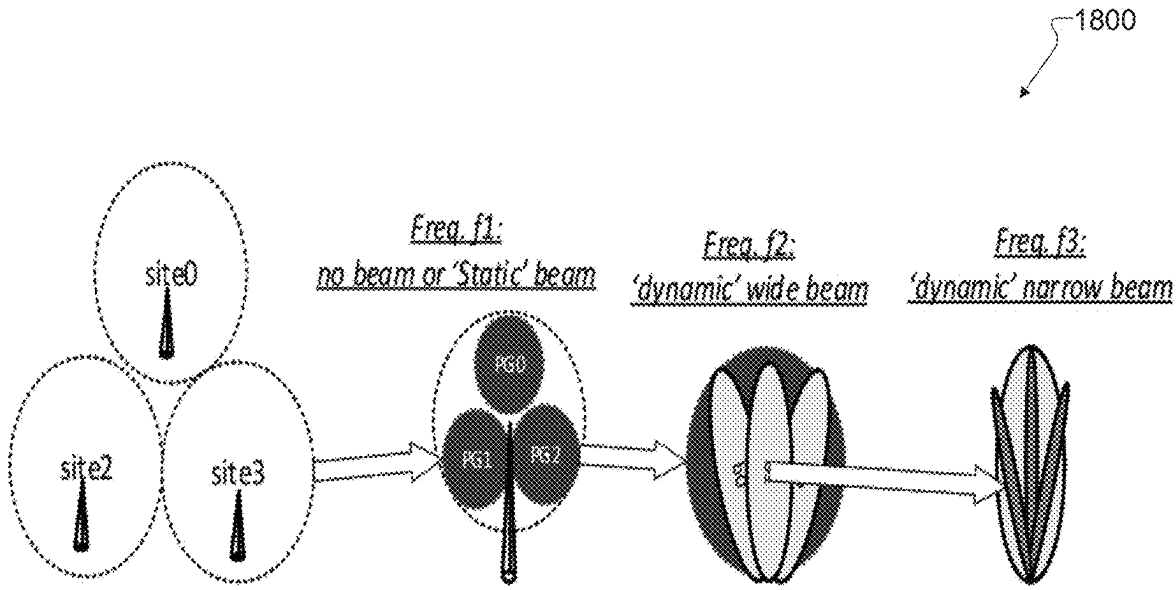

1800
site0
site2
site3
Freq. f1:
no beam or 'Static' beam
PG0
PG1
PG2
Freq. f2:
'dynamic' wide beam
Freq. f3:
'dynamic' narrow beam

FIG. 18

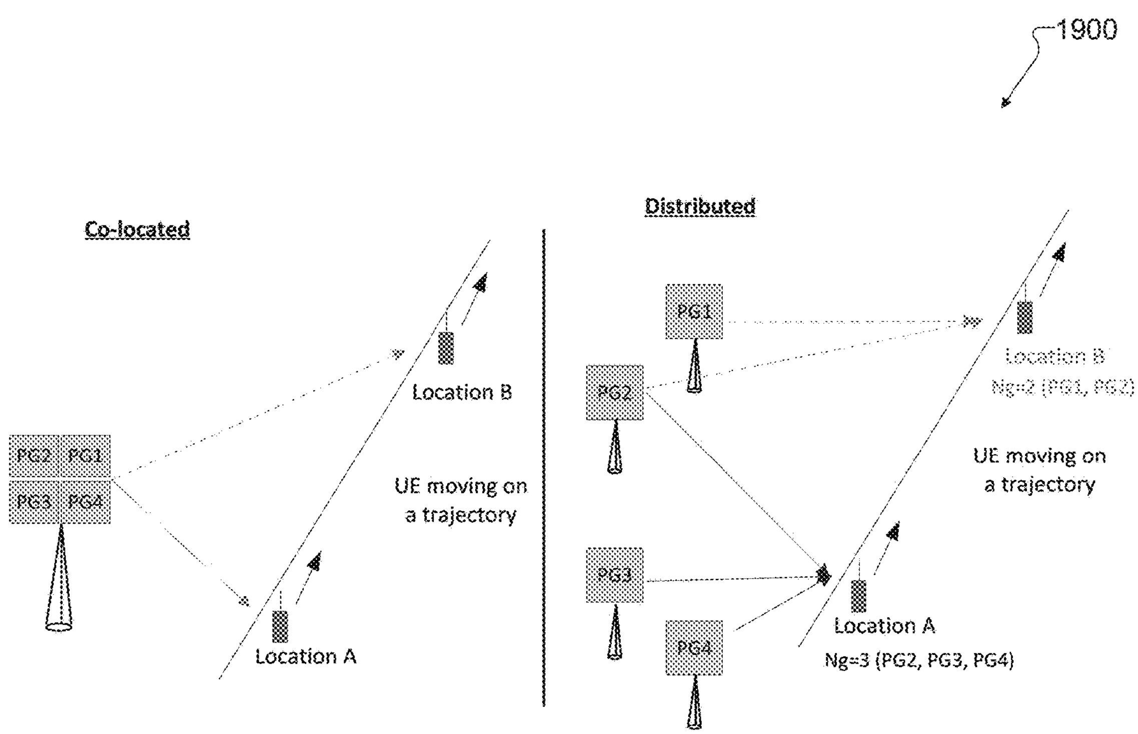

1900
Co-located
PG2
PG1
PG3
PG4
Location B
UE moving on
a trajectory
Location A
Distributed
PG1
PG2
PG3
PG4
Location B
Ng=2 (PG1, PG2)
UE moving on
a trajectory
Location A
Ng=3 (PG2, PG3, PG4)

FIG. 19

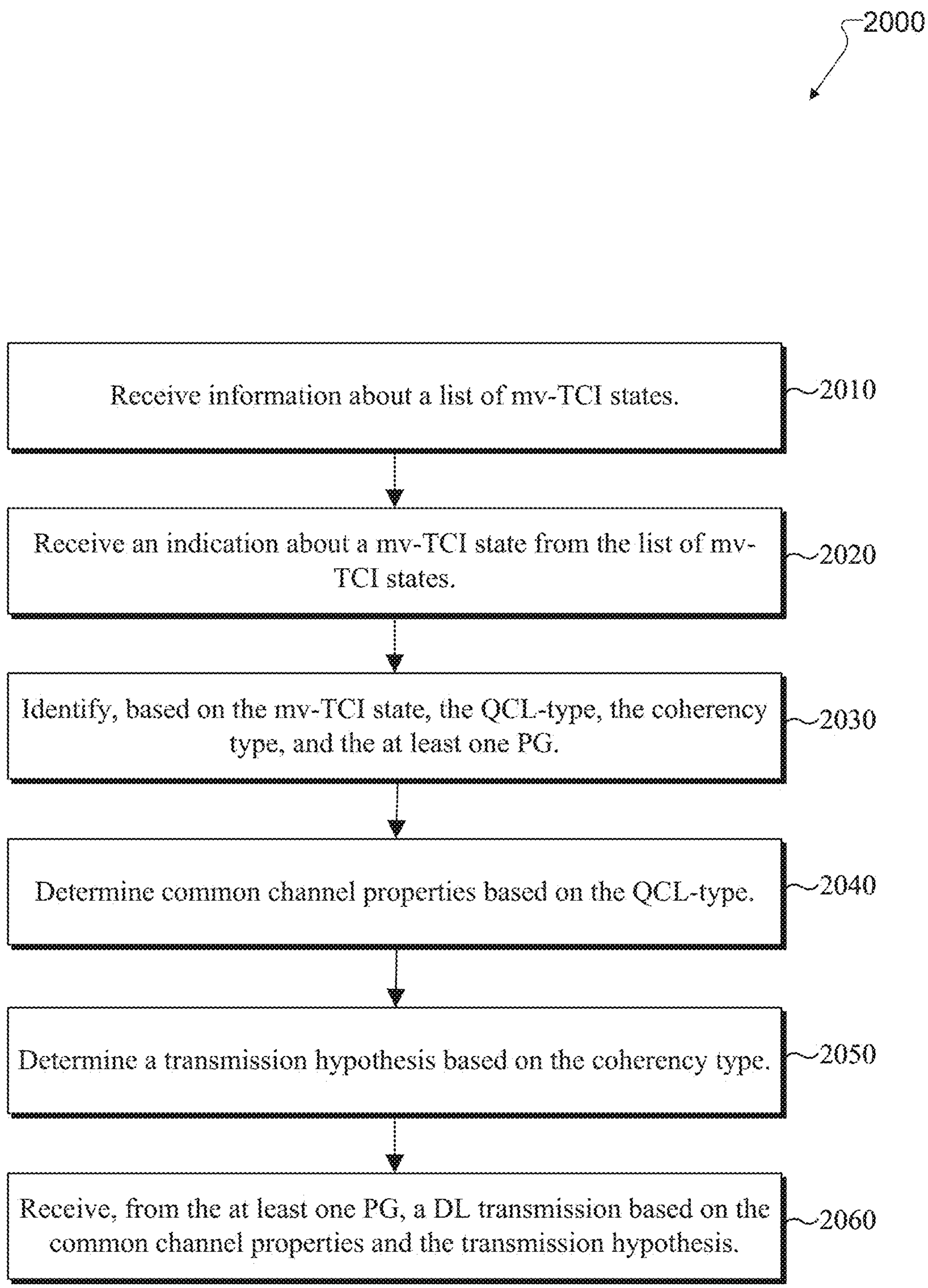

2000
Receive information about a list of mv-TCI states.
2010
Receive an indication about a mv-TCI state from the list of mv-TCI states.
2020
Identify, based on the mv-TCI state, the QCL-type, the coherency type, and the at least one PG.
2030
Determine common channel properties based on the QCL-type.
2040
Determine a transmission hypothesis based on the coherency type.
2050
Receive, from the at least one PG, a DL transmission based on the common channel properties and the transmission hypothesis.
2060

FIG. 20

# MIMO OPERATIONS

## CROSS-REFERENCE TO RELATED AND CLAIM OF PRIORITY

[0001] The present application claims priority under 35 U.S.C. § 119(e) to U.S. Provisional Patent Application No. 63/555,778 filed on Feb. 20, 2024, which is hereby incorporated by reference in its entirety.

## TECHNICAL FIELD

[0002] The present disclosure relates generally to wireless communication systems and, more specifically, the present disclosure is related to apparatuses and methods for multiple-input multiple-output (MIMO) operations.

## BACKGROUND

[0003] Wireless communication has been one of the most successful innovations in modern history. Recently, the number of subscribers to wireless communication services exceeded five billion and continues to grow quickly. The demand of wireless data traffic is rapidly increasing due to the growing popularity among consumers and businesses of smart phones and other mobile data devices, such as tablets, “note pad” computers, net books, eBook readers, and machine type of devices. In order to meet the high growth in mobile data traffic and support new applications and deployments, improvements in radio interface efficiency and coverage are of paramount importance. To meet the demand for wireless data traffic having increased since deployment of 4G communication systems, and to enable various vertical applications, 5G communication systems have been developed and are currently being deployed.

## SUMMARY

[0004] The present disclosure relates to MIMO operations.

[0005] In one embodiment, a user equipment (UE) is provided. The UE includes a transceiver configured to receive information about a list of multivariate transmission configuration indicator (mv-TCI) states and receive an indication about a mv-TCI state from the list of mv-TCI states. Each of the mv-TCI states includes a TCI state ID, a quasi co-location-type (QCL-type), and a coherency type and is associated with at least one port group (PG) comprising n ports. The UE further includes a processor operably coupled to the transceiver. The processor is configured to identify, based on the mv-TCI state, the QCL-type, the coherency type, and the at least one PG, determine, based on the QCL-type, common channel properties, and determine, based on the coherency type, a transmission hypothesis. The transceiver is further configured to receive, from the at least one PG, a downlink (DL) transmission based on the determined common channel properties and the determined transmission hypothesis. $1 \leq n \leq N$ and N is a total number of ports.

[0006] In another embodiment, a base station (BS) is provided. The BS includes a transceiver configured to transmit information about a list of mv-TCI states and transmit an indication about a mv-TCI state from the list of mv-TCI states. Each of the mv-TCI states includes a TCI state ID, a QCL-type, and a coherency type and is associated with at least one PG comprising n ports. The BS further includes a processor operably coupled to the transceiver. The processor is configured to identify, based on the mv-TCI state, the QCL-type, the coherency type, and the at least one PG, determine, based on the QCL-type, common channel properties, and determine, based on the coherency type, a transmission hypothesis. The transceiver is further configured to transmit, from the at least one PG, a DL transmission based on the determined common channel properties and the determined transmission hypothesis. $1 \leq n \leq N$ and N is a total number of ports.

[0007] In yet another embodiment, a method performed by a UE is provided The method includes receiving information about a list of mv-TCI states and receiving an indication about a mv-TCI state from the list of mv-TCI states. Each of the mv-TCI states includes a TCI state ID, a QCL-type, and a coherency type and is associated with at least one PG comprising n ports. The method further includes identifying, based on the mv-TCI state, the QCL-type, the coherency type, and the at least one PG; determining, based on the QCL-type, common channel properties; determining, based on the coherency type, a transmission hypothesis; and receiving, from the at least one PG, a DL transmission based on the determined common channel properties and the determined transmission hypothesis. $1 \leq n \leq N$ and N is a total number of ports.

[0008] Other technical features may be readily apparent to one skilled in the art from the following figures, descriptions, and claims.

[0009] 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.

[0010] 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.

