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- (54) **Title:** SYSTEM AND METHOD FOR CHANNEL QUALITY MEASUREMENT IN SINGLE USER SUPERIMPOSED TRANSMISSION

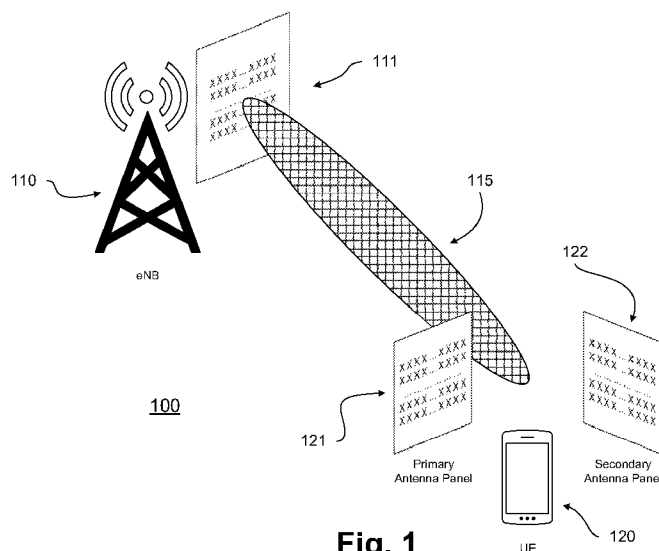


**Fig. 1**

- (57) **Abstract:** Described is an apparatus of an eNB comprising a first circuitry configurable to enable a Single User Superimposed Transmission (SUST) Transmission Mode (TM), and comprising one or more processors to generate a plurality of codewords for a downlink shared channel transmission to a multiple-directional UE antenna-panel structure, including a first codeword a first antenna panel of the multiple-directional UE antenna-panel structure and a second codeword for a second antenna panel of the multiple-directional UE antenna-panel structure. Also described is an apparatus of a UE comprising one or more processors to enable an SUST TM, and to process a plurality of codewords of a downlink shared channel transmission, including a first codeword a first antenna panel of the multiple-directional UE antenna-panel structure and a second codeword for a second antenna panel of the multiple-directional UE antenna-panel structure.





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## **SYSTEM AND METHOD FOR CHANNEL QUALITY MEASUREMENT IN SINGLE USER SUPER IMPOSED TRANSMISSION**

### **CLAIM OF PRIORITY**

**[0001]** The present application claims priority under 35 U.S.C. § 119(e) to United States Provisional Patent Application Serial Number 62/254,363 filed November 12, 2015 and entitled "Single User Super-Imposed Coding," which is herein incorporated by reference in its entirety; and claims priority under 35 U.S.C. § 365(c) to Patent Cooperation Treaty International Patent Application Number PCT/CN2015/095921 filed November 30, 2015 and entitled "Measurement With Simultaneous Receiving Beamforming," which is herein incorporated by reference in its entirety; and claims priority under 35 U.S.C. § 365(c) to Patent Cooperation Treaty International Patent Application Number PCT/CN2015/096633 filed December 8, 2015 and entitled "Channel Quality Measurement In Single User Super Imposed Transmission," which is herein incorporated by reference in its entirety.

### **BACKGROUND**

**[0002]** Various wireless cellular communication systems have been implemented or are being proposed, including a 3rd Generation Partnership Project (3GPP) Universal Mobile Telecommunications System (UMTS), a 3GPP Long-Term Evolution (LTE) system, a 3GPP LTE-Advanced (LTE-A) system, and a 5<sup>th</sup> Generation wireless / 5<sup>th</sup> Generation mobile networks (5G) system. Some wireless cellular communication systems may support Multiple Input Multiple Output (MIMO) techniques in which a User Equipment (UE) may have multiple directional Receiving (Rx) based antenna panels. In such UEs, the boresight directions of the antennas may be configured at angles with each other, perhaps even pointing in opposite directions for purposes of spatial coverage.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0003]** The embodiments of the disclosure will be understood more fully from the detailed description given below and from the accompanying drawings of various embodiments of the disclosure. However, while the drawings are to aid in explanation and understanding, they are only an aid, and should not be taken to limit the disclosure to the specific embodiments depicted therein.

[0004] **Fig. 1** illustrates a Single User Superimposed Transmission (SUST) scenario, in accordance with some embodiments of the disclosure.

[0005] **Fig. 2** illustrates a Single User Superimposed Transmission (SUST) scenario, in accordance with some embodiments of the disclosure.

[0006] **Fig. 3** illustrates a flow chart for deriving an SUST Modulation and Coding Scheme (MCS) from a non-SUST Channel Quality Indicator (CQI), in accordance with some embodiments of the disclosure.

[0007] **Fig. 4** illustrates a flow chart for deriving Channel State Information (CSI) assuming SUST transmission, in accordance with some embodiments of the disclosure.

[0008] **Fig. 5** illustrates CSI Reference Signal (CSI-RS) symbols for channel measurement of inner data symbols and outer data symbols, in accordance with some embodiments of the disclosure.

[0009] **Fig. 6** illustrates an Evolved Node-B (eNB) and a User Equipment (UE), in accordance with some embodiments of the disclosure.

[0010] **Fig. 7** illustrates hardware processing circuitry for an eNB for enabling an SUST Transmission Mode (TM), in accordance with some embodiments of the disclosure.

[0011] **Fig. 8** illustrates hardware processing circuitry for a UE for enabling an SUST TM, in accordance with some embodiments of the disclosure.

[0012] **Fig. 9** illustrates methods for an eNB for enabling an SUST TM, in accordance with some embodiments of the disclosure.

[0013] **Fig. 10** illustrates methods for a UE for enabling an SUST TM, in accordance with some embodiments of the disclosure.

[0014] **Fig. 11** illustrates hardware processing circuitry for an eNB for determining a highest Beam Reference Signal (BRS) Receiving Power (BRS-RP) for a UE antenna panel, in accordance with some embodiments of the disclosure.

[0015] **Fig. 12** illustrates hardware processing circuitry for a UE for determining a highest BRS-RP for a UE antenna panel, in accordance with some embodiments of the disclosure.

[0016] **Fig. 13** illustrates methods for an eNB for determining a highest BRS-RP for a UE antenna panel, in accordance with some embodiments of the disclosure.

[0017] **Fig. 14** illustrates methods for a UE for determining a highest BRS-RP for a UE antenna panel, in accordance with some embodiments of the disclosure.

**[0018]**        **Fig. 15** illustrates hardware processing circuitry for an eNB for measuring channel quality for SUST transmissions, in accordance with some embodiments of the disclosure.

**[0019]**        **Fig. 16** illustrates hardware processing circuitry for a UE for measuring channel quality for SUST transmissions, in accordance with some embodiments of the disclosure.

**[0020]**        **Fig. 17** illustrates methods for an eNB for measuring channel quality for SUST transmissions, in accordance with some embodiments of the disclosure.

**[0021]**        **Fig. 18** illustrates methods for a UE for measuring channel quality for SUST transmissions, in accordance with some embodiments of the disclosure.

**[0022]**        **Fig. 19** illustrates example components of a UE device, in accordance with some embodiments of the disclosure.

#### **DETAILED DESCRIPTION**

**[0023]**        Non-Orthogonal Multiple Access (NOMA) or Multi-User Superimposed Transmission (MUST) may be applied in 3rd Generation Partnership Project (3GPP) Long-Term Evolution (LTE) Advanced (LTE-A) systems and 5<sup>th</sup> Generation wireless / 5<sup>th</sup> Generation mobile networks (5G) systems in which multiple users are multiplexed in the power domain or in modulated data symbols on a transmitter side, and multi-user signal separation on a receiver side is realized through Successive Interference Cancellation (SIC). When MUST is applied, a user may partially locate in a cell center and partially locate in a cell edge. Cell center users may decode data by cancelling interference coming from downlink signals to cell edge users. For cell edge users, the signal power is much stronger than interference from cell center users, so data may be decoded without consideration of interference coming to cell center users.

**[0024]**        In millimeter wave (mmWave) based small cell deployment, peak throughput for a Line-of-Sight (LoS) User Equipment (UE) may be limited by a channel rank, which may be two with horizontal and vertical polarization. For mmWave based small cells, when higher per-UE peak throughput is desired in areas of dense Evolved Node-B (eNB) deployment, beam aggregation may increase UE peak throughput.

**[0025]**        For mmWave based small cells, when higher per-UE peak throughput is desired in areas of non-dense eNB deployment—for single-home eNB's, for example—a Single User Superimposed Transmission (SUST) may increase UE peak throughput.

Multiple directional antenna-panel structures used for MUST purposes may be applicable to superimposed transmissions to a single UE, since Reference Signal Receiving Powers (RSRPs) may differ greatly between antenna panels. For scenarios in which an eNB has abundant transmit power, such as scenarios in which a number of Transmitting (Tx) based Antenna Ports (APs) are lower than a number of Receiving (Rx) based APs, MUST may help increase a total Single User (SU) rank to greater than a number of transmission APs.

**[0026]** MUST may be well suited for mmWave communications for small cells for which LoS probability may be high, and UEs may be in close proximity to transmission points. With two Rx antenna panels, each connected to two digital ports, an eNB may be able to serve a UE with up to rank four data transmission with merely two digital ports.

**[0027]** The following description first addresses systems and methods for MUST coding. Proceeding, the description addresses systems and methods for measurement with simultaneous receiving beamforming. Finally, the description addresses systems and methods for channel quality measurement in an MUST transmission mode.

**[0028]** In the following description, numerous details are discussed to provide a more thorough explanation of embodiments of the present disclosure. It will be apparent to one skilled in the art, however, that embodiments of the present disclosure may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form, rather than in detail, in order to avoid obscuring embodiments of the present disclosure.

**[0029]** Note that in the corresponding drawings of the embodiments, signals are represented with lines. Some lines may be thicker, to indicate a greater number of constituent signal paths, and/or have arrows at one or more ends, to indicate a direction of information flow. Such indications are not intended to be limiting. Rather, the lines are used in connection with one or more exemplary embodiments to facilitate easier understanding of a circuit or a logical unit. Any represented signal, as dictated by design needs or preferences, may actually comprise one or more signals that may travel in either direction and may be implemented with any suitable type of signal scheme.

**[0030]** Throughout the specification, and in the claims, the term "connected" means a direct electrical, mechanical, or magnetic connection between the things that are connected, without any intermediary devices. The term "coupled" means either a direct electrical, mechanical, or magnetic connection between the things that are connected or an indirect connection through one or more passive or active intermediary devices. The term "circuit" or

"module" may refer to one or more passive and/or active components that are arranged to cooperate with one another to provide a desired function. The term "signal" may refer to at least one current signal, voltage signal, magnetic signal, or data/clock signal. The meaning of "a," "an," and "the" include plural references. The meaning of "in" includes "in" and "on."

**[0031]** The terms "substantially," "close," "approximately," "near," and "about" generally refer to being within  $\pm 10\%$  of a target value. Unless otherwise specified the use of the ordinal adjectives "first," "second," and "third," etc., to describe a common object, merely indicate that different instances of like objects are being referred to, and are not intended to imply that the objects so described must be in a given sequence, either temporally, spatially, in ranking, or in any other manner.

**[0032]** It is to be understood that the terms so used are interchangeable under appropriate circumstances such that the embodiments of the invention described herein are, for example, capable of operation in other orientations than those illustrated or otherwise described herein.

**[0033]** The terms "left," "right," "front," "back," "top," "bottom," "over," "under," and the like in the description and in the claims, if any, are used for descriptive purposes and not necessarily for describing permanent relative positions.