**[0011]** 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.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0012]** 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:

**[0013]** FIG. **1** illustrates an example wireless network according to embodiments of the present disclosure;

**[0014]** FIG. **2** illustrates an example gNodeB (gNB) according to embodiments of the present disclosure;

**[0015]** FIG. **3** illustrates an example user equipment (UE) according to embodiments of the present disclosure;

**[0016]** FIGS. **4**A and **4**B illustrate an example of a wireless transmit and receive paths according to embodiments of the present disclosure;

**[0017]** FIG. **5** illustrates an example of a transmitter structure for beamforming according to embodiments of the present disclosure;

**[0018]** FIG. **6** illustrates an example of a transmitter structure for physical downlink shared channel (PDSCH) in a subframe according to embodiments of the present disclosure;

**[0019]** FIG. **7** illustrates an example of a receiver structure for PDSCH in a subframe according to embodiments of the present disclosure;

**[0020]** FIG. **8** illustrates an example of a transmitter structure for physical uplink shared channel (PUSCH) in a subframe according to embodiments of the present disclosure;

**[0021]** FIG. **9** illustrates an example of a receiver structure for a PUSCH in a subframe according to embodiments of the present disclosure;

**[0022]** FIG. **10** illustrates a diagram of example radio access network (RAN) configurations according to embodiments of the present disclosure;

**[0023]** FIG. **11** illustrates a diagram of example functional split points/options according to embodiments of the present disclosure;

**[0024]** FIG. **12** illustrates an example of a fully digital transmitter structure for beamforming according to embodiments of the present disclosure;

**[0025]** FIG. **13** illustrates a diagram of an example antenna port layout according to embodiments of the present disclosure;

**[0026]** FIG. **14** illustrates a timeline of example spatial-domain (SD) units and frequency-domain (FD) units according to embodiments of the present disclosure;

**[0027]** FIG. **15** illustrates a diagram of example port group (PG) hypotheses according to embodiments of the present disclosure;

**[0028]** FIG. **16** illustrates a diagram of an example transmission configuration indication (TCI) state configuration according to embodiments of the present disclosure;

**[0029]** FIG. **17** illustrates a diagram of an example TCI state configuration according to embodiments of the present disclosure;

**[0030]** FIG. **18** illustrates a diagram of an example analog beam-based network according to embodiments of the present disclosure;

**[0031]** FIG. **19** illustrates examples of a UE moving on a trajectory located in co-located and distributed PGs according to embodiments of the present disclosure; and

**[0032]** FIG. **20** illustrates an example method performed by a UE in a wireless communication system according to embodiments of the present disclosure.

## DETAILED DESCRIPTION

**[0033]** FIGS. **1-20** discussed below, and the various, non-limiting 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.

**[0034]** To meet the demand for wireless data traffic having increased since deployment of 4G communication systems, and to enable various vertical applications, 5G/NR communication systems have been developed and are currently being deployed. The 5G/NR communication system is implemented in higher frequency (mmWave) bands, e.g., 28 GHz or 60 GHz bands, so as to accomplish higher data rates or in lower frequency bands, such as 6 GHz, to enable robust coverage and mobility support. To decrease propagation loss of the radio waves and increase the transmission distance, the beamforming, massive MIMO, full dimensional MIMO (FD-MIMO), array antenna, an analog beam forming, large scale antenna techniques are discussed in 5G/NR communication systems.

**[0035]** In addition, in 5G/NR communication systems, development for system network improvement is under way based on advanced small cells, cloud radio access networks (RANs), ultra-dense networks, device-to-device (D2D) communication, wireless backhaul, moving network, cooperative communication, coordinated multi-points (CoMP), reception-end interference cancelation and the like.

**[0036]** In the 5G system, Hybrid frequency shift keying (FSK) and QAM Modulation (FQAM) and sliding window superposition coding (SWSC) as an advanced coding modulation (ACM), and filter bank multi carrier (FBMC), non-orthogonal multiple access (NOMA), and sparse code multiple access (SCMA) as an advanced access technology have been developed.

**[0037]** 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.

**[0038]** The following documents and standards descriptions are hereby incorporated by reference into the present disclosure as if fully set forth herein: [REF1] 3GPP TS 36.211 v17.3.0, "E-UTRA, Physical channels and modulation;" [REF 2] 3GPP TS 36.212 v17.3.0, "E-UTRA, Multiplexing and Channel coding;" [REF 3] 3GPP TS 36.213 v17.3.0, "E-UTRA, Physical Layer Procedures;" [REF 4]3GPP TS 36.321 v17.3.0, "E-UTRA, Medium Access Control (MAC) protocol specification;" [REF 5] 3GPP TS 36.331 v17.3.0, "E-UTRA, Radio Resource Control (RRC) Protocol Specification;" [REF 6] 3GPP TR 22.891 v1.2.0; [REF 7] 3GPP TS 38.212 v18.0.0, "E-UTRA, NR, Multiplexing and Channel coding;" [REF 8] 3GPP TS 38.214 v18.0.0, "E-UTRA, NR, Physical layer procedures for data;" [REF 9] 3GPP TS 38.211 v18.0.0, "E-UTRA, NR, Physical channels and modulation;" [REF 10] 3GPP TS 38.104 v18.3.0, "E-UTRA, NR, Physical channels and modulation;" [REF 11] O-RAN.WG4.CONF.0-R003-v09.00, "O-RAN Working Group 4 (Fronthaul Working Group) Conformance Test Specification;" and [REF 12]O-RAN. WG4.CUS.0-R003-v13.00, "O-RAN Working Group 4 (Open Fronthaul Interfaces WG)—Control, User and Synchronization Plane Specification.

**[0039]** FIGS. **1-20** 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 FIGS. **1-3** are not meant to imply physical or architectural limitations to how different embodiments may be implemented. Different embodiments of the present disclosure may be implemented in any suitably arranged communications system.

**[0040]** FIG. **1** illustrates an example wireless network **100** according to embodiments of the present disclosure. The embodiment of the wireless network **100** shown in FIG. **1** is for illustration only. Other embodiments of the wireless network **100** could be used without departing from the scope of the present disclosure.

**[0041]** As shown in FIG. **1**, the wireless network **100** includes a gNB **101** (e.g., base station, BS), a gNB **102**, and a gNB **103**. The gNB **101** communicates with the gNB **102** and the gNB **103**. The gNB **101** also communicates with at least one network **130**, such as the Internet, a proprietary Internet Protocol (IP) network, or other data network.

**[0042]** The gNB **102** provides wireless broadband access to the network **130** for a first plurality of user equipments (UEs) within a coverage area **120** of the gNB **102**. The first plurality of UEs includes a UE **111**, which may be located in a small business; a UE **112**, which may be located in an enterprise; a UE **113**, which may be a WiFi hotspot; a UE **114**, which may be located in a first residence; a UE **115**, which may be located in a second residence; and a UE **116**, which may be a mobile device, such as a cell phone, a wireless laptop, a wireless PDA, or the like. The gNB **103** provides wireless broadband access to the network **130** for a second plurality of UEs within a coverage area **125** of the gNB **103**. The second plurality of UEs includes the UE **115** and the UE **116**. In some embodiments, one or more of the gNBs **101-103** may communicate with each other and with the UEs **111-116** using 5G/NR, long term evolution (LTE), long term evolution-advanced (LTE-A), WiMAX, WiFi, or other wireless communication techniques.

**[0043]** Depending on the network type, the term "base station" or "BS" can refer to any component (or collection of components) configured to provide wireless access to a network, such as transmit point (TP), transmit-receive point (TRP), an enhanced base station (eNodeB or eNB), a 5G/NR base station (gNB), a macrocell, a femtocell, a WiFi access point (AP), or other wirelessly enabled devices. Base stations may provide wireless access in accordance with one or more wireless communication protocols, e.g., 5G/NR 3$^{rd}$ generation partnership project (3GPP) NR, long term evolution (LTE), LTE advanced (LTE-A), high speed packet access (HSPA), Wi-Fi 802.11a/b/g/n/ac, etc. For the sake of convenience, the terms "BS" and "TRP" are used interchangeably in this patent document to refer to network infrastructure components that provide wireless access to remote terminals. Also, depending on the network type, the term "user equipment" or "UE" can refer to any component such as "mobile station," "subscriber station," "remote terminal," "wireless terminal," "receive point," or "user device." For the sake of convenience, the terms "user equipment" and "UE" are used in this patent document to refer to remote wireless equipment that wirelessly accesses a BS, whether the UE is a mobile device (such as a mobile telephone or smartphone) or is normally considered a stationary device (such as a desktop computer or vending machine).

**[0044]** The 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.

**[0045]** As described in more detail below, one or more of the UEs **111-116** include circuitry, programing, or a combination thereof for MIMO operations. In certain embodiments, one or more of the BSs **101-103** include circuitry, programing, or a combination thereof to support MIMO operations.

**[0046]** Although FIG. **1** illustrates one example of a wireless network, various changes may be made to FIG. **1**. For example, the wireless network **100** 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.

**[0047]** FIG. **2** illustrates an example gNB **102** according to embodiments of the present disclosure. The embodiment of the gNB **102** illustrated in FIG. **2** is for illustration only, and the gNBs **101** and **103** of FIG. **1** could have the same or similar configuration. However, gNBs come in a wide variety of configurations, and FIG. **2** does not limit the scope of the present disclosure to any particular implementation of a gNB.

**[0048]** As shown in FIG. **2**, the gNB **102** includes multiple antennas **205**$a$-**205**$n$, multiple transceivers **210**$a$-**210**$n$, a controller/processor **225**, a memory **230**, and a backhaul or network interface **235**.

**[0049]** The transceivers **210**$a$-**210**$n$ receive, from the antennas **205**$a$-**205**$n$, incoming radio frequency (RF) signals, such as signals transmitted by UEs in the wireless network **100**. The transceivers **210**$a$-**210**$n$ down-convert the incoming RF signals to generate IF or baseband signals. The IF or baseband signals are processed by receive (RX) processing circuitry in the transceivers **210**$a$-**210**$n$ and/or controller/processor **225**, which generates processed baseband signals by filtering, decoding, and/or digitizing the baseband or IF signals. The controller/processor **225** may further process the baseband signals.

**[0050]** Transmit (TX) processing circuitry in the transceivers **210**$a$-**210**$n$ and/or controller/processor **225** receives analog or digital data (such as voice data, web data, e-mail, or interactive video game data) from the controller/processor **225**. The TX processing circuitry encodes, multiplexes, and/or digitizes the outgoing baseband data to generate processed baseband or IF signals. The transceivers **210**$a$-**210**$n$ up-converts the baseband or IF signals to RF signals that are transmitted via the antennas **205**$a$-**205**$n$.

**[0051]** 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 uplink (UL) channel signals and the transmission of downlink (DL) channel signals by the transceivers **210**$a$-**210**$n$ in accordance with well-known principles. The controller/processor **225** could support additional functions as well, such as more advanced wireless communication functions. For instance, the controller/processor **225** could support beam forming or directional routing operations in which outgoing/incoming signals from/to multiple antennas **205**$a$-**205**$n$ are weighted differently to effectively steer the outgoing signals in a desired direction. As another example, the controller/processor **225** could support methods for MIMO operations. Any of a wide variety of other functions could be supported in the gNB **102** by the controller/processor **225**.

**[0052]** The controller/processor **225** is also capable of executing programs and other processes resident in the memory **230**, such as processes to support MIMO operations. The controller/processor **225** can move data into or out of the memory **230** as required by an executing process.

**[0053]** The controller/processor **225** is also coupled to the backhaul or network interface **235**. The backhaul or network interface **235** allows the gNB **102** to communicate with other devices or systems over a backhaul connection or over a network. The interface **235** could support communications over any suitable wired or wireless connection(s). For example, when the gNB **102** is implemented as part of a cellular communication system (such as one supporting 5G/NR, LTE, or LTE-A), the interface **235** could allow the gNB **102** to communicate with other gNBs over a wired or wireless backhaul connection. When the gNB **102** is implemented as an access point, the interface **235** could allow the gNB **102** to communicate over a wired or wireless local area network or over a wired or wireless connection to a larger network (such as the Internet). The interface **235** includes any suitable structure supporting communications over a wired or wireless connection, such as an Ethernet or transceiver.

**[0054]** 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.

**[0055]** Although FIG. **2** illustrates one example of gNB **102**, various changes may be made to FIG. **2**. For example, the gNB **102** could include any number of each component shown in FIG. **2**. Also, various components in FIG. **2** could be combined, further subdivided, or omitted and additional components could be added according to particular needs.

**[0056]** FIG. **3** illustrates an example UE **116** according to embodiments of the present disclosure. The embodiment of the UE **116** illustrated in FIG. **3** is for illustration only, and the UEs **111-115** of FIG. **1** could have the same or similar configuration. However, UEs come in a wide variety of configurations, and FIG. **3** does not limit the scope of the present disclosure to any particular implementation of a UE.

**[0057]** As shown in FIG. **3**, the UE **116** includes antenna (s) **305**, a transceiver(s) **310**, and a microphone **320**. The UE **116** also includes a speaker **330**, a processor **340**, an input/output (I/O) interface (IF) **345**, an input **350**, a display **355**, and a memory **360**. The memory **360** includes an operating system (OS) **361** and one or more applications **362**.

**[0058]** The transceiver(s) **310** receives from the antenna(s) **305**, an incoming RF signal transmitted by a gNB of the wireless network **100**. The transceiver(s) **310** down-converts the incoming RF signal to generate an intermediate frequency (IF) or baseband signal. The IF or baseband signal is processed by RX processing circuitry in the transceiver(s) **310** and/or processor **340**, which generates a processed baseband signal by filtering, decoding, and/or digitizing the baseband or IF signal. The RX processing circuitry sends the processed baseband signal to the speaker **330** (such as for voice data) or is processed by the processor **340** (such as for web browsing data).

**[0059]** TX processing circuitry in the transceiver(s) **310** and/or processor **340** receives analog or digital voice data from the microphone **320** or other outgoing baseband data (such as web data, e-mail, or interactive video game data) from the processor **340**. The TX processing circuitry encodes, multiplexes, and/or digitizes the outgoing baseband data to generate a processed baseband or IF signal. The transceiver(s) **310** up-converts the baseband or IF signal to an RF signal that is transmitted via the antenna(s) **305**.

**[0060]** 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 uplink (UL) channel signals by the transceiver(s) **310** in accordance with well-known principles. In some embodiments, the processor **340** includes at least one microprocessor or microcontroller.

**[0061]** The processor **340** is also capable of executing other processes and programs resident in the memory **360**. For example, the processor **340** may execute processes for MIMO operations as described in embodiments of the present disclosure. 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**.

**[0062]** The processor **340** is also coupled to the input **350**, which includes, for example, a touchscreen, keypad, etc., and the display **355**. The operator of the UE **116** can use the input **350** to enter data into the UE **116**. The display **355** may be a liquid crystal display, light emitting diode display, or other display capable of rendering text and/or at least limited graphics, such as from web sites.