**[0034]** For purposes of the embodiments, the transistors in various circuits, modules, and logic blocks are Tunneling FETs (TFETs). Some transistors of various embodiments may comprise metal oxide semiconductor (MOS) transistors, which include drain, source, gate, and bulk terminals. The transistors may also include Tri-Gate and FinFET transistors, Gate All Around Cylindrical Transistors, Square Wire, or Rectangular Ribbon Transistors or other devices implementing transistor functionality like carbon nanotubes or spintronic devices. MOSFET symmetrical source and drain terminals i.e., are identical terminals and are interchangeably used here. A TFET device, on the other hand, has asymmetric Source and Drain terminals. Those skilled in the art will appreciate that other transistors, for example, Bi-polar junction transistors-BJT PNP/NPN, BiCMOS, CMOS, etc., may be used for some transistors without departing from the scope of the disclosure.

**[0035]** For the purposes of the present disclosure, the phrases "A and/or B" and "A or B" mean (A), (B), or (A and B). For the purposes of the present disclosure, the phrase "A, B, and/or C" means (A), (B), (C), (A and B), (A and C), (B and C), or (A, B and C).

**[0036]** In addition, the various elements of combinatorial logic and sequential logic discussed in the present disclosure may pertain both to physical structures (such as AND

gates, OR gates, or XOR gates), or to synthesized or otherwise optimized collections of devices implementing the logical structures that are Boolean equivalents of the logic under discussion.

### **A. Systems and methods for SUST coding**

**[0037]** Systems and methods for SUST coding may generally relate to physical downlink shared channel (PDSCH) transmissions and/or xPDSCH specifications for SUST and Downlink (DL) control signaling for SUST. SUST may be applicable to UEs with multiple directional antenna panels, since differences in RSRPs from the same transmission point as received by different antenna panels may be largely due to signal separation among multiple antenna panels. **Fig. 1** illustrates a Single User Superimposed Transmission (SUST) scenario, in accordance with some embodiments of the disclosure.

**[0038]** In scenario 100, an eNB 110 is transmitting a beamformed beam 115 toward a UE 120 using a Tx antenna panel 111. UE 120 has multiple directional receiving antenna panels. UE 120 may have a primary antenna panel 121 and a secondary antenna panel 122. Primary antenna panel 121 may have a first boresight direction, and secondary antenna panel 122 may have a second boresight direction at an angle with the first boresight direction.

**[0039]** RSRPs for primary antenna panel 121 may be higher than RSRPs for secondary antenna panel 122. In comparison with MUST, primary antenna panel 121 may perform as a cell center UE and secondary antenna panel 122 may perform as a cell edge UE for one superimposed transmission.

**[0040]** Mathematically, an SUST transmission on a PDSCH resource element may be described by equation (1):

$$y_i = W_{rx,i} H_i W_{tx} \left( \underbrace{\sqrt{P_1} \underbrace{\begin{bmatrix} P_{1,1} & P_{1,2} \end{bmatrix}}_{P_1} / \sqrt{2} \underbrace{\begin{bmatrix} x_{1,1} \\ x_{1,2} \end{bmatrix}}_{x_1}}_x + \sqrt{P_2} P_2 x_2 \right) + n_i \quad (1)$$

**[0041]** Where:

**[0042]**  $y_i$  may be an  $N_r \times 1$  received signal vector of Rx panel  $i$ ;

**[0043]**  $W_{rx,i}$  may be a  $2 \times N_r$  Rx analog beamforming matrix of Rx panel  $i$ ;

**[0044]**  $H_i$  may be an  $N_r \times N_t$  channel matrix between Rx panel  $i$  and the single Tx panel;

- [0045]  $W_{tx}$  may be an  $N_t \times 2$  Tx analog beamforming matrix of single Tx panel;
- [0046]  $p_i$  may be a transmit power scaling factor for the codeword to be received by  $i$ ;
- [0047]  $[P_{1,1}, P_{1,2}]/\sqrt{2}$  may be a  $2 \times 2$  precoder for the first codeword and may be reduced to  $P_{1,1}$  if CW1 has rank one transmission;
- [0048]  $P_2$  may be a  $2 \times 1$  precoder for the second codeword and may be simply set to the same as  $P_{1,1}$  or  $P_{1,2}$ ;
- [0049]  $x_i$  may be one or more data symbols of one or more codewords intended for Rx panel  $i$ ;
- [0050]  $x$  may be a superimposed data symbol of both Rx panels;
- [0051]  $n_i$  may be a  $2 \times 1$  noise vector;
- [0052]  $N_r$  may be a number of receive antennas; and
- [0053]  $N_t$  may be a number of transmit antennas.

#### **A.1. Physical downlink shared channel specifications for SUST**

[0054] For PDSCH, or what may be called xPDSCH for 5G wireless cellular communication systems, signals to a primary antenna panel and a secondary antenna panel may come from different codewords. One codeword may then be applied to one antenna panel, for example, or two codewords may be mapped to two antenna panels, respectively.

[0055] In some embodiments, SUST may use more than one codeword for PDSCH and/or xPDSCH. The number of codewords used may depend on a number of Rx antenna panels for the PDSCH and/or xPDSCH, and a maximum number of codewords may be defined by the network or Radio Resource Control (RRC) signaling. One codeword may be mapped to a number of layers from one to  $N_{layer}$ , where:

- [0056]  $N_{layer}$  may equal  $\min(N_{Tx}^{port}, N_{Rx}^{port})$ ;
- [0057]  $N_{Tx}^{port}$  may be a number of Tx antenna ports for current Tx antenna panel; and
- [0058]  $N_{Rx}^{port}$  may be a number of Rx antenna ports for one Rx antenna panel.
- [0059]  $N_{Tx}^{port}$  may equal 2 and  $N_{Rx}^{port}$  may equal 2 in equation (1).
- [0060] A Tx signal for each subcarrier in one or more Tx antenna ports may be generated in accordance with equation (2):

$$x = \sum_{j=1}^{N_{cw}} \sqrt{p_j} d_j \quad (2)$$

- [0061] Where:
- [0062]  $N_{cw}$  may represent a number of a codeword;
- [0063]  $p_j$  may indicate a Tx power of codeword  $j$ ; and
- [0064]  $d_j$  may denote a Tx symbol for codeword  $j$ .
- [0065] A Tx power of each codeword may meet the condition indicated by equation (3):

$$\sum_{j=1}^{N_{cw}} p_j = 1 \quad (3)$$

- [0066] In other words, a total power across codewords may equal 1.
- [0067] As an example, a UE may have two Rx antenna panels for PDSCH and/or xPDSCH reception, and there may be two codewords if SUST is enabled. A first codeword may be decoded by a primary antenna panel and a second codeword may be decoded by a secondary antenna panel. A codeword-specific SIC receiver may then be applied.
- [0068] Some embodiments may use a codeword-to-layer mapping method in which a number of layers per codeword may be indicated by higher layers, and each codeword may be mapped (e.g., to multiple layers) independently. For a UE-specific Reference Signal (UE-RS, which may also be referred to below as a Demodulation Reference Signal (DMRS)) associated with PDSCH and/or xPDSCH, its number of antenna ports may be a maximum number of layers in all the codewords as indicated by equation (4):

$$N_{Tx}^{UE-RS} = \max(N_{Tx}^1, N_{Tx}^2, \dots, N_{Tx}^{N_{cw}-1}, N_{Tx}^{N_{cw}}) \quad (4)$$

- [0069] Where:
- [0070]  $N_{Tx}^{UE-RS}$  may denote a number of antenna ports for UE-RS; and
- [0071]  $N_{Tx}^j$  may denote a number of layers in codeword  $j$ .
- [0072] In accordance with equation (1),  $N_{Tx}^{UE-RS}$  may equal 2.
- [0073] Although an exact precoding architecture for DMRS may depend upon the way in which multiple DMRS antenna ports may be multiplexed and mapped to one

Resource Element (RE), an equivalent precoding for both DMRS antenna ports using the example in equation (1) may be described as indicated by equation (5):

$$y_{i,k} = W_{rx,i} H_i W_{tx} P_{1,k} x_k + n_{i,k} \quad (5)$$

[0074] Where:

[0075]  $k$  may be a DMRS port index; and

[0076]  $k \in \{1,2\}$ .

[0077] In this example, a first Rx antenna panel may have a rank two data transmission and may be disposed to performing channel estimation from both DMRS ports, and a second Rx antenna panel may have a rank one data transmission and may merely be disposed to performing channel estimation from either DMRS antenna port. The DMRS antenna port to use for the second Rx antenna panel may either be predefined by specification, or dynamically indicated in DL control signaling.

[0078] Alternatively, a number of DMRS antenna ports may be equal to a total number of antenna ports in each codeword, which can be obtained as indicated by equation (6):

$$N_{Tx}^{UE-RS} = \sum_{j=1}^{N_{cw}} N_{Tx}^j \quad (6)$$

[0079] In addition, the precoder for each codeword may be different. The receiving signal for DMRS in each antenna panel may be as indicated by equation (1).

[0080] In some embodiments, if a number of layers for a second codeword may be smaller than a number of layers for a first codeword. In such embodiments, DMRS antenna ports for the second codeword may either be set as one of the DMRS antenna ports for the first codeword, or may be set as indicated in DL control signaling.

## **A.2. Control signaling for SUST**

[0081] SUST may be considered a new Transmission Mode (TM) in the network. This new TM may be configured by dedicated RRC signaling.

[0082] In some embodiment, codewords and Rx antenna panels may be one-to-one mapped. For example, a codeword  $j$  may be mapped to an Rx antenna panel  $j$ . Alternatively a codeword-to-antenna-panel mapping may be configured by RRC signaling or by DL

assignment. In addition, a number of layers for each codeword may be configured by DL assignment. For each transport block, the control signaling in the Downlink Control Information (DCI) format may be listed as follows:

- [0083] Modulation and Coding Scheme;
- [0084] New Data Indicator;
- [0085] Redundancy Version;
- [0086] Number of Layers;
- [0087] DMRS Antenna Port(s) Indication; and
- [0088] Energy Per Resource Element (EPRE) Ratio between one codeword and DMRS  $P_j$ .

[0089] A number of bits for the Number of Layers may be obtained from  $\lceil \log_2 \min(N_{Tx}^{port}, N_{Rx}^{port}) \rceil$ .

[0090] In some embodiments, the DMRS Antenna Port(s) Indication may be one per DCI instead of one per CW. When the Number of Layers is included for each codeword, the DMRS Antenna Port(s) Indication can be defined for all the codewords. Otherwise, the number of layers may not be needed for each codeword, and may be implicitly indicated in the DMRS Antenna Port(s) Indication. Alternatively, the number of DMRS antenna ports may be equal to the total number of layers for each codeword. In some embodiments, the DMRS Antenna Port(s) Indication might not be used in the DCI.

[0091] For each codeword, the EPRE Ratio between PDSCH and/or xPDSCH and its corresponding DMRS may be 1. In such embodiments, the EPRE Ratio between one codeword and DMRS might not be transmitted in the DCI.

[0092] For the DMRS, in some embodiments, the first  $N_{tx}^1$  antenna ports may be used by codeword 1, and the rest of the antenna ports may be used by codeword 2. For some embodiments, the Rx antenna panel which acts as a cell center UE may be implicitly indicated in a reception panel of the corresponding Physical Downlink Control Channel (PDCCH and/or EPDCCH).

[0093] If a number of Rx antenna panels is greater than a maximum number of codewords, Rx antenna panel selection may be used in some embodiments. A UE may report an RSRP or a Beam Reference Signal (BRS) Receiving Power (BRS-RP) measured from one Tx beam and different Rx antenna panels. An eNB may then configure an index of the Rx antenna panels or Rx antenna ports for PDSCH and/or xPDSCH reception via RRC signaling.

[0094] In another embodiment, the capability of a UE to support SUST may be reported to an eNB during a UE capability enquiry. The SUST transmission mode might be merely applied to UEs with SUST reception capability and more than one Rx antenna panel.