**[0063]** 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).

**[0064]** Although FIG. **3** illustrates one example of UE **116**, various changes may be made to FIG. **3**. For example, various components in FIG. **3** could be combined, further subdivided, or omitted and additional components could be added according to particular needs. As a particular example, the processor **340** could be divided into multiple processors, such as one or more central processing units (CPUs) and one or more graphics processing units (GPUs). In another example, the transceiver(s) **310** may include any number of transceivers and signal processing chains and may be connected to any number of antennas. Also, while FIG. **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.

**[0065]** FIG. **4**A and FIG. **4**B illustrate an example of wireless transmit and receive paths **400** and **450**, respectively, according to embodiments of the present disclosure. For example, a transmit path **400** may be described as being implemented in a gNB (such as gNB **102**), while a receive path **450** may be described as being implemented in a UE (such as UE **116**). However, it will be understood that the receive path **450** can be implemented in a gNB and that the transmit path **400** can be implemented in a UE. In some embodiments, the transmit path **400** and/or receive path **450** is configured for MIMO operations as described in embodiments of the present disclosure.

**[0066]** As illustrated in FIG. **4**A, the transmit path **400** includes a channel coding and modulation block **405**, a serial-to-parallel (S-to-P) block **410**, a size N Inverse Fast Fourier Transform (IFFT) block **415**, a parallel-to-serial (P-to-S) block **420**, an add cyclic prefix block **425**, and an up-converter (UC) **430**. The receive path **450** includes a down-converter (DC) **455**, a remove cyclic prefix block **460**, a S-to-P block **465**, a size N Fast Fourier Transform (FFT) block **470**, a parallel-to-serial (P-to-S) block **475**, and a channel decoding and demodulation block **480**.

**[0067]** In the transmit path **400**, the channel coding and modulation block **405** receives a set of information bits, applies coding (such as a low-density parity check (LDPC) coding), and modulates the input bits (such as with Quadrature Phase Shift Keying (QPSK) or Quadrature Amplitude Modulation (QAM)) to generate a sequence of frequency-domain modulation symbols. The serial-to-parallel block **410** converts (such as de-multiplexes) the serial modulated symbols to parallel data in order to generate N parallel symbol streams, where N is the IFFT/FFT size used in the gNB and the UE. The size N IFFT block **415** performs an IFFT operation on the N parallel symbol streams to generate time-domain output signals. The parallel-to-serial block **420** converts (such as multiplexes) the parallel time-domain output symbols from the size N IFFT block **415** in order to generate a serial time-domain signal. The add cyclic prefix block **425** inserts a cyclic prefix to the time-domain signal. The up-converter **430** modulates (such as up-converts) the output of the add cyclic prefix block **425** to a RF frequency for transmission via a wireless channel. The signal may also be filtered at a baseband before conversion to the RF frequency.

**[0068]** As illustrated in FIG. **4**B, the down-converter **455** down-converts the received signal to a baseband frequency, and the remove cyclic prefix block **460** removes the cyclic prefix to generate a serial time-domain baseband signal. The serial-to-parallel block **465** converts the time-domain baseband signal to parallel time-domain signals. The size N FFT block **470** performs an FFT algorithm to generate N parallel frequency-domain signals. The (P-to-S) block **475** converts the parallel frequency-domain signals to a sequence of modulated data symbols. The channel decoding and demodulation block **480** demodulates and decodes the modulated symbols to recover the original input data stream.

**[0069]** Each of the gNBs **101-103** may implement a transmit path **400** that is analogous to transmitting in the downlink to UEs **111-116** and may implement a receive path **450** that is analogous to receiving in the uplink from UEs **111-116**. Similarly, each of UEs **111-116** may implement a transmit path **400** for transmitting in the uplink to gNBs **101-103** and may implement a receive path **450** for receiving in the downlink from gNBs **101-103**.

**[0070]** Each of the components in FIGS. **4**A and **4**B can be implemented using only hardware or using a combination of hardware and software/firmware. As a particular example, at least some of the components in FIGS. **4**A and **4**B may be implemented in software, while other components may be implemented by configurable hardware or a mixture of software and configurable hardware. For instance, the FFT block **470** and the IFFT block **415** may be implemented as configurable software algorithms, where the value of size N may be modified according to the implementation.

**[0071]** Furthermore, although described as using FFT and IFFT, this is by way of illustration only and should not be construed to limit the scope of the present disclosure. Other types of transforms, such as Discrete Fourier Transform (DFT) and Inverse Discrete Fourier Transform (IDFT) functions, can be used. It will be appreciated that the value of the variable N may be any integer number (such as 1, 2, 3, 4, or the like) for DFT and IDFT functions, while the value of the variable N may be any integer number that is a power of two (such as 1, 2, 4, 8, 16, or the like) for FFT and IFFT functions.

**[0072]** Although FIGS. **4**A and **4**B illustrate examples of wireless transmit and receive paths **400** and **450**, respectively, various changes may be made to FIGS. **4**A and **4**B. For example, various components in FIGS. **4**A and **4**B can be combined, further subdivided, or omitted and additional components can be added according to particular needs. Also, FIGS. **4**A and **4**B are meant to illustrate examples of the types of transmit and receive paths that can be used in a wireless network. Any other suitable architectures can be used to support wireless communications in a wireless network.

[0073] FIG. 5 illustrates an example of a transmitter structure 500 for beamforming according to embodiments of the present disclosure. In certain embodiments, one or more of gNB 102 or UE 116 includes the transmitter structure 500. For example, one or more of antenna 205 and its associated systems or antenna 305 and its associated systems can be included in transmitter structure 500. This example is for illustration only and other embodiments can be used without departing from the scope of the present disclosure.

[0074] Accordingly, embodiments of the present disclosure recognize that Rel-14 LTE and Rel-15 NR support up to 32 channel state indication CSI reference signal (CSI-RS) antenna ports which enable an eNB or a gNB to be equipped with a large number of antenna elements (such as 64 or 128). A plurality of antenna elements can then be mapped onto one CSI-RS port. For mmWave bands, although a number of antenna elements can be larger for a given form factor, a number of CSI-RS ports, that can correspond to the number of digitally precoded ports, can be limited due to hardware constraints (such as the feasibility to install a large number of analog-to-digital converters (ADCs)/digital-to-analog converters (DACs) at mmWave frequencies) as illustrated in FIG. 5. Then, one CSI-RS port can be mapped onto a large number of antenna elements that can be controlled by a bank of analog phase shifters 501. One CSI-RS port can then correspond to one sub-array which produces a narrow analog beam through analog beamforming 505. This analog beam can be configured to sweep across a wider range of angles 520 by varying the phase shifter bank across symbols or slots/subframes. The number of sub-arrays (equal to the number of RF chains) is the same as the number of CSI-RS ports NCS-PORT. A digital beamforming unit 510 performs a linear combination across NCSI-PORT analog beams to further increase a precoding gain. While analog beams are wideband (hence not frequency-selective), digital precoding can be varied across frequency sub-bands or resource blocks. Receiver operation can be conceived analogously.

[0075] Since the transmitter structure 500 of FIG. 5 utilizes multiple analog beams for transmission and reception (wherein one or a small number of analog beams are selected out of a large number, for instance, after a training duration that is occasionally or periodically performed), the term "multi-beam operation" is used to refer to the overall system aspect. This includes, for the purpose of illustration, indicating the assigned DL or UL TX beam (also termed "beam indication"), measuring at least one reference signal for calculating and performing beam reporting (also termed "beam measurement" and "beam reporting", respectively), and receiving a DL or UL transmission via a selection of a corresponding RX beam. The system of FIG. 5 is also applicable to higher frequency bands such as >52.6 GHz (also termed frequency range 4 or FR4). In this case, the system can employ only analog beams. Due to the O2 absorption loss around 60 GHz frequency (~10 dB additional loss per 100 m distance), a larger number and narrower analog beams (hence a larger number of radiators in the array) are essential to compensate for the additional path loss.

[0076] The present disclosure relates generally to wireless communication systems and, more specifically, to next generation of MIMO systems.

[0077] 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.

[0078] In a communication system, such as LTE, DL signals can include data signals conveying information content, control signals conveying DL Control Information (DCI), and Reference Signals (RS) that are also known as pilot signals. An eNodeB transmits data information through a Physical DL Shared CHannel (PDSCH). An eNodeB transmits DCI through a Physical DL Control CHannel (PDCCH) or an Enhanced PDCCH (EPDCCH)—see also REF 3. An eNodeB transmits acknowledgement information in response to data Transport Block (TB) transmission from a UE in a Physical Hybrid ARQ Indicator CHannel (PHICH). An eNodeB transmits one or more of multiple types of RS including a UE-Common RS (CRS), a Channel State Information RS (CSI-RS), or a DeModulation RS (DMRS). A CRS is transmitted over a DL system Band-Width (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 (or slot) and can have, for example, duration of 1 millisecond.

[0079] DL signals also include transmission of a logical channel that carries system control information. A broadcast control channel (BCCH) is mapped to either a transport channel referred to as a Broadcast CHannel (BCH) when it conveys a Master Information Block (MIB) or to a DL Shared CHannel (DL-SCH) when it conveys a System Information Block (SIB)—see also REF3 and REF 5. 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 (or slot) can be indicated by a transmission of a corresponding PDCCH conveying a codeword with a cyclic redundancy check (CRC) scrambled with a special 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.

[0080] DL resource allocation is performed in a unit of subframe (or slot) and a group of Physical resource blocks (PRBs). A transmission BW includes of frequency resource units referred to as Resource Blocks (RBs). Each RB includes of $N_{sc}^{RB}$ sub-carriers, or Resource Elements (REs), such as 12 REs. A unit of one RB over one subframe (or slot) 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.

[0081] 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 (or slot), it 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 its buffer, Rank Indicator (RI), and Channel State Information (CSI) enabling an eNodeB to perform link adaptation for PDSCH transmissions to a UE. HARQ-ACK information is also transmitted by a UE in response to a detection of a PDCCH/EPDCCH indicating a release of semi-persistently scheduled PDSCH (see also REF 3).

**[0082]** An UL subframe (or slot) 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 a RB. A UE is allocated $N_{RB}$ RBs for a total of $N_{RB} \cdot N_{sc}^{RB}$ REs for a transmission BW. For a PUCCH, $N_{RB}=1$. A last subframe (or slot) symbol can be used to multiplex SRS transmissions from one or more UEs. A number of subframe (or slot) symbols that are available for data/UCI/DMRS transmission is $N_{symb}=2\cdot(N_{symb}^{UL}-1)-N_{SRS}$, where $N_{SRS}=1$ if a last subframe (or slot) symbol is used to transmit SRS and $N_{SRS}=0$ otherwise.

**[0083]** FIG. **6** illustrates an example of a transmitter structure **600** for PDSCH in a subframe according to embodiments of the present disclosure. For example, transmitter structure **600** can be implemented in gNB **102** of FIG. **1**. This example is for illustration only and other embodiments can be used without departing from the scope of the present disclosure.

**[0084]** As illustrated in FIG. **6**, information bits **610** are encoded by encoder **620**, such as a turbo encoder, and modulated by modulator **630**, for example using Quadrature Phase Shift Keying (QPSK) modulation. A Serial to Parallel (S/P) converter **640** generates M modulation symbols that are subsequently provided to a mapper **650** to be mapped to REs selected by a transmission BW selection unit **655** for an assigned PDSCH transmission BW, unit **660** applies an Inverse Fast Fourier Transform (IFFT), the output is then serialized by a Parallel to Serial (P/S) converter **670** to create a time domain signal, filtering is applied by filter **680**, and a signal transmitted **690**. Additional functionalities, such as data scrambling, cyclic prefix insertion, time windowing, interleaving, and others are well known in the art and are not shown for brevity.

**[0085]** FIG. **7** illustrates an example of a receiver structure **700** for PDSCH in a subframe according to embodiments of the present disclosure. For example, receiver structure **700** can be implemented by any of the UEs **111-116** of FIG. **1**. This example is for illustration only and other embodiments can be used without departing from the scope of the present disclosure.

**[0086]** With reference to FIG. **7**, a received signal **710** is filtered by filter **720**, REs **730** for an assigned reception BW are selected by BW selector **735**, unit **740** applies a Fast Fourier Transform (FFT), and an output is serialized by a parallel-to-serial converter **750**. Subsequently, a demodulator **760** coherently demodulates data symbols by applying a channel estimate obtained from a DMRS or a CRS (not shown), and a decoder **770**, such as a turbo decoder, decodes the demodulated data to provide an estimate of the information data bits **780**. Additional functionalities such as time-windowing, cyclic prefix removal, de-scrambling, channel estimation, and de-interleaving are not shown for brevity.

**[0087]** FIG. **8** illustrates an example of a transmitter structure **800** for PUSCH in a subframe according to embodiments of the present disclosure. For example, transmitter structure **800** can be implemented in gNB **103** of FIG. **1**. This example is for illustration only and other embodiments can be used without departing from the scope of the present disclosure.

**[0088]** As illustrated in FIG. **8**, information data bits **810** are encoded by encoder **820**, such as a turbo encoder, and modulated by modulator **830**. A Discrete Fourier Transform (DFT) unit **840** applies a DFT on the modulated data bits, REs **850** corresponding to an assigned PUSCH transmission BW are selected by transmission BW selection unit **855**, unit **860** applies an IFFT and, after a cyclic prefix insertion (not shown), filtering is applied by filter **870** and a signal transmitted **880**.

**[0089]** FIG. **9** illustrates an example of a receiver structure **900** for a PUSCH in a subframe according to embodiments of the present disclosure; For example, receiver structure **900** can be implemented by the UE **116** of FIG. **3**. This example is for illustration only and other embodiments can be used without departing from the scope of the present disclosure.

**[0090]** As illustrated in FIG. **9**, a received signal **910** is filtered by filter **920**. Subsequently, after a cyclic prefix is removed (not shown), unit **930** applies a FFT, REs **940** corresponding to an assigned PUSCH reception BW are selected by a reception BW selector **945**, unit **950** applies an Inverse DFT (IDFT), a demodulator **960** coherently demodulates data symbols by applying a channel estimate obtained from a DMRS (not shown), a decoder **970**, such as a turbo decoder, decodes the demodulated data to provide an estimate of the information data bits **980**.

**[0091]** There are two types of frequency range (FR) defined in 3GPP 5G NR specifications. The sub-6 GHz range is called frequency range 1 (FR1) and millimeter wave range is called frequency range 2 (FR2). An example of the frequency range for FR1 and FR2 is shown herein.