#### **B. Systems and methods for measurement with simultaneous receiving beamforming**

[0095] Systems and methods for measurement with simultaneous receiving beamforming may relate to DL control signaling for measurement with simultaneous Rx beams, and Uplink Control Information (UCI) formats for BRS-RP reporting. In MIMO systems, a number of Tx beams may be utilized on the eNB side. A UE may measure the receiving power of each Tx beam based on a BRS and may report a BRS-RP via UCI.

[0096] Rx beamforming may be used by a UE to enhance a link budget and coverage.

[0097] In MUST, an antenna panel with a higher BRS-RP may perform as a cell center UE, and another antenna panel with lower BRS-RP may perform as a cell edge UE. Reporting all BRS-RPs as measured along each Rx beam may slightly increase the overhead of UCI. However, accounting for different BRS-RPs for different antenna panels and along different Rx beams for each antenna panel may enhance SUST, which may be similar to MUST.

[0098] **Fig. 2** illustrates a Single User Superimposed Transmission (SUST) scenario, in accordance with some embodiments of the disclosure. In scenario 200, an eNB 210 may transmit along any of a plurality of Tx beams 211 in the general direction of a UE 220, such as through MIMO-based beamforming. UE 220 may have multiple directional receiving panels, which may include a primary antenna panel 221 and a secondary antenna panel 222. Primary antenna panel 221 and secondary antenna panel 222 may receive along any of a plurality of Rx. Primary antenna panel 221 may perform similarly to a cell center UE and secondary antenna panel 222 may perform similarly to a cell edge UE.

[0099] With respect to DL control signaling for measurement with simultaneous Rx beams, eNB 210 may transmit a physical downlink shared channel (e.g., PDSCH and/or xPDSCH) in an SUST manner. UE 220 may then decode the PDSCH and/or xPDSCH with an advanced receiver, such as an SIC receiver.

[00100] With respect to UCI formats for BRS-RP reporting, UE 220 may measure a BRS-RP in each Tx beam with a single Rx beam, or with non-simultaneous Rx beams. Up to N BRS-RPs may be reported via UCI (in some embodiments, for example, N may be 8). A BRS-RP reporting structure may include the following information:

[00101] Cell ID, which may indicate the cell for which BRS has been measured;

**[00102]** BRS index, which may be equal to the BRS ID for the measured BRS sequence;

**[00103]** BRS-RP value; and

**[00104]** Subframe index, which may be used to indicate the subframe index for the measured BRS.

### **B.1. Example methods**

**[00105]** As discussed above, a UE may have two antenna panels that support directional Receiving (Rx) beamforming, with different Rx beams being utilized in different antenna panels. Different BRS-RPs may then be observed for each antenna panels. Table 1 below shows an example of BRS-RP results, in which a Tx beam 2 may be selected to be the best Tx beam as the highest BRS-RP is acquired. An Rx beam 2 of antenna panel 1 may be the best Rx beam for antenna panel 1, and an Rx beam 4 of antenna panel 2 may be the best Rx beam for antenna panel 2.

Table 1: one example for BRS-RP results

| BRS-RP [dBm]                  |   | Tx beam |            |     |   |   |
|-------------------------------|---|---------|------------|-----|---|---|
|                               |   | 1       | 2          | 3   | 4 | 5 |
| Rx beam<br>Antenna<br>Panel 1 | 1 |         | -88        |     |   |   |
|                               | 2 | -83     | <b>-71</b> | -82 |   |   |
|                               | 3 |         | -80        |     |   |   |
|                               | 4 |         |            |     |   |   |
|                               | 5 |         |            |     |   |   |
| Rx beam<br>Antenna<br>Panel 2 | 1 |         |            |     |   |   |
|                               | 2 |         |            |     |   |   |
|                               | 3 |         | -90        |     |   |   |
|                               | 4 | -84     | <b>-77</b> | -88 |   |   |
|                               | 5 |         | -89        |     |   |   |

**[00106]** In some embodiments, as simultaneous Rx beams may be used for BRS-RP measurement, a BRS-RP reporting structure may include the following information:

**[00107]** Cell ID, which may indicate the cell for which BRS has been measured;

**[00108]** BRS index, which may be equal to the BRS ID for the measured BRS sequence;

**[00109]** BRS-RP value for a first antenna panel;

**[00110]** BRS-RP value for a second antenna panel; and

**[00111]** Subframe index, which may be used to indicate a subframe index for the measured BRS.

[00112] For some embodiments, such as when a difference between BRS-RP values for the two antenna panels is not too high, it may not necessary to transmit the absolute value of the BRS-RP for the second antenna panel. Instead, a BRS-RP reporting structure may include the following information:

[00113] Cell ID, which may indicate the cell for which BRS has been measured;

[00114] BRS index, which may be equal to the BRS ID for the measured BRS sequence;

[00115] BRS-RP value for a first antenna panel;

[00116] BRS-RP difference between the BRS-RP value for the first antenna panel and a BRS-RP value for a second antenna panel; and

[00117] Subframe index, which may be used to indicate the subframe index for the measured BRS.

[00118] The BRS-RP difference may be calculated as  $\Delta = r_1 - r_2$ , where  $r_j$  may denote the BRS-RP value for antenna panel  $j$  (in dBm). In some embodiments,  $\Delta$  may be a sign-less number, and may represent an absolute value or magnitude of a difference between BRS-RP values for two antenna panels. A BRS-RP difference between antenna panels may be quantized and represented by one or more bits in accordance with a pre-defined table (e.g., a table per specification). An exemplary pre-defined table in which two bits may represent a quantized BRS-RP difference is given in Table 2 below.