TABLE 0

| Frequency range designation | Corresponding frequency range |
|---|---|
| FR1 | 450 MHz-600 MHz |
| FR2 | 24250 MHz-52600 MHz |

**[0092]** For MIMO in FR1, up to 32 CSI-RS antenna ports is supported, and in FR2, up to 8 CSI-RS antenna ports is supported. In next generation cellular standards (e.g., 6G), in addition to FR1 and FR2, new carrier frequency bands can be evaluated, e.g., FR4 (>52.6 GHz), terahertz (>100 GHz) and upper mid-band (10-15 GHz). The number of CSI-RS ports that can be supported for these new bands is likely to be different from FR1 and FR2. In particular, for 10-15 GHz band, the max number of CSI-RS antenna ports is likely to be more than FR1, due to smaller antenna form factors, and feasibility of fully digital beamforming (as in FR1) at these frequencies. For instance, the number of CSI-RS antenna ports can grow up to 128. Besides, the NW (e.g., the network **130**) deployment/topology at these frequencies is also expected to be denser/distributed, for example, antenna ports distributed at multiple (non-co-located, hence geographically separated) TRPs within a cellular region can be the main scenario of interest, due to which the number of CSI-RS antenna ports for MIMO can be even larger (e.g., up to 256).

**[0093]** A (spatial or digital) precoding/beamforming can be used across these large number of antenna ports in order to achieve MIMO gains. Depending on the carrier frequency, and the feasibility of radio RF/hardware (HW)-related components, the (spatial) precoding/beamforming can be fully digital or hybrid analog-digital. In fully digital beamforming, there can be one-to-one mapping between an antenna port and an antenna element, or a 'static/fixed' virtualization of multiple antenna elements to one antenna port can be used. Each antenna port can be digitally controlled. Hence, a spatial multiplexing across antenna ports is provided.

**[0094]** In next generation cellular standards (e.g. 6G), in addition to FR1 and FR2, new carrier frequency bands can be evaluated, e.g., FR4 (>52.6 GHz), terahertz (>100 GHz) and upper mid-band (10-15 GHz). The number of CSI-RS ports that can be supported for these new bands is likely to be different from FR1 and FR2. In particular, for 10-15 GHz band, the max number of CSI-RS antenna ports is likely to be more than FR1, due to smaller antenna form factors, and feasibility of fully digital beamforming (as in FR1) at these frequencies. For instance, the number of CSI-RS antenna ports can grow up to 128. Besides, the NW deployment/topology at these frequencies is also expected to be denser/distributed, for example, antenna ports distributed at multiple (non-co-located, hence geographically separated) TRPs within a cellular region can be the main scenario of interest, due to which the number of CSI-RS antenna ports for MIMO can be even larger (e.g. up to 256).

**[0095]** Likewise, for a cellular system operating in low carrier frequency in general, a sub-1 GHz frequency range (e.g. less than 1 GHz) as an example, supporting large number of CSI-RS antenna ports (e.g. 32) or many antenna elements at a single location or remote radio head (RRH) or TRP is challenging due to a larger antenna form factor size needed taking into account carrier frequency wavelength than a system operating at a higher frequency such as 2 GHz or 4 GHz. At such low frequencies, the maximum number of CSI-RS antenna ports that can be co-located at a site (or RRH or TRP) can be limited, for example to 8. This limits the spectral efficiency of such systems. In particular, the multiuser MIMO (MU-MIMO) spatial multiplexing gains offered due to large number of CSI-RS antenna ports (such as 32) can't be achieved due to the antenna form factor limitation. One plausible way to operate a system with large number of CSI-RS antenna ports at low carrier frequency is to distribute the physical antenna ports to different panels/RRHs/TRPs, which can be non-collocated. The multiple sites or panels/RRHs/TRPs can still be connected to a single (common) base unit forming a single antenna system, hence the signal transmitted/received via multiple distributed RRHs/TRPs can still be processed at a centralized location.

**[0096]** As described herein, for low (FR1), high (FR2 and beyond), or mid (6-15 GHz) band, the NW topology/architecture is likely to be more and more distributed in future due to reasons explained herein (e.g. use cases, HW requirements, antenna form factors, mobility etc.). In this disclosure, such a distributed system is referred to as a distributed MIMO (D-MIMO) or multiple TRP (mTRP) system (multiple antenna port groups, which can be non-co-located). The transmission in such a system can be coherent joint transmission (CJT), i.e., a layer can be transmitted across/using multiple TRPs, or non-coherent joint transmission (NCJT). Due to distributed nature of operation, the groups of antenna ports (or TRPs) need to be calibrated/synchronized by compensating for the non-idealities such as time/frequency/phase offsets non-ideal backhaul across TRPs, due to HW impairments, different delay profiles, and Doppler profile (in high-speed scenarios) associated with different TRPs.

**[0097]** In one example, a TRP or RRH can be functionally equivalent to (hence can be replaced with) or is interchangeable with one of more of the following: an antenna, or an antenna group (multiple antennae), an antenna port, an antenna port group (multiple ports), a CSI-RS resource, multiple CSI-RS resources, a CSI-RS resource set, multiple CSI-RS resource sets, an antenna panel, multiple antenna panels, a Tx-Rx entity, a (analog) beam, a (analog) beam group, a cell, a cell group.

**[0098]** FIG. **10** illustrates a diagram of example RAN configurations **1000** according to embodiments of the present disclosure. For example, RAN configurations **1000** can be implemented by the BS **102** of FIG. **1**. This example is for illustration only and other embodiments can be used without departing from the scope of the present disclosure.

**[0099]** In an O-RAN, a TRP can be functionally equivalent to (hence can be replaced with) or is interchangeable with one of more of the following:

- **[0100]** One RU or O-RU: a logical node that includes a subset of the eNB/gNB functions (e.g. as listed in clause 4.2 split option 7-2x)
- **[0101]** More than one RUs or O-RUs
- **[0102]** One or more than one RUs or O-RUs

**[0103]** Two examples are shown in FIG. **10**.

**[0104]** The following are defined in [REF11 and REF12].

| | |
|---|---|
| O-CU | O-RAN Central Unit—a logical node hosting PDCP, RRC, SDAP and other control functions |
| O-DU | O-RAN Distributed Unit: a logical node hosting RLC/MAC/High-PHY layers based on a lower layer functional split. O-DU in addition hosts an M-Plane instance. |
| O-RU | O-RAN Radio Unit: a logical node hosting Low-PHY layer and RF processing based<br>on a lower layer functional split. This is similar to 3GPP's "TRP" or "RRH" but more specific in including the Low-PHY layer (FFT/iFFT, PRACH extraction). O-RU in addition hosts M-Plane instance. |

**[0105]** A typical up to 5G network (NW) can be described in terms of transmit-receive points (TRPs). For a first frequency range (FR1), i.e., <6 GHz, a TRP can comprise one or more antenna ports, and is fully-digital (i.e. each antenna port is driven by a dedicated baseband processing chain); and for a second frequency range 24.25-52.6 GHz (FR2), i.e., for mmWave frequencies, a TRP comprises one of more antenna panels (sub-arrays), each comprising one or two antenna ports that are controlled by analog phase shifters that result in an analog beam (pointing in certain spatial direction). An antenna port in FR1 can also be beamformed (aka virtualization); however, such a beamforming (BF) is generally static (non-adaptive, hence not requiring measurement and reporting). In FR2, due to large propagation loss at mmWave frequencies, each antenna panel requires dynamic frequent update of the analog BF, which is often based on (analog) beam measurement and reporting.

**[0106]** A communication between the 5G NW and a user is broadly based on: (A1) NW resources, and (A2) signaling components, where the former corresponds to spatial-domain, frequency-domain, and time-domain (SD, FD, TD) resources allocated to the user for the communication, and the latter corresponds to components that are signaled over the NW resources. The SD resources can be based on a single TRP (sTRP) or multiple TRPs (mTRP), where mTRP can be (B1) co-located at a site/location or (B2) non-co-located/distributed at multiple sites/locations, where the latter corresponds to a distributed SD resource, hence the corresponding communication hypothesis can be (C1) non-coherent joint transmission (NCJT) where a data stream (layer) is transmitted from one of the mTRPs, or (C2) coherent JT (CJT), where a data stream (layer) can be transmitted from multiple of the mTRPs. The FD resources can comprise a set of PRBs, and the TD resources can comprise one or multiple time slots (i.e., 1 slot=$N_{sym}$ consecutive symbols).

**[0107]** The signaling components include signaling associated with (D1) measurement, (D2) channel state information (CSI) report, and (D3) DL reception or UL transmission.

**[0108]** For (D1), the user measures channel measurement RSs (CMRs) to estimate the channel condition between the sTRP/mTRP and the user. In case of sTRP, the user can measure a set comprising one or multiple DL measurement resources. For mTRP, the measurement resources can be (E1) one resource set comprising one group per TRP, or (E2) one resource set per TRP. The user can also measure the interference based on interference measurement RSs (IMRs). A CMR can correspond to an analog beam, and can be repeated in multiple symbols for determining user's analog beam.

**[0109]** For (D2), the user, based on the measurement, determines the CSI and reports it to the NW, where the CSI can be (F1) (analog) beam-related CSI, or (F2) (digital) non-beam-related CSI. For (F1), the user determines one or multiple pairs (indicator, metric), where the indicator indicates a CMR and the metric indicates a (beam) quality (e.g. reference signal received power (RSRP), signal-to-interference-plus-noise ratio (SINR)).

**[0110]** For (F2), a low-resolution (Type-I) CSI and a high-resolution (Type-II) CSI are supported. The Type-I CSI is based on L=1 DFT SD vector per layer, requires low feedback overhead and is expected to work reasonably well for single user (SU)-MIMO. For multiuser-(MU-)MIMO transmission, however, high-resolution Type II CSI capturing multiple dominant directions of the channel is essential in order to suppress inter-user interference. The Type-II CSI is based on a weighted linear combination L>1 SD DFT vectors where the weights correspond to coefficients. The FD DFT vectors were additionally introduced enhanced Type-II CSI to reduce the CSI feedback overhead by compressing channel coefficients in both SD and FD. A further enhanced Type-II port-selection (PS) CSI was specified to further reduce the CSI overhead by exploiting a reciprocity of angle-and-delay domain between uplink and downlink channels. Expecting NW performs pre-processing with beamformed CSI-RS to concentrate angle-and-delay domain components in few SD and FD basis directions, the user can be configured to select a subset of antenna ports (at a TRP) and one or two FD vectors. Additionally, a NCJT Type-I CSI was supported for up to two TRPs and multiple (sTRP or NCJT) hypotheses. Furthermore, the enhanced Type-II CSI is extended to support CJT Type-II CSI from mTRP and for high/medium user velocities exploiting time-domain correlation or Doppler-domain information, respectively.

**[0111]** A transmission configuration indication (TCI) framework is shared between (non-beam-related) CSI and beam management (BM). While the complexity of such a TCI framework is justified for CSI acquisition in FR1, it makes BM procedures less efficient in FR2. Furthermore, the BM procedures can be different for different channels due to their different target scenarios. Having different beam indication/update mechanisms increases the complexity, overhead, and latency of BM. Such drawbacks are especially troublesome for high mobility scenarios (such as highway and high-speed train). These drawbacks motivated a streamlined BM framework for beam-based operations and procedures that is common for data and control, and uplink (UL) and downlink (DL) channels. This framework is referred to as a unified TCI (uTCI) framework, firstly introduced for sTRP and now being enhanced for mTRP.

**[0112]** The uTCI framework supports signaling of a unified TCI state to a user, where the unified TCI state can be a DL-TCI, an UL-TCI or a joint TCI (J-TCI) state, where a DL-TCI state is applied for receiving DL channels/signals, an UL-TCI state is applied for transmitting UL channels/signals, and a J-TCI state is applied for both DL and UL channels/signals. The uTCI framework is designed to support DL receptions and UL transmissions (i) with a joint (common) beam indication for DL and UL by leveraging beam correspondence (reciprocity between DL and UL), and (ii) with separate beam indications for DL and UL, for example to mitigate maximum permissible exposure, where the beam direction of an UL transmission is different from the beam direction of a DL reception to avoid exposure of the human body to radiation.

**[0113]** The uTCI framework can support a beam-level mobility, known as inter-cell BM (ICBM). In ICBM, the user-dedicated channels can be configured to use a beam (i.e., TCI state) associated with a (non-serving) cell having a physical cell identity (PCI) that is different from the PCI of the serving cell. This allows fast beam-switch to a non-serving cell for user-dedicated channels at a lower layer without involving a higher layer and without incurring latency and overhead of handover.

**[0114]** The ICBM is being further enhanced to support a complete cell-switch triggered by lower layers, which is known as lower-layer triggered mobility (LTM). In LTM, the NW can acquire beam measurements, and UL timing information for target candidate cells before cell-switch. The lower layers of the NW decide when to perform a cell-switch, and send a medium access control channel element

(MAC CE) containing a cell-switch command (CSC) that triggers the cell-switch from a source cell to a target cell. The CSC includes beam (i.e., TCI state) and UL timing information for the user to use on the target cell. After a beam application delay, the user and the NW communicates via the target cell.

**[0115]** NW energy saving (NES) is another advanced feature, wherein the NW can optimize energy usage by turning TRPs ON/OFF, thereby saving power. From a user's perspective, this is akin to dynamic SD resource update between transmissions. The CSI in the NES scenario can be based on multiple sub-configurations, each corresponding to different SD resource assignments, and dynamically (via DCI) triggering one or multiple of the sub-configurations for CSI reporting.

**[0116]** Full-duplex transmission and reception in the same NR channel BW or using non-contiguous intra-band carrier aggregation (CA) is a promising technology to enhance UL coverage, reduce latency and improve system capacity and to overcome limitations inherent to the use of de-facto mandated semi-static TDD UL-DL frame configurations in today's NR TDD deployments. Currently, 3GPP is studying benefits, feasibility and deployment scenarios for enabling NW-side full-duplex operation where simultaneous transmissions and receptions by the NW on the same time-domain symbol on the NR carrier can only occur in non-overlapping UL and DL subbands, e.g., subbandfull-duplex (SBFD) mode. In this first step of NR duplex evolution, users with support for NW-side SBFD operation still operate in half-duplex, i.e., the user can either transmit or receive on an SBFD symbol but not transmit and receive simultaneously. An SBFD UL subband can be located in the center or at the edge of the NR carrier in FR1 or FR2-1. For CA-based SBFD in FR2-1, one component carrier (CC) is allocated for UL transmissions whereas the remaining CCs are used for DL transmission.