Table 2: one example for the BRS-RP difference indication

| BRS-RP difference indicator | $\Delta$ (dB)       |
|-----------------------------|---------------------|
| 0                           | $0 < \Delta < 3$    |
| 1                           | $3 \leq \Delta < 6$ |
| 2                           | $6 \leq \Delta < 9$ |
| 3                           | $\Delta \geq 9$     |

[00119] In another embodiment, a UE may maintain two Rx beams in each antenna panel to support beam switching. One Rx beam may be used for current data and control receiving, and may be designated as a current Rx beam. The other Rx beam may be used for measurement and beam switching, and may be designated as a candidate Rx beam. In such embodiments, a BRS-RP reporting structure may include the following information:

[00120] Cell ID, which may indicate the cell for which BRS has been measured;

[00121] BRS index, which may be equal to the BRS ID for the measured BRS sequence;

- [00122] BRS-RP value for a first antenna panel;
- [00123] Rx beam indicator for a first antenna panel;
- [00124] BRS-RP difference between the BRS-RP value for the first antenna panel and a BRS-RP value for a second antenna panel;
- [00125] Rx beam indicator for the second antenna panel; and
- [00126] Subframe index, which may be used to indicate the subframe index for the measured BRS.
- [00127] The Rx beam indicator for the first antenna panel and the Rx beam indicator for the second antenna panel may be one-bit indicators, where a value of “0” (or a value of “1” in alternate embodiments) may indicate that the BRS-RP for the antenna panel is measured from a current Rx beam, and a value of “1” (or a value of “0” in the alternate embodiments) may indicate that the BRS-RP for the antenna panel is measured from a candidate Rx beam.
- [00128] In some embodiments, BRS-RP reporting structures such as those discussed above may be applied if a UE’s capability for simultaneous Rx beamforming and use of multiple antenna panels is reported.
- [00129] Alternatively, for inter-Transmission Point (TP) switching, a difference between a combined BRS-RP for both antenna panels for a current TP and a combined BRS-RP for both antenna panels for a target TP may be used as an indicator. An eNB may then make use of information regarding combined BRS-RPs.
- [00130] In one UCI including BRS-RP reporting, there may be up to N BRS-RP values, where M BRS-RP values may be reported by a BRS-RP reporting structure such as those discussed above, and the remaining BRS-RPs may be a combined BRS-RP. The value of M may be configured by the system, such as by high layer signaling or Downlink Control Information (DCI).
- [00131] Alternatively, a one-bit indicator for a BRS-RP reporting structure may be added in the DCI, where a value of “0” (or a value of “1” in alternate embodiments) may indicate a prior art BRS-RP reporting structure may be used, and a value of “1” (or a value of “0” in the alternate embodiments) may indicate a BRS-RP reporting structure such as those discussed above may be used. A maximum number of new BRS-RPs in one UCI may be configured by the system or higher layer signaling.

### **C. Systems and methods for channel quality measurement in an SUST transmission mode**

**[00132]** Superimposed transmission is an attractive technology for utilizing a channel quality gap between different receivers to support concurrent transmission in the same spatial direction, and thereby improve effective data ranks in spatially rank-deficient channels. In multi-user transmissions, superimposed transmission may be useful when users cannot be separated in the spatial domain. The number of RF chains called for to support superimposed transmission may also be reduced compared to that of spatial multiplexing for the same number of data layers. For users with better channel link quality, superimposed transmission may reconstruct transmitted data of a poor user, and may perform successive interference cancellation before demodulating its own data. For users with poor channel link quality, even with interference from another user, a ratio of signal to interference and noise (SINR) may still be sufficient for correct demodulation, due to a transmit power adjustment between paired users.

**[00133]** In a high-frequency-band system, a UE may be equipped with multiple antenna panels, so as to obtain better beamforming gain and avoid coverage holes. Boresight directions and/or broadside directions of different panels may be at angles with respect to each other, and may even be at a 180-degree angle with respect to each other if two panels are mounted on opposite sides of a UE. In one realistic scenario, a boresight direction of a first panel may align to an LoS direction to a serving eNB, while a boresight direction of a second panel may point in an opposite direction. As a result, a link gain between the eNB and the first panel may be much stronger than a link gain between the eNB and the second panel. At the same time, the channel may also be in a LoS condition which lacks spatial richness to support high rank spatial multiplexing.

**[00134]** SUST may advantageously realized under these conditions. In SUST, two data symbols may be transmitted with different transmit power, and there may be mutual inference between two superimposed data symbols. A transmit power of the two superimposed data symbols may be carefully scaled according to a link gain difference, so as to provide for correct demodulation at two Rx panels. For example, for two Rx panels, two power scaling factors  $p_1$  and  $p_2$  may be estimated by an eNB according to reported BRS-RP or reported Channel Quality Indicator (CQI) and/or Modulation and Coding Scheme (MCS) measured from the same non-zero power (NZP) Channel State Information (CSI) Reference Signal (CSI-RS).

**[00135]** Discussed below are various ways of measuring channel quality, taking into account mutual interference and receiver processing, and estimating an appropriate CQI

and/or MCS for the superimposed data symbols becomes a problem: (1) CSI measurement using two CSI processes, assuming non-SUST transmission, with an eNB deriving SUST MCS from non-SUST CQI; (2) CSI measurement using two CSI processes, assuming SUST transmission; (3) CSI measurement using two CSI processes, with either SUST or non-SUST transmission for UE deriving CSI; and (4) CSI measurement using a single CSI process and supporting dynamic switching between SUST and non-SUST transmission

**[00136]** Reference Signal Receiving Powers (RSRPs) of multiple directional antenna panels from the same transmit beam may differ greatly, which may provide a basis for single user super imposed transmission (SUST). An example of SUST transmission may be described by equation (7) below:

$$y_i = W_{rx,i} H_i W_{tx} \left( \underbrace{\underbrace{\sqrt{p_1} [P_{1,1}, P_{1,2}] / \sqrt{2}}_{P_1} \underbrace{\begin{bmatrix} x_{1,1} \\ x_{1,2} \end{bmatrix}}_{x_1}}_x + \sqrt{p_2} P_2 x_2 \right) + n_i \quad (7)$$