**[0117]** NW-side self-interference cancellation (SIC) capability to enable SBFD can be realized through a combination of solutions. For example, the NW can use Tx/Rx antenna isolation on the antenna panel(s), beam steering, analog and/or digital pre-distortion, digital interference cancellation, and analog and/or digital filtering solutions. Note that passive Tx/Rx antenna isolation has been demonstrated to achieve in excess of 80 dB in FR1 with even higher isolation in FR2-1. For example, SBFD for the Local Area base station class characterized by small Tx power and reduced Rx sensitivity can already achieve a significant amount of SIC capability by relying on antenna isolation alone. Wide Area base stations characterized by much higher transmit power and higher Rx sensitivity may need to implement a more extensive set of solutions to support SBFD.

**[0118]** NW-side SBFD operation can be enabled transparently for typical NR users and has been shown feasible and providing gains. In this case, typical users are scheduled UL transmissions in the SBFD UL subband of the NR carrier on symbols configured as flexible by SIB1. More gains in the NR TDD cell supporting NW-side SBFD operation can be achieved in presence of SBFD-aware users, e.g., supporting resource allocation enhancements for PDSCH, PUSCH and PUCCH including handling of TCI states and BF, and CSI reporting enhancements to best exploit the link conditions on SBFD and non-SBFD slots/symbols on the serving cell.

**[0119]** As explained, the 5G NW can support several features, services, use cases, and deployment scenarios. It however also introduces too many different abstractions (for specification) of NW entities and involved signaling for components of these abstractions. For instance, the specification supports abstractions for single-cell, multi-cell, sTRP, mTRP, panel, antenna panel, antenna port, resource, resource set, and beam; and signaling for a complicated CSI framework based on components such as CSI resource setting (one or more CSI-RS resources sets, each with one or more CSI-RS/synchronization signal block (SSB) resources) and CSI report setting that links a CSI resource setting to a report quantity from a set of multiple supported report quantities, wherein a report quantity can correspond to beam report (i.e. an analog beam and a beam quality) or a non-beam report (i.e. RI/CQI/PMI/CRI). In addition, for PMI, too many different codebooks are supported. Due to these reasons, deployment of the 5G NW is challenging in reality. A direct scaling/extension/reuse of these typical up to 5G solutions for 6G will add to the complexity, which is undesired in real NW deployments.

**[0120]** FIG. **11** illustrates a diagram of example functional split points/options **1100** according to embodiments of the present disclosure. For example, functional split points/options **1100** may be implemented by the BS **103** of FIG. **1**. This example is for illustration only and other embodiments can be used without departing from the scope of the present disclosure.

**[0121]** Embodiments of the present disclosure recognize that in next-gen MIMO systems (e.g. 6G), at least two aspects need to be evaluated.

**[0122]** (A) 3GPP PHY specification: The significance of a single NW entity, namely PG (as a collection of ports) in terms of port-common channel properties. This is analogous to the 5G QCL (or TCI state), coherency expectation (e.g. FC, PC, NC).

**[0123]** (B) NW architecture as perceived in O-RAN: The functionality split among O-RAN entities for DL and UL operations, such as O-RU, O-DU, and O-CU (as described herein). An example is shown in FIG. **11**. In particular, the PHY functionality split between O-DU and O-RU includes at least the following aspects.

**[0124]** (B1) PHY processing:

**[0125]** bit-level processing,

**[0126]** symbol-level processing

**[0127]** (B2) Scheduling (residing in MAC): SU-MIMO/MU-MIMO scheduling across different O-RUs or/and allocated frequency-domain resources (e.g. PRBs, PRGs, SBs)

**[0128]** Utilizing UCI carrying CSI

**[0129]** If DL/UL reciprocity is feasible, also utilizing SRS-based channel measurement

**[0130]** (B3) Precoder calculation at a gNB (NW side) for DL-SCH transmission:

**[0131]** For SU-MIMO, precoder can simply follow the PMI (calculated expecting SU-MIMO hypothesis) reported by the UE, or, if DL/UL reciprocity is feasible, be calculated from the eigenvector(s) of the measured DL channels.

**[0132]** For MU-MIMO, precoder needs to be calculated based on additional orthogonalization (e.g. ZFBF, SLNR) among PMIs, or, if DL/UL reciprocity is feasible, the eigenvectors of the measured channels of the co-scheduled UEs

[0133] The first (A) can be achieved by removing/merging duplicate/redundant abstractions, and simplifying signaling for components of the abstractions. One such framework, namely dynamic MIMO, is provided in this disclosure, wherein abstractions such as CSI-RS resource, CSI-RS resource set, port, beam, TRP, panel etc. can be clubbed into one basic entity, namely antenna/port group (PG or O-RU (or RU)), and essential features of PGs are specified. A few essential features discussed include dynamic PG or O-RU (or RU) selection and long-term stats and expectations across PGs, e.g., quasi co-location (QCL) and coherency relationships across PGs. The provided framework can also facilitate fast and accurate CSI acquisition, where the CSI can be beam-related (e.g. beam indicator, beam metric), non-beam-related (e.g. rank indicator (RI)/precoding matrix indicator (PMI)/channel quality indicator (CQI)), or both. Additionally, the concept of a cell is replaced with PGs that are distributed through the NW. The mobility can be handled via the PG or O-RU (or RU) selection/update (from one set of PGs to another set of PGs).

[0134] A few relevant (more-probable) candidates discussed in the O-RAN Alliance (depicted in FIG. **11**) are shown in Table 1.

TABLE 1

(both DL and UL)

| | PDCP | RLC | MAC | High-PHY | Low-PHY | RF | HLS | LLS |
|---|---|---|---|---|---|---|---|---|
| O-RAN[1] (Opt7-2x) | O-CU: PDCP | O-DU: RLC, MAC, High-PHY | | | O-RU: Low-PHY, RF | | Y | symbol-level PHY |
| Opt7-3 | O-CU: PDCP | O-DU: RLC, MAC, High-PHY | | | O-RU: Low-PHY,RF | | Y | bit-level PHY |
| Opt8 | | DU: RLC, MAC, PHY | | | | RU: RF | Y | CPRI |

O-RAN[1]: [REF 12]
Cat-A, Cat-B
UL: Cat-C

[0135] The 5G NR MIMO inherits a number of unnecessary hierarchical specification entities from 4G LTE. In relation to multi-antenna (MIMO), such entities include:

[0136] Pointless "middlemen" abstractions: resource and resource-set entities for RS

[0137] Obsolete implementation-based abstractions: panel, multi-panel, "TRP", FR1 port vs FR2 beam/resource, "cell"

[0138] Going into 6G, the MIMO framework should be simplified/streamlined in order to (i) support both typical (up to 5G) and new frequency bands (e.g. FR3), (ii) enable new features/services (such as AI/ML-based learning, evolved duplexing, and energy saving), (iii) make it implementation friendly, and (iv) have a future-proof and easily upgradable system.

[0139] FIG. **12** illustrates an example of a fully digital transmitter structure **1200** for beamforming according to embodiments of the present disclosure. For example, fully digital transmitter structure **1200** can be implemented in the BS **102** of FIG. **2**. This example is for illustration only and other embodiments can be used without departing from the scope of the present disclosure.

[0140] The fully digital transmitter structure **1200** includes a digital beamformer **1210**, a fixed beam/virtualization **1201**, and antenna array angles **1220**.

[0141] A 5G NW can be built upon a spatial resource entity, say X. For a first frequency range (FR1), i.e., <6 GHz, the spatial entity X comprises one or more antenna ports that are fully-digital (i.e. each antenna port is driven by a dedicated baseband processing chain), as shown in FIG. **12**; and for a second frequency range 24.25-52.6 GHz (FR2), i.e., for mmWave frequencies, the entity X comprises one or more antenna panels (sub-arrays), each comprising one (or two) antenna ports that is (are) controlled by analog phase shifters that result in an analog beam (pointing in certain spatial direction), as shown in FIG. **5**. An antenna port in FR1 can also be beam-formed (aka virtualization); however, such a beamforming (BF) is generally static (non-adaptive, hence does not requiring measurement and reporting). In FR2, due to large propagation loss at mmWave frequencies, each antenna panel requires dynamic/frequent update of the analog BF, which is often based on (analog) beam measurement and reporting.

[0142] Thus, the main difference between a FR1 port and a FR2 panel is that the beam/virtualization (i.e. port assignment) is fixed in the former, and it requires (a) measurement and reporting from UE (e.g., the UE **116**) and (b) a beam indication from the NW (TCI state with QCL-TypeD). It is therefore plausible to have a unified framework in which a port in FR1 and a panel in FR2 can be abstracted based on a unified, band-agnostic spatial entity, e.g. port or port group (PG), and associated QCL and coherency properties across ports or PGs (intra-/inter PG). For instance,

[0143] Port: a FR1 port and a FR2 beam/source

[0144] Port group (PG): TRP, resource, resource set, panel, cell

[0145] While the O-RAN Alliance is intended for 5G NR, it is expected that its framework will continue, or at most refined, for 6G. The O-RAN Alliance specifies **3** levels of functional splits—namely CU, DU, and RU—to facilitate multi-vendor inter-operability within a NW. The manner in which PHY-layer functions are split between DU and RU(s) imposes serious impact on the feasibility, performance, and complexity of different MIMO schemes—mainly due to the latency and quantization loss incurred by the O-RAN-standardized RU-DU interface.

[0146] Instead of reusing the 4G/5G abstraction of CSI-RS resource or resource set, the terms "port" as a spatial-domain resource unit and "port group" (PG) as a collection of ports sharing a same set of channel properties are used irrespective of the frequency band. In this sense, a "port" can be associated with a digital port in FR1 or an analog beam in FR2 (thereby abandoning the 5G association between an analog beam and a CSI-RS resource for FR2).

[0147] The present disclosure relates to next generation MIMO systems (e.g. adv. 5G and 6G). In particular, it relates to a dynamic MIMO operations based on a single basis entity, namely antenna/port group (PG), that can be useful for a wide range of applications such as common MIMO (FR1), beam-formed MIMO (FR2 and beyond), dynamic port assignment for network energy saving and duplexing operations, predictive MIMO (mobility scenarios) etc.:

[0148] PG: configurability depending on use case and scenarios

[0149] Example of PG: port, beam (QCL Type D source RS), panel, TRP, CSI-RS resource etc.

[0150] Multiple MIMO hypotheses

[0151] Long-term stats and expectations across PGs

[0152] QCL relationship

[0153] Coherency (full, partial, non-coherent)

[0154] Supporting advanced features such as mobility, network (e.g., the network **130**) energy saving, duplexing, user-initiated beam management etc.

[0155] 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.

[0156] In the following, for brevity, both frequency division duplexing (FDD) and time division duplexing (TDD) are provided as the duplex method for both DL and UL signaling.

[0157] Although exemplary descriptions and embodiments to follow expect orthogonal frequency division multiplexing (OFDM) or orthogonal frequency division multiple access (OFDMA), this disclosure can be extended to other OFDM-based transmission waveforms or multiple access schemes such as filtered OFDM (F-OFDM).

[0158] This disclosure of disclosure covers several components which can be used in conjunction or in combination with one another, or can operate as standalone schemes.

[0159] 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), 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).

[0160] 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, the following components and embodiments are applicable for UL transmission when the scheduling unit in time is either one subframe (which can include one or multiple slots) or one slot.

[0161] 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.

[0162] 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.

[0163] "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 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".

[0164] 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" or bandwidth part (BWP) can also be used.

[0165] 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 $n \le N$CSI reporting bands. For instance, >6 GHz, 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.

[0166] 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 $M_n$ subbands when one CSI parameter for the $M_n$ subbands within the CSI reporting band. A CSI parameter is configured with "subband" for the CSI reporting band with $M_n$ subbands when one CSI parameter is reported for each of the $M_n$ subbands within the CSI reporting band.

[0167] FIG. **13** illustrates a diagram of an example antenna port layout **1300** according to embodiments of the present disclosure. For example, antenna port layout **1300** can be implemented in the wireless network **100** of FIG. **1**. This example is for illustration only and can be used without departing from the scope of the present disclosure.

[0168] In the following, $N_1$ and $N_2$ are the number of antenna ports with the same polarization in the first and second dimensions, respectively. For 2D antenna port layouts, $N_1>1$, $N_2>1$, and for 1D antenna port layouts $N_1>1$ and $N_2=1$ or $N_2>1$ and $N_1=1$. In the rest of the disclosure, 1D antenna port layouts with $N_1>1$ and $N_2=1$ is provided. The disclosure, however, is applicable to the other 1D port layouts with $N_2>1$ and $N_1=1$. Also, in the rest of the disclosure, $N_1 \ge N_2$. The disclosure, however, is applicable to the case when $N_1<N_2$, and the embodiments for $N_1>N_2$ apply to the case $N_1<N_2$ by swapping/switching $(N_1, N_2)$ with $(N_2, N_1)$. For a single-polarized (or co-polarized) antenna port layout, the total number of antenna ports is $P_{CSIRS}=N_1N_2$. And, for a dual-polarized antenna port layout, the total number of antenna ports is $P_{CSIRS}=2N_1N_2$. An

illustration is shown in FIG. **13** where "X" represents two antenna polarizations (dual-pol, s=2) and "/" represents one antenna polarization (co-pol, s=1). In this disclosure, the term "polarization" refers to a group of antenna ports with the same polarization. For example, antenna ports j=X+0, X+1, . . . , X+$P_{CSIRS}$/2−1 comprise a first antenna polarization, and antenna ports j=X+$P_{CSIRS}$/2, X+$P_{CSIRS}$/2+1, . . . , X+$P_{CSIRS}$−1 comprise a second antenna polarization, where $P_{CSIRS}$ is a number of CSI-RS antenna ports and X is a starting antenna port number (e.g. X=3000, then antenna ports are 3000, 3001, 3002, . . . ). Unless stated otherwise, dual-polarized antenna layouts are expected in this disclosure. The embodiments (and examples) in this disclosure however are general and are applicable to single-polarized antenna layouts as well.

**[0169]** Let s denotes the number of antenna polarizations (or groups of antenna ports with the same polarization). Then, for co-polarized antenna ports, s=1, and for dual- or cross (X)-polarized antenna ports s=2. So, the total number of antenna ports $P_{CSIRS}=sN_1N_2$.

**[0170]** Let $N_g$ be a number of antenna/port groups (PGs). When there are multiple antenna/port groups ($N_g$>1), each group ($g\in\{1, \ldots, N_g\}$) comprises $N_{1,g}$ and $N_{2,g}$ ports in two dimensions. This is illustrated in FIG. **13**. Note that the antenna port layouts may be the same ($N_{1,g}=N_1$ and $N_{2,g}=N_2$) in different antenna/port groups, or they can be different across antenna/port groups. For group g, the number of antenna ports is $P_{CSIRS,g}=N_{1,g}N_{2,g}$ or $2N_{1,g}N_{2,g}$ (for co-polarized or dual-polarized respectively), i.e., $P_{CSIRS,g}=s_gN_{1,g}N_{2,g}$ where $s_g$=1 or 2.

**[0171]** In one example, an antenna/port group corresponds to an antenna panel. In one example, an antenna/port group corresponds to a TRP. In one example, an antenna/port group corresponds to an RRH. In one example, an antenna/port group corresponds to CSI-RS antenna ports of a NZP CSI-RS resource. In one example, an antenna/port group corresponds to a subset of CSI-RS antenna ports of a NZP CSI-RS resource (comprising multiple antenna/port groups). In one example, an antenna/port group corresponds to CSI-RS antenna ports of multiple NZP CSI-RS resources (e.g. comprising a CSI-RS resource set).

**[0172]** In one example, an antenna/port group corresponds to a reconfigurable intelligent surface (RIS) in which the antenna/port group can be (re-)configured more dynamically (e.g. via MAC CE or/and DCI). For example, the number of antenna ports associated with the antenna/port group can be changed dynamically.

**[0173]** In one example, the antenna architecture of the MIMO system is structured. For example, the antenna structure at each PG or O-RU (or RU) is dual-polarized (single or multi-panel as shown in FIG. **13**. The antenna structure at each PG or O-RU (or RU) can be the same. Or the antenna structure at an PG or O-RU (or RU) can be different from another PG or O-RU (or RU). Likewise, the number of ports at each PG (OR O-RU OR RU) can be the same. Or the number of ports at one PG (OR O-RU OR RU) can be different from another PG (OR O-RU OR RU).

**[0174]** In another example, the antenna architecture of the MIMO system is unstructured. For example, the antenna structure at one PG (OR O-RU OR RU) can be different from another PG (OR O-RU OR RU).

**[0175]** A structured antenna architecture is expected in the rest of the disclosure. For simplicity, each PG (OR O-RU OR RU) is equivalent to a panel (cf. FIG. **13**), although, an PG (OR O-RU OR RU) can have multiple panels in practice. The disclosure however is not restrictive to a single panel expectation at each PG (OR O-RU OR RU), and can easily be extended (covers) the case when an PG (OR O-RU OR RU) has multiple antenna panels.

**[0176]** In one or more embodiments described herein, an PG (OR O-RU OR RU) constitutes (or corresponds to or is equivalent to) at least one of the following:

**[0177]** In one or more examples described herein, an PG OR O-RU (OR RU) corresponds to a TRP.

**[0178]** In one or more examples described herein, an PG or O-RU (or RU) corresponds to a CSI-RS resource. A UE is configured with K=$N_g$>1 non-zero-power (NZP) CSI-RS resources, and a CSI reporting is configured to be across multiple CSI-RS resources. This is similar to Class B, K>1 configuration in Rel. 14 LTE. The K NZP CSI-RS resources can belong to a CSI-RS resource set or multiple CSI-RS resource sets (e.g. K resource sets each comprising one CSI-RS resource). The details are as explained in this disclosure herein.

**[0179]** In one or more examples described herein, an PG or O-RU (or RU) corresponds to a CSI-RS resource group, where a group comprises one or multiple NZP CSI-RS resources. A UE is configured with K≥$N_g$>1 non-zero-power (NZP) CSI-RS resources, and a CSI reporting is configured to be across multiple CSI-RS resources from resource groups. This is similar to Class B, K>1 configuration in Rel. 14 LTE. The K NZP CSI-RS resources can belong to a CSI-RS resource set or multiple CSI-RS resource sets (e.g. K resource sets each comprising one CSI-RS resource). The details are as explained in this disclosure herein. In particular, the K CSI-RS resources can be partitioned into $N_g$ resource groups. The information about the resource grouping can be provided together with the CSI-RS resource setting/configuration, or with the CSI reporting setting/configuration, or with the CSI-RS resource configuration.

**[0180]** In one or more examples described herein, an PG or O-RU (or RU) corresponds to a subset (or a group) of CSI-RS ports. A UE is configured with at least one NZP CSI-RS resource comprising (or associated with) CSI-RS ports that can be grouped (or partitioned) multiple subsets/groups/parts of antenna ports, each corresponding to (or constituting) an PG or O-RU (or RU). The information about the subsets of ports or grouping of ports can be provided together with the CSI-RS resource setting/configuration, or with the CSI reporting setting/configuration, or with the CSI-RS resource configuration.

**[0181]** In one or more examples described herein, an PG or O-RU (or RU) corresponds to or more examples described herein depending on a configuration. For example, this configuration can be explicit via a parameter (e.g. an RRC parameter). Or it can be implicit.

**[0182]** In one example, when implicit, it could be based on the value of K. For example, when K>1 CSI-RS resources, an PG or O-RU (or RU) corresponds to or more examples described herein, and when K=1 CSI-RS resource, an PG or O-RU (or RU) corresponds to or more examples described herein.

**[0183]** In another example, the configuration could be based on the configured codebook. For example, an PG or O-RU (or RU) corresponds to a CSI-RS resource or resource group when the codebook corresponds to a decoupled codebook (modular or separate codebook for each PG or O-RU (or RU)), and an PG or O-RU (or RU) corresponds to a subset (or a group) of CSI-RS ports when codebook corresponds to a coupled (joint or coherent) codebook (one joint codebook across PGs).

**[0184]** In one example, when PG or O-RU (or RU) maps (or corresponds to) a CSI-RS resource or resource group, and a UE can select a subset of PGs (resources or resource groups) and report the CSI for the selected PGs (resources or resource groups), the selected PGs can be reported via an indicator. For example, the indicator can be a CRI or a PMI (component) or a new indicator.

**[0185]** In one example, when PG or O-RU (or RU) maps (or corresponds to) a CSI-RS port group, and a UE can select a subset of PGs (port groups) and report the CSI for the selected PGs (port groups), the selected PGs can be reported via an indicator. For example, the indicator can be a CRI or a PMI (component) or a new indicator.

**[0186]** In one example, when multiple (K>1) CSI-RS resources are configured for $N_g$ PGs, a decoupled (modular) codebook is used/configured, and when a single (K=1) CSI-RS resource for $N_g$ PGs, a joint codebook is used/configured.

**[0187]** FIG. **14** illustrates a timeline **1400** of example SD units and FD units according to embodiments of the present disclosure. For example, timeline **1400** can be followed by any of the UEs **111-116** of FIG. **1**. This example is for illustration only and other embodiments can be used without departing from the scope of the present disclosure.

**[0188]** In one embodiment, a UE is configured (e.g. via a higher layer CSI configuration information) with a CSI report, where the CSI report is based on a channel measurement (and interference measurement) and a codebook. When the CSI report is configured to be aperiodic, it is reported when triggered via a DCI field (e.g. a CSI request field) in a DCI.

**[0189]** The channel measurement can be based on K≥1 channel measurement resources (CMRs) that are transmitted from a plurality of spatial-domain (SD) units (e.g. a SD unit=a CSI-RS antenna port), and are measured via a plurality of frequency-domain (FD) units (e.g. a FD unit=one or more PRBs/SBs) and via either a time-domain (TD) unit or a plurality of TD units (e.g. a TD unit=one or more time slots). In one example, a CMR can be a NZP-CSI-RS resource.

**[0190]** The CSI report can be associated with the plurality of FD units and the plurality of TD units associated with the channel measurement. Alternatively, the CSI report can be associated with a second set of FD units (different from the plurality of FD units associated with the channel measurement) or/and a second set of TD units (different from the plurality of TD units associated with the channel measurement). In this later case, the UE, based on the channel measurement, can perform prediction (interpolation or extrapolation) in the second set of FD units or/and the second set of TD units associated with the CSI report.

**[0191]** An illustration of the SD units (in $1^{st}$ and $2^{nd}$ antenna dimensions), FD units, and, and TD units is shown in FIG. **14**.

**[0192]** The first dimension is associated with the 1st antenna port dimension and comprises $N_1$ units,

**[0193]** The second dimension is associated with the 2nd antenna port dimension and comprises $N_2$ units,

**[0194]** The third dimension is associated with the frequency dimension and comprises $N_3$ units, and

**[0195]** The fourth dimension is associated with the time/Doppler dimension and comprises $N_4$ units.

**[0196]** Alternatively, the SD units, FD units, and, and TD units are as follows.

**[0197]** The first dimension is associated with the antenna port dimension and comprises $P_{CSIRS}$ units,

**[0198]** The second dimension is associated with the frequency dimension and comprises $N_3$ units, and

**[0199]** The third dimension is associated with the time/Doppler dimension and comprises $N_4$ units.

**[0200]** The plurality of SD units can be associated with antenna ports (e.g. co-located at one site or distributed across multiple sites) comprising one or multiple antenna/port groups (i.e., $N_g$≥1), and dimensionalizes the spatial-domain profile of the channel measurement.

**[0201]** When K=1, there is one CMR comprising $P_{CSIRS}$ CSI-RS antenna ports.

**[0202]** When $N_g$=1, there is one PG comprising $P_{CSIRS}$ ports, and the CSI report is based on the channel measurement from the one PG.

**[0203]** When $N_g$>1, there are multiple PGs, and the CSI report is based on the channel measurement from/across the multiple PGs.

**[0204]** When K>1, there are multiple CMRs, and the CSI report is based on the channel measurement across the multiple CMRs. In one example, a CMR corresponds to an PG (one-to-one mapping). In one example, multiple CMRs can correspond to an PG (many-to-one mapping).

**[0205]** In one example, when of the $P_{CSIRS}$ antenna ports are co-located at one site, $N_g$=1. In one example, when of the $P_{CSIRS}$ antenna ports are distributed (non-co-located) across multiple sites, $N_g$>1.

**[0206]** In one example, when of the $P_{CSIRS}$ antenna ports are co-located at one site and within a single antenna panel, $N_g$=1. In one example, when of the $P_{CSIRS}$ antenna ports are distributed across multiple antenna panels (can be co-located or non-co-located), $N_g$>1.

**[0207]** The value of $N_g$ can be configured, e.g. via higher layer RRC parameter. Or it can be indicated via a MAC CE. Or it can be provided via a DCI field.

**[0208]** Likewise, the value of K can be configured, e.g. via higher layer RRC parameter. Or it can be indicated via a MAC CE. Or it can be provided via a DCI field.

**[0209]** In one example, $K=N_g=X$. The value of X can be configured, e.g. via higher layer RRC parameter. Or it can be indicated via a MAC CE. Or it can be provided via a DCI field.

**[0210]** In one example, the value of K is determined based on the value of $N_g$. In one example, the value of $N_g$ is determined based on the value of K.

**[0211]** The plurality of FD units can be associated with a frequency domain allocation of resources (e.g. one or multiple CSI reporting bands, each comprising multiple PRBs) and dimensionalizes the frequency (or delay)-domain profile of the channel measurement.

**[0212]** The plurality of TD units can be associated with a time domain allocation of resources (e.g. one or multiple CSI reporting windows, each comprising multiple time slots) and dimensionalizes the time (or Doppler)-domain profile of the channel measurement.

**[0213]** In one example, the number of antenna ports across K CSI-RS resources is the same. For example, each of the K CSI-RS resources can be associated with $2N_1N_2$ antenna ports. In this case, the total number of antenna ports is $P_{CSIRS,tot}=2KN_1N_2$.

**[0214]** In one example, the number of antenna ports across K CSI-RS resources can be the same or different. For example, each of the K CSI-RS resources can be associated with $2N_{1,r}N_{2,r}$ antenna ports. In this case, the total number of antenna ports is $P_{CSIRS,tot}=\Sigma_{r=1}^{K}2N_{1,r}N_{2,r}$.

**[0215]** In port numbering scheme 1, the CSI-RS ports are numbered according to the order of (polarization p, NZP CSI-RS resource r) as CSI-RS ports of (p=0, r=1) followed by CSI-RS ports of (p=1,r=1), followed by CSI-RS ports of (p=0,r=2), followed by CSI-RS ports of (p=1, r=2), . . . , followed by CSI-RS ports of (p=0, r=N) followed by CSI-RS ports of (p=1,r=N).

**[0216]** In port numbering scheme 2, the CSI-RS ports are numbered according to the order of (polarization p, NZP CSI-RS resource r) as

**[0217]** CSI-RS ports of (p=0, r=1) followed by CSI-RS ports of (p=0, r=1), . . . , followed by CSI-RS ports of (p=0, r=N), and

**[0218]** then CSI-RS ports of (p=1, r=1) followed by CSI-RS ports of (p=1, r=1), . . . , followed by CSI-RS ports of (p=1, r=N).

**[0219]** In one example, an PG corresponds to an antenna, an antenna group (multiple antennae), an antenna port, an antenna port group (multiple ports), a CSI-RS resource, a CSI-RS resource set, a group of CSI-RS resources, a panel, an RRH, a Tx-Rx entity, a (analog) beam, a (analog) beam group, a cell, a cell group.

**[0220]** In one example, PGs can have a uniform (the same/common) structure. For example, they can have the same number of ports ($P_{CSIRS,r}=P_{CSIRS}$) or the same antenna port layout $(N_{1,r}, N_{2,r})=(N_1, N_2)$. In one example, PGs can have non-uniform (or different) structure. For example, they can have the same or different number of ports ($P_{CSIRS,r_1}=P_{CSIRS,r_2}$ or $P_{CSIRS,r_1}\neq P_{CSIRS,r_2}$) or the same antenna port layout, i.e., $(N_{1,r_1}, N_{2,r_1})=(N_{1,r_2}, N_{2,r_2})$ or $(N_{1,r_1}, N_{2,r_1})\neq(N_{1,r_2}, N_{2,r_2})$.