**[00137]** Where:

**[00138]**  $y_i$  may be a  $2 \times 1$  received signal vector of Rx panel  $i$ ;

**[00139]**  $W_{rx,i}$  may be a  $2 \times N_r$  Rx analog beamforming matrix of Rx panel  $i$ ;

**[00140]**  $H_i$  may be an  $N_r \times N_t$  channel matrix between Rx panel  $i$  and the single Tx panel;

**[00141]**  $W_{tx}$  may be an  $N_t \times 2$  Tx analog beamforming matrix of single Tx panel;

**[00142]**  $p_i$  may be a transmit power scaling factor for the codeword to be received by  $i$ , and may satisfy  $p_1 + p_2 = 1$ ;

**[00143]**  $[P_{1,1}, P_{1,2}] / \sqrt{2}$  may be a  $2 \times 2$  precoder for the first codeword and may be reduced to  $P_{1,1}$  if CW1 has rank one transmission;

**[00144]**  $P_2$  may be a  $2 \times 1$  precoder for the second codeword and may be simply set to the same as  $P_{1,1}$  or  $P_{1,2}$ ;

**[00145]**  $x_i$  may be one or more data symbols of one or more codewords intended for Rx panel  $i$ ;

**[00146]**  $x$  may be a superimposed data symbol of both Rx panels;

**[00147]**  $n_i$  may be a  $2 \times 1$  noise vector;

[00148]  $N_r$  may be a number of receive antennas; and

[00149]  $N_t$  may be a number of transmit antennas.

[00150] In accordance with equation (7), a transmit power of two codewords may be calculated according to a link quality gap of different Rx panels, so as to provide that the mutual interference from each other is acceptable and may not affect a final correct demodulation. Since the transmit power may be adjusted and the mutual interference may be introduced, channel quality measurement and MCS calculation may be greatly impacted. Discussed below are various ways to accurately measure CSI in an SUST environment, and to determine MCS of different superimposed data symbols, where:

[00151]  $x_1$  may be an outer data symbol, which may be transmitted using less than half of the total power in the superimposed data symbol; and

[00152]  $x_2$  may be an inner data symbol, which may be transmitted using more than half of the total power in the superimposed data symbol.

### **C.1. CSI measurement using two CSI processes assuming non-SUST transmission and eNB deriving SUST MCS from non-SUST CQI**

[00153] In some embodiments, an eNB may configure two CSI processes having the same list of NZP CSI-RS and Interference Measurement Resources (IMRs), and the eNB may configure a UE to report the same CSI-RS resource indicator (CRI) for both processes.

[00154] An eNB may, in some embodiments, configure two CSI processes to have the same list of NZP CSI-RS and IMRs, and the eNB may mandate the same CRI or different CRI for both CSI processes in the DCI using, for example, a one-bit CRI search indicator. A bit value of "0" (or "1" in alternate embodiments) may indicate that a UE should report the same CRI for both CSI processes, and a bit value of "1" (or "0" in the alternate embodiments) may indicate that the UE should report different CRI for both CSI processes.

[00155] **Fig. 3** illustrates a flow chart 300 for deriving an SUST Modulation and Coding Scheme (MCS) from a non-SUST Channel Quality Indicator (CQI), in accordance with some embodiments of the disclosure. An eNB 310 may configure a UE 320 for CSI-RS transmission. The CSI-RS, which may be two ports per NZP resource, may be transmitted with unit power. UE 320 may derive CSI assuming rank one or two PDSCH and/or xPDSCH transmission per CSI process. eNB 310 may then derive the SUST MCS from the reported CSIs of two simultaneous Rx beams by properly scaling the signal and interference from the reported non-SUST CQI for data transmission.

[00156] In some embodiments, a one-bit CRI search indicator may be encoded with other existing fields in the DCI. Assuming a beam search algorithm field in the DCI, one value point of the BSA field may be interpreted to request CSI from two CSI processes for the same CRI.

## **C.2. CSI measurement using two CSI processes assuming SUST transmission**

[00157] **Fig. 4** illustrates a flow chart 400 for deriving Channel State Information (CSI) assuming SUST transmission, in accordance with some embodiments of the disclosure. An eNB 410 may configure a UE 420 for CSI-RS transmission. UE 420 may derive CSI measurements assuming SUST transmission of PDSCH and/or xPDSCH. CSI corresponding to an inner data symbol may be measured by taking both the power  $P_1$  of the inner data symbol and the power  $P_2$  of an outer data symbol into consideration. Similarly, CSI corresponding to the outer data symbol may be measured by taking both the power  $P_1$  of the inner data symbol and the power  $P_2$  of an outer data symbol into consideration. Detailed algorithms may be up to implementation by UE 420, as they may relate to how the interference cancelation receiver is designed. CSI for both the inner data symbol and outer data symbol may then be fed back to eNB 410 assuming SUST transmission.

[00158] In some embodiments, an eNB may configure two CSI processes having the same list of NZP CSI-RS and IMRs, where a hypothetical Tx power scaling  $P_c$  may be configured for each CSI process. The eNB may configure the first CSI process assuming the PDSCH and/or xPDSCH transmission is for an inner data symbol with a higher  $P_c$ , and may configure the second CSI process assuming the PDSCH and/or xPDSCH transmission is for an outer data symbol with a lower  $P_c$ .

[00159] A one-bit indicator may be added into a CSI-Process Information Element (IE), in some embodiments, to explicitly inform a UE whether a CSI process is for an inner data symbol or an outer data symbol. In another embodiment, an eNB may configure two CSI processes, and may additionally configure power scaling factors for inner data symbols and outer data symbols in an implicit or explicit way for both CSI processes.

[00160] In some embodiments, an inner-data-symbol-specific grouping and/or an outer-data-symbol-specific antenna port grouping for SUST may be configured by higher layer signaling. The transmit power of the inner data symbol and outer data symbol may then be implicitly indicated by scaling different powers on different CSI-RSs APs according to the inner data symbol or outer data symbol in the SUST transmission.