**[0221]** FIG. **15** illustrates a diagram of example PG hypotheses **1500** according to embodiments of the present disclosure. For example, PG hypotheses **1500** can be utilized by the BS **102** of FIG. **2**. This example is for illustration only and other embodiments can be used without departing from the scope of the present disclosure.

**[0222]** In one embodiment, a user is configured with a dynamic (flex-) MIMO framework based on a single basic NW entity, namely a port group (PG) is provided. The basic NW entity can be an O-RAN RU. A PG can be an abstraction for antenna panel ($N_g=1$), TRP ($N_g\geq1$), CSI-RS antenna ports of a NZP CSI-RS resource ($N_g=1$), a subset of CSI-RS antenna ports of a NZP CSI-RS resource ($N_g\geq1$), CSI-RS antenna ports of multiple NZP CSI-RS resources comprising a CSI-RS resource set. The MIMO operations in the provided framework includes at least three steps:

**[0223]** 1) NW configuring a UE (e.g., the UE **116**) to measure $N_g\geq1$ PGs

**[0224]** 2) The selection of at least one PG selection hypothesis

**[0225]** 3) CSI reporting and DL-precoding according to the at least one of the PG selection hypotheses.

**[0226]** Let $Y\geq1$ be a number of PG selection hypotheses. An example is shown in FIG. **15**, wherein $N_g=4$, and six examples of PG selection hypotheses are shown. For each $l\in\{1, \ldots, Y\}$, an PG selection hypothesis selects $n_l$ PGs, where $1\leq n_l\leq N_{AG}$. The PG selection can either be user-reported (performed by the user, and reported to the NW), or NW-controlled (performed by the NW, and indicated to the user), and can either be a standalone/separate or a non-standalone procedure. When non-standalone, the PG selection can be included or/and multiplexed either with a DL indication such as beam or TCI state indication, or with a report (e.g. CSI or beam report). When user-reported, the PG selection report includes an information about the selected $\{n_l\}$PGs, and can also include a metric (e.g. RSRP, power level, SINR). The PG selection is signaled dynamically, e.g., via a MAC CE or a DCI or a DCI with MAC CE activation (similar to beam/TCI state indication) or via UCI (similar to aperiodic beam/CSI report). Note that the PG selection can support both NW-controlled features such as beam (TCI state) indication, TRP indication (CJT), port indication (non-PMI feedback), sub-configurations (NES), and SBFD (duplexing); and User-reported features such as dynamic TRP selection (CJT), dynamic port selection (PS T2 codebook).

**[0227]** Depending on the antenna architecture (fully digital vs hybrid), a PG can comprise one or more than one antenna port, wherein the port can be with a fixed beam/virtualization, or a dynamic beam/virtualization. Likewise, in mobility scenarios, the PG selection can be via layer **1** control in order to facilitate fast PG selection switch/update.

**[0228]** FIG. **16** illustrates a diagram of an example TCI state configuration **1600** according to embodiments of the present disclosure. For example, TCI state configuration **1600** can be configured by the BS **103** of FIG. **1**. This example is for illustration only and other embodiments can be used without departing from the scope of the present disclosure.

**[0229]** FIG. **17** illustrates a diagram of an example TCI state configuration **1700** according to embodiments of the present disclosure. For example, TCI state configuration **1700** can be configured by the BS **102** of FIG. **1**. This example is for illustration only and other embodiments can be used without departing from the scope of the present disclosure.

**[0230]** In one embodiment, properties/expectations associated with port(s) of the one or multiple PGs need to be established. Two main properties include: (a) QCL relation and (b) coherency. As for (a), it refers to channel properties that are common across ports associated with PGs, and (b) refers to transmission/reception hypothesis using multiple ports within/across PG(s). In NR MIMO, (a) and (b) are treated separately. In particular, for DL, (a) is via TCI state, and (b) is via expected transmission hypothesis (such as single-panel, multi-panel, sTRP, mTRP dynamic point selection (DPS), mTRP NCJT, mTRP CJT etc.). Likewise, for UL, (a) is via SRS resource indicator (SRI) or joint TCI state or UL TCI state, and (b) is via transmit precoding matrix indicator (TPMI). Also, there are two separate indications for Rel. 17 uTCI, i.e. UL TCI state indication via DL-DCI and TPMI indication via UL-DCI. Such a decoupled design clearly is unnecessary and inefficient, especially for layer **1** control signalling. It can be coupled into one by consolidating variables (and associated properties) into one indication framework. One such framework, namely multivariate TCI state, is provided as follows.

[0231] In one embodiment, the ports within a PG can be associated with properties regarding QCL (or TCI state) and coherency. A multivariate TCI framework for acquiring/indicating these properties is used, where the multivariate TCI state definition includes at least one or more of the following:

[0232] PG selection hypotheses

[0233] Scheme: DPS, NCJT, CJT, D-MIMO

[0234] QCL relation

[0235] Coherency within/across PGs

[0236] For QCL, relevant channel properties include (i) angular profile such as spatial filter parameter (analog beam), (ii) Delay profile such as average delay, delay spread, and (iii) Doppler profile such as Doppler shift, Doppler spread.

[0237] Quasi co-location (QCL) expectations correspond to LT channel properties that are common across antenna ports associated with PGs. In 5G, the following CL relations are supported:

[0238] {Doppler shift, Doppler spread, average delay, delay spread}

[0239] {Doppler shift, Doppler spread}

[0240] {Doppler shift, average delay}

[0241] {Spatial filter parameter}

[0242] The following are viable options for coherency.

[0243] Option 1: coherency based on new QCL-info or QCL-type (e.g. Type E) into the QCL or TCI-state definition

[0244] Option 2: coherency and the PG selection hypothesis are included in the QCL or TCI-state definition

[0245] Option 3: coherency is separate from QCL-info or TCI state definition. It can be a dedicated IE or RRC parameter, e.g. coherency-Info.

[0246] Examples for Option 1 and Option 2 are shown in FIG. **17** and FIG. **16**, respectively, where QCL-Type A, B, C, D can be the same as defined in 5G specification (38.214), or they can be different, and Type E corresponds to coherency.

[0247] A measurement and reporting to enable multivariate TCI state indication can be supported. Such reporting can be aperiodic: either NW-controlled (via DCI either UL-DCI or DL-DCI, including two-stage DCI) or UE-initiated (e.g. UCI either PUCCH or PUSCH, including two-stage UCI). The UE-initiated can be based on an event detection such as probability of beam failure, maximum permissible exposure (MPE), beam blocking, panel switch (for a multi-panel user equipment (MPUE)) etc. The SP reporting can be configured/triggered as an aperiodic report with repetition ON.

[0248] As mentioned herein, the inter-PG mobility can be used to update a candidate set of PGs in order to maintain seamless "cell-free" access to RRC-connected UEs.

[0249] Akin to NR UL codebook, the Coherency between/within PGs can be (1) full-coherence (FC), i.e., a layer (stream) is transmitted using antenna ports, (2) partial-coherence (PC), i.e., a layer (stream) is transmitted using at least two but not antenna ports, or (3) non-coherence (NC), i.e., a layer (stream) is transmitted using one antenna port.

[0250] FIG. **18** illustrates a diagram of an example analog beam-based network **1800** according to embodiments of the present disclosure. For example, analog beam-based network **1800** can be implemented within the wireless network **100** of FIG. **1**. This example is for illustration only and other embodiments can be used without departing from the scope of the present disclosure.

[0251] FIG. **19** illustrates examples of a UE moving on a trajectory **1900** located in co-located and distributed PGs according to embodiments of the present disclosure. For example, UE moving on a trajectory **1900** can be implemented by any of the UEs **111-116** of FIG. **1**. This example is for illustration only and other embodiments can be used without departing from the scope of the present disclosure.

[0252] In one embodiment, facilitated by the provided unified band-agnostic framework, a cellular region can be served by partitioning (or covering) the region into (with) multiple sites and deploying multiple PGs at each site. An example is illustrated in FIG. **18** wherein there are three PGs per site. For a frequency f1 (e.g. FR1), each PG is controlled by a fully-digital processing chain, implying there is no analog beam or a fixed beam, and PGs at one site together can serve users belonging to the respective site. At a higher frequency f2 (e.g. FR2), each PG is associated with a hybrid analog-digital structure, implying each antenna port of the PG needs to be assigned/updated with one of the three wide beams. At an even higher frequency, since analog beams get narrower (reduced beamwidth), number of analog beams increases, hence antenna ports of an PG need to be assigned/updated with one of the nine narrow beams. In general, a PG can be assigned/updated with $A_g$ analog beams. When $A_g=1$, there is one analog beam per PG. When $A_g=N_{panel}$, there is one analog beam per antenna panel/port per PG. In a mobility scenario, multiple PGs can serve a moving user. An illustration is shown in FIG. **19**. While the user moves from a location A to another location B, the set of PGs is updated from {PG2, PG3, PG4} to {PG1, PG2}. Consequently, a seamless beam-based (as opposed to cell-based) mobility is feasible especially for RRC-connected UEs.

[0253] An example of parameters relevant for PGs are tabulated in Table 2. Depending on carrier frequency, BF, and NW topology, the user can be configured with $N_g$ PGs and values of relevant parameters.

TABLE 2

| Parameters | Values: Fully digital | Values: Hybrid BF |
|---|---|---|
| Number of PGs, $N_g$ | {1, 2, 3, 4} | $N_{panel} \in \{1, 2, 4\}$ |
| Number of ports per PG, $P_g$ | {1, 2, 4, . . . , 256} | 1 |
| Number of beams per port, $N_b$ | 1 | $1 \le n_b \le 256$ |
| Port assignment/update | Semi-static (fixed) | Dynamic |
| FD granularity | T-F patterns, | WB |
| TD granularity | repeats across RBs | Multiple symbols (one per beam) |
| Density | {0.5, 1} | {1, 3} |
| Measurement | One-shot: AP<br>Multi-shot: P/SP | Beam-sweeping (symbol-level) |

[0254] In one example, for antenna ports within an PG, LT channel properties (QCL and coherency) remain the same, and for antenna ports across PGs, LT channel properties (QCL and coherency) can be different. In one example, for antenna ports within an PG or across PGs, LT channel properties (QCL and coherency) can be same or different.

[0255] The DCI payload size for indicating a multivariate TCI state can be large (due to multiple variables associated with properties). If a single DCI is used for indicating this multivariate TCI state, this will result in a large number of

DCI decoding hypotheses, an issue for UE power consumption. Besides, the UE would need to buffer the control channel carrying DCI bit before decoding, adding further to the UE power consumption. In 5G, an indication of only a small number of TCI states (2 TCI states) is supported, which is insufficient for 6G taking into account multi-beam scenarios (JPTA, dynamic PG selection, dynamic NES etc.). Besides, if UL high-resolution or frequency-selective precoding is supported in 6G, then the payload of UL DCI is also likely to increase significantly due to (indication of multiple UL TPMIs). It is therefore essential to design more efficient layer **1** control signalling in 6G. One such design can be based on a dual-/two-stage DCI.

**[0256]** In one embodiment, a dual-stage control (DCI) can also use/configure/indicate for the NW-controlled PG selection, and the indication of the multivariate TCI state, especially when the number of activated TCI states is large (e.g. multi-beam MIMO, inter-cell multi-beam operations, coherent transmission etc.), including a fixed first stage payload size that indicates the information size and content of the second stage. For instance, for the NW-controlled PG selection,

**[0257]** DCI part 1 includes a first information about the PG selection hypothesis, and size (payload) of the second stage DCI

**[0258]** DCI part 2 includes a second information based on the first information

**[0259]** Two examples can be as follows.

**[0260]** Ex1: (1st information, 2nd information)=(number of PG selection hypotheses, indices of selected PGs)

**[0261]** Ex2: (1st information, 2nd information)=(a set of PGs, properties of the selected PGs)

**[0262]** In one embodiment, in mobility scenarios, to provide seamless (un-interrupted) service to a RRC-connected UE, the herein MIMO framework can include a dynamic (layer **1**)-based update of PG(s) for the UE, this update can be based measurement/reporting of PG(s) from a set of configured/activated candidate PG(s), akin to the beam measurement/reporting and TCI state indication in NR.

**[0263]** In one embodiment, a UE can be configured with the PG-based framework to support advanced features such as NES, dynamic port assignment (ON/OFF) for FR2, and MIMO for Duplex. In particular, these features can be based on the multivariate TCI state definition, e.g. via different PG selection hypotheses.

**[0264]** In one embodiment, the QCL and coherency relationships/expectations are indicated separately. For example, QCL indication is via TCI state, and coherency indication is via a separate/dedicated parameter. The indication of the two however can be joint/together via the same indication medium (e.g. DCI), or it can be via separate mediums (e.g. QCL via DCI, and coherency via MAC CE, or QCL is via first-stage DCI and coherency is via second-stage DCI, or vice-versa).

**[0265]** In one example, the UE is configured with a list of QCL-Infos, each QCL-Info includes an information about a QCL-Type. It can also include an information about a source/reference measurement entity associated with the QCL-Type. The source/reference measurement entity can be at least one of the following:

**[0266]** In one example, it includes a PG (e.g. source/reference PG) or multiple PGs.

**[0267]** In one example, it includes an antenna port (e.g. source/reference port) or multiple antenna ports.

**[0268]** In one example, it includes one antenna port or multiple ports within an PG (e.g. source/reference port within a source/reference PG).

**[0269]** In one example, it includes a (PG, antenna port) pair or a (PG, ≥1 antenna ports) pair.

**[0270]** In one example, it includes an RS (e.g. source/reference RS such as synchronization signal/physical broadcast channel (SSB/PBCH) or CSI-RS or CSI-RS for tracking, tracking reference signal (TRS).

**[0271]** In one example, it includes a 1-port PG for tracking, tracking PG or TAG.

**[0272]** In one example, it includes a 1-port CSI-RS.

**[0273]** In one example, the UE is configured with a list of TCI states, each TCI state include up to X QCL-Infos, each of different types. In one example, X=1 or 2 or it is configured (e.g. RRC). In one example, each QCL-Info is according to the following example.

```
TCI-State ::=                SEQUENCE {
   tci-StateId                 TCI-StateId,
   qcl-Type1                     QCL-Info,
   qcl-Type2                     QCL-Info                         OPTIONAL,   -- Need R
   ...,
   [[
   additionalPCI-r17                 AdditionalPCIIndex-r17              OPTIONAL,   --
Need R
   pathlossReferenceRS-Id-r17              PUSCH-PathlossReferenceRS-Id-r17
OPTIONAL,   -- Cond JointTCI
   ul-powerControl-r17               Uplink-powerControlId-r17           OPTIONAL   --
Cond JointTCI
   ]]
}
QCL-Info ::=                   SEQUENCE {
   cell                      ServCellIndex                         OPTIONAL,   -- Need R
   bwp-Id                      BWP-Id                                OPTIONAL, -- Cond CSI-RS-
Indicated
   referenceSignal                 CHOICE {
      csi-rs                     NZP-CSI-RS-ResourceId,
      ssb                           SSB-Index
   },
   qcl-Type                  ENUMERATED {typeA, typeB, typeC, typeD},
   ...
}
```

**[0274]** In one example, the coherency expectation is included in the TCI state definition as a separate parameter, as shown herein, and two examples (A and B) are shown.

```
TCI-State ::=                 SEQUENCE {
  tci-StateId                   TCI-StateId,
  qcl-Type1                       QCL-Info,
  qcl-Type2                       QCL-Info                    OPTIONAL,   -- Need R
  ...,
  [[
  additionalPCI-r17                 AdditionalPCIIndex-r17         OPTIONAL,   --
Need R
  pathlossReferenceRS-Id-r17          PUSCH-PathlossReferenceRS-Id-r17
OPTIONAL,   -- Cond JointTCI
  ul-powerControl-r17               Uplink-powerControlId-r17        OPTIONAL   --
Cond JointTCI
  ]]
  Coherency                       CoherenceType,
```

Example A:

**[0275]** CoherenceType::=ENUMERATED {FC, PC, NC}

Example B:

```
CoherenceType ::= {
  Type {intra-PG, inter-PG},
  ENUMERATED {FC, PC, NC}
}
```

**[0276]** In one example, when $N_g>1$

**[0277]** In one example, there is one TCI state or QCL-info, or QCL-Type associated with each PG and the coherency is intra-PG (i.e. applies to port(s) within the respective PG).

**[0278]** In one example, there is up to X TCI state(s) or QCL-info(s), or QCL-Type(s) associated with each PG, the coherency can be intra-PG (i.e. applies to port(s) within the respective PG), or inter-PG (i.e. applies to port(s) across multiple PG). In one example, X is fixed (e.g. 1 or 2), or configured (e.g. via RRC, or MAC CE or DCI), or configured subject to UE capability reporting.

**[0279]** In one example, there is up to X TCI state(s) or QCL-info(s), or QCL-Type(s) associated with each PG, and the coherency is inter-PG (expecting that the coherency for each PG is fixed, e.g. FC).

**[0280]** In one example, the PG selection hypothesis is also included in the TCI state definition. In one example, the TCI state definition is as follows.

```
TCI-State ::=                 SEQUENCE {
  tci-StateId                   TCI-StateId,
  qcl-Type1                       QCL-Info,
  qcl-Type2                       QCL-Info                              OPTIONAL,   -- Need R
  ...,
  [[
  additionalPCI-r17                 AdditionalPCIIndex-r17                 OPTIONAL,   --
Need R
  pathlossReferenceRS-Id-r17          PUSCH-PathlossReferenceRS-Id-r17
OPTIONAL,   -- Cond JointTCI
  ul-powerControl-r17               Uplink-powerControlId-r17               OPTIONAL   --
Cond JointTCI
  ]]
  PG selection                    Hypothesis ID or list/indices of selected PGs
  Coherency                       CoherenceType
```

**[0281]** In one example, the TCI state definition is as follows.

```
TCI-State ::=                 SEQUENCE {
  tci-StateId                   TCI-StateId,
  qcl-Type1                       QCL-Info,
  qcl-Type2                       QCL-Info                              OPTIONAL,   -- Need R
  ...,
  [[
  additionalPCI-r17                 AdditionalPCIIndex-r17                 OPTIONAL,   --
Need R
  pathlossReferenceRS-Id-r17          PUSCH-PathlossReferenceRS-Id-r17
OPTIONAL,   -- Cond JointTCI
```

-continued

| | | |
|---|---|---|
| ul-powerControl-r17 | Uplink-powerControlId-r17 | OPTIONAL -- |
| Cond JointTCI | | |
| ]] | | |
| CoherencyPerAG | SEQUENCE (SIZE ($N_g$)) OF CoherenceType | |
| CoherencyAcrossAG | CoherenceType | |

**[0282]** In one example, the coherency is indicated separately from the TCI state definition. It can be indicated via a dedicated IE or RRC parameter. For instance, coherency is a separate IE (RRC), e.g. Coherency-Info.

**[0283]** FIG. **20** illustrates an example method **2000** performed by a UE in a wireless communication system according to embodiments of the present disclosure. The method **2000** of FIG. **20** can be performed by any of the UEs **111-116** of FIG. **1**, such as the UE **116** of FIG. **3**, and a corresponding method can be performed by any of the BSs **101-103** of FIG. **1**, such as BS **102** of FIG. **2**. The method **2000** is for illustration only and other embodiments can be used without departing from the scope of the present disclosure.

**[0284]** The method **2000** begins with the UE receiving information about a list of mv-TCI states (**2010**). For example, in **2010**, each of the mv-TCI states includes a TCI state ID, a QCL-type, and a coherency type and is associated with at least one PG comprising n ports. $1 \le n \le N$ and N is a total number of ports. In various embodiments, the at least one PG corresponds to one or multiple PGs and the coherency type is intra-PG that applies only to ports within a PG. In various embodiments, the at least one PG corresponds to multiple PGs and the coherency type is inter-PG that applies to ports within as well as across multiple PGs.

**[0285]** The UE then receives an indication about a mv-TCI state from the list of mv-TCI states (**2020**). The UE then identifies, based on the mv-TCI state, the QCL-type, the coherency type, and the at least one PG (**2030**). In various embodiments, the mv-TCI state further includes a PG selection hypothesis taking a value from DPS, NCJT, CJT, and D-MIMO. In various embodiments, the coherency type corresponds to a QCL-type=typeE. In various embodiments, the QCL-type takes a value from A: {Doppler shift, Doppler spread, average delay, delay spread}, B: {Doppler shift, Doppler spread}, C: {Doppler shift, average delay}, and D: {Spatial filter parameter}.

**[0286]** The UE then determines, based on the QCL-type, common channel properties (**2040**). The UE then determines, based on the coherency type, a transmission hypothesis (**2050**). For example, in **2050**, in one example, the transmission hypothesis is DPS, where the at least one PG is selected from multiple PGs, and each transmission layer is associated with one PG. In another example, the transmission hypothesis is coherent joint transmission (CJT), where the at least one PG includes one PG and each transmission layer extends across all ports in the one PG. In another example, the transmission hypothesis is D-MIMO, where the at least one PG includes multiple PGs and each transmission layer extends across all PGs. In another example, the transmission hypothesis is NCJT, where the at least one PG being multiple PGs and each transmission layer is associated with one PG.

**[0287]** The UE then receives, from the at least one PG, a DL transmission based on the common channel properties and the transmission hypothesis (**2060**).

**[0288]** Any of the above variation embodiments can be utilized independently or in combination with at least one other variation embodiment. The above flowchart(s) 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.

**[0289]** Although the present disclosure has been described with exemplary embodiments, various changes and modifications may be suggested to one skilled in the art. It is intended that the present disclosure encompass such changes and modifications as fall within the scope of the appended claims. None of the descriptions 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.

What is claimed is:

**1**. A user equipment (UE) comprising:

a transceiver configured to:

receive information about a list of multivariate transmission configuration indicator (mv-TCI) states, wherein each of the mv-TCI states (i) includes a TCI state ID, a quasi co-location-type (QCL-type), and a coherency type, and (ii) is associated with at least one port group (PG) comprising n ports, and

receive an indication about a mv-TCI state from the list of mv-TCI states; and

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

identify, based on the mv-TCI state, the QCL-type, the coherency type, and the at least one PG,

determine, based on the QCL-type, common channel properties, and

determine, based on the coherency type, a transmission hypothesis,

wherein the transceiver is further configured to receive, from the at least one PG, a downlink (DL) transmission based on the determined common channel properties and the determined transmission hypothesis, and

wherein $1 \le n \le N$ and N is a total number of ports.

**2**. The UE of claim **1**, wherein the transmission hypothesis is at least one of:

dynamic point selection (DPS), wherein:

the at least one PG is selected from multiple PGs, and each transmission layer is associated with one PG,

coherent joint transmission (CJT), wherein:

the at least one PG includes one PG, and

each transmission layer extends across all ports in the one PG,

distributed-multiple input multiple output (D-MIMO), wherein:
the at least one PG includes multiple PGs, and
each transmission layer extends across all PGs, and
non-coherent JT (NCJT), wherein:
the at least one PG being multiple PGs, and
each transmission layer is associated with one PG.

**3**. The UE of claim **1**, wherein:
the at least one PG corresponds to one or multiple PGs, and
the coherency type is intra-PG that applies only to ports within a PG.

**4**. The UE of claim **1**, wherein:
the at least one PG corresponds to multiple PGs, and
the coherency type is inter-PG that applies to ports within as well as across multiple PGs.

**5**. The UE of claim **1**, wherein the coherency type corresponds to a QCL-type=typeE.

**6**. The UE of claim **1**, wherein the mv-TCI state further includes a PG selection hypothesis taking a value from dynamic point selection (DPS), non-coherent joint transmission (NCJT), coherent joint transmission (CJT), and distributed-multiple input multiple output (D-MIMO).

**7**. The UE of claim **1**, wherein the QCL-type takes a value from:
A: {Doppler shift, Doppler spread, average delay, delay spread},
B: {Doppler shift, Doppler spread},
C: {Doppler shift, average delay}, and
D: {Spatial filter parameter}.

**8**. A base station (BS) comprising:
a transceiver configured to:
transmit information about a list of multivariate transmission configuration indicator (mv-TCI) states, wherein each of the mv-TCI states (i) includes a TCI state ID, a quasi co-location-type (QCL-type), and a coherency type, and (ii) is associated with at least one port group (PG) comprising n ports, and
transmit an indication about a mv-TCI state from the list of mv-TCI states; and
a processor operably coupled to the transceiver, the processor configured to:
determine, based on the mv-TCI state, the QCL-type, the coherency type, and the at least one PG,
determine, based on the QCL-type, common channel properties, and
determine, based on the coherency type, a transmission hypothesis,
wherein the transceiver is further configured to transmit, from the at least one PG, a downlink (DL) transmission based on the determined common channel properties and the determined transmission hypothesis,
wherein $1 \le n \le N$ and N is a total number of ports.

**9**. The BS of claim **8**, wherein the transmission hypothesis is at least one of:
dynamic point selection (DPS), wherein:
the at least one PG is selected from multiple PGs, and
each transmission layer is associated with one PG,
coherent joint transmission (CJT), wherein:
the at least one PG includes one PG, and
each transmission layer extends across all ports in the one PG,
distributed-multiple input multiple output (D-MIMO), wherein:
the at least one PG includes multiple PGs, and
each transmission layer extends across all PGs, and
non-coherent JT (NCJT), wherein:
the at least one PG being multiple PGs, and
each transmission layer is associated with one PG.

**10**. The BS of claim **8**, wherein:
the at least one PG corresponds to one or multiple PGs, and
the coherency type is intra-PG that applies only to ports within a PG.

**11**. The BS of claim **8**, wherein:
the at least one PG corresponds to multiple PGs, and
the coherency type is inter-PG that applies to ports within as well as across multiple PGs.

**12**. The BS of claim **8**, wherein the coherency type corresponds to a QCL-type=typeE.

**13**. The BS of claim **8**, wherein the mv-TCI state further includes a PG selection hypothesis taking a value from dynamic point selection (DPS), non-coherent joint transmission (NCJT), coherent joint transmission (CJT), and distributed-multiple input multiple output (D-MIMO).

**14**. The BS of claim **8**, wherein the QCL-type takes a value from:
A: {Doppler shift, Doppler spread, average delay, delay spread},
B: {Doppler shift, Doppler spread},
C: {Doppler shift, average delay}, and
D: {Spatial filter parameter}.

**15**. A method performed by a user equipment (UE), the method comprising:
receiving information about a list of multivariate transmission configuration indicator (mv-TCI) states, wherein each of the mv-TCI states (i) includes a TCI state ID, a quasi co-location-type (QCL-type), and a coherency type, and (ii) is associated with at least one port group (PG) comprising n ports;
receiving an indication about a mv-TCI state from the list of mv-TCI states;
identifying, based on the mv-TCI state, the QCL-type, the coherency type, and the at least one PG;
determining, based on the QCL-type, common channel properties;
determining, based on the coherency type, a transmission hypothesis; and
receiving, from the at least one PG, a downlink (DL) transmission based on the determined common channel properties and the determined transmission hypothesis,
wherein $1 \le n \le N$ and N is a total number of ports.

**16**. The method of claim **15**, wherein the transmission hypothesis is at least one of:
dynamic point selection (DPS), wherein:
the at least one PG is selected from multiple PGs, and
each transmission layer is associated with one PG,
coherent joint transmission (CJT), wherein:
the at least one PG includes one PG, and
each transmission layer extends across all ports in the one PG,

distributed-multiple input multiple output (D-MIMO), wherein:

the at least one PG includes multiple PGs, and

each transmission layer extends across all PGs, and

non-coherent JT (NCJT), wherein:

the at least one PG being multiple PGs, and

each transmission layer is associated with one PG.

**17**. The method of claim **15**, wherein:

the at least one PG corresponds to one or multiple PGs, and

the coherency type is intra-PG that applies only to ports within a PG.

**18**. The method of claim **15**, wherein:

the at least one PG corresponds to multiple PGs, and

the coherency type is inter-PG that applies to ports within as well as across multiple PGs.

**19**. The method of claim **15**, wherein the coherency type corresponds to a QCL-type=typeE.

**20**. The method of claim **15**, wherein the mv-TCI state further includes a PG selection hypothesis taking a value from dynamic point selection (DPS), non-coherent joint transmission (NCJT), coherent joint transmission (CJT), and distributed-multiple input multiple output (D-MIMO).

* * * * *