**[00161]** **Fig. 5** illustrates Channel State Information (CSI) Reference Signal (CSI-RS) symbols for channel measurement of inner data symbols and outer data symbols, in accordance with some embodiments of the disclosure. A plurality of CSI-RS symbols 510 may include a set of first CSI-RS symbols 511 and a set of second CSI-RS symbols 512. First CSI-RS symbols 511 may be for inner data symbols of an SUST transmission, and second CSI-RS symbols 512 may be for outer data symbols of an SUST transmission. Various Antenna Ports (APs) 520 may be mapped to first CSI-RS symbols 511 and second CSI-RS symbols 512.

**[00162]** In some embodiments, one NZP CSI-RS may contain APs 15, 16, 23, and 24. APs 15 and 16 in a first CSI-RS symbol may be for channel measurement of an inner data symbol, while APs 23 and 24 in a second CSI-RS symbol may be for channel measurement of an outer data symbol. While deriving CSI for an inner data symbol, a UE may also measure an outer data symbol to derive inter-symbol interference. Similarly, while deriving CSI for an outer data symbol, a UE may also measure an inner data symbol to derive inter-symbol interference. The detailed CSI deriving algorithm may be up to UE implementation.

**[00163]** Various embodiments may have two NZP CSI-RSs, with two ports per NZP CSI-RS, and may be configured in one CSI-RS process with one for the inner data symbol and one for the outer data symbol.

**[00164]** In some embodiments, APs for an outer data symbol and an inner data symbol may be frequency division multiplexed in the same CSI-RS symbol. For example, APs 15 and 16 may be for inner data symbols, and APs 17 and 18 may be for outer data symbols.

**[00165]** In some embodiments, whether a power scaling may be applied to each NZP CSI-RS, for inner data symbols or outer data symbols, may be indicated in the DCI. One SUST CSI-RS power scaling indicator may be included in the DCI. When this bit is set to a value of “0” (or “1” in alternate embodiments), the SUST power scaling may be disabled and all NZP CSI-RS may be treated equally by each CSI process. A UE may then derive CSI assuming non-SUST transmission. When this bit is set to a value of “1” (or “0” in alternate embodiments), SUST power scaling may be applied to each NZP CSI-RS, and the UE may derive CSI assuming SUST transmission. This may advantageously facilitate dynamic PDSCH and/or xPDSCH hypothesis switching without high layer reconfiguration.

**[00166]** Various embodiments may employ different power scaling factors that may be applied to Code Division Multiplexing (CDM) based CSI-RS ports. For example, two orthogonal sequences  $\mathbf{s}_1$  and  $\mathbf{s}_2$  may be multiplied by power scaling factors  $\sqrt{P_1}$  and  $\sqrt{P_2}$ .

The combined signal  $\sqrt{P_1}s_1 + \sqrt{P_2}s_2$  may then be mapped to two resource elements for two CSI-RS ports. The sequence information may be configured by eNB through high layer signaling.

**[00167]** In some embodiments, instead of directly scaling transmit power of NZP CSI-RS resources and marking each NZP CSI-RS either for an inner data symbol or an outer data symbol, a transmit power of each NZP CSI-RS might not be scaled, and power scaling factors to derive the CQI of the inner data symbol and outer data symbol may be hypothetical and may be configured by high layer signaling. An eNB may configure power scaling of inner data symbols and outer data symbols for both CSI processes as one pair of values  $P_1$  and  $P_2$ . Alternatively, the eNB may merely configure power scaling of inner data symbols or outer data symbols using a single value  $P_1$  or  $P_2$ , and the other value ( $P_2$  or  $P_1$ ) may be inferred.

**[00168]** In some embodiments, an eNB may configure multiple pairs of hypothetical power scaling values for a UE to choose from in deriving SUST CQI. In some embodiments, an eNB may use an additional field in the DCI to choose from among various higher-layer-configured power scaling values. In various embodiments, a UE may select one power scaling factor out of multiple candidate power scaling factors, and may report it back to an eNB in SUST CSI using a new UCI type: an SUST power control indicator (SPCI).

### **C.3. CSI measurement using two CSI processes and with either SUST or non-SUST transmission for UE deriving CSI**

**[00169]** In some embodiments, an eNB may configure a UE with two CSI processes with the same list of NZP CSI-RS resources and IMRs. The UE may report CRI and/or Rank Indicator (RI) and/or Pre-coding Matrix Indicator (PMI) and/or CQI for each CSI processes. The UE may recommend SUST or non-SUST transmission by recommending the same CRI from both CSI processes.

**[00170]** When the UE recommends SUST transmission, it may recommend the same CRI from both CSI processes. The UE may derive CSI assuming SUST transmission according to what is defined in CSI process 1 or CSI process 2.

**[00171]** In some cases, the UE may recommend non-SUST transmission, by recommending different CRI from both CSI processes. If those CRI correspond to spatially-uncorrelated Tx beams, the UE may recommend dual-beam operation or beam aggregation. Otherwise, the UE may recommend beam interpolation among two spatially correlated Tx beams.

#### **C.4. CSI measurement using single CSI process and supporting dynamic switching between SUST and non-SUST transmission**

[00172] In some embodiments, an eNB may configure one CSI process and may add a one-bit indicator in the downlink DCI to mandate that a UE report one CQI for single beam transmission assuming non-SUST transmission, or two CQIs assuming SUST transmission. The configured CSI-process, in some embodiments, may contain CSI reports measured from multiple simultaneous Rx beams, e.g., two Rx beams.

[00173] In some embodiments, the CSI report may be for one Tx beam, and two Rx beams may contain the following information:

[00174] The selected NZP CSI-RS resource index CRI corresponding to the single Tx beam;

[00175] The RI and/or PMI and/or CQI on the first Rx beam;

[00176] The RI and/or PMI and/or CQI on the second Rx beam; and

[00177] If multiple SUST power scaling factors are configured by the eNB, the index of SUST power scaling factor, SUST power control indicator (SPCI), may be reported.

[00178] In some embodiments, the CSI report may be for two Tx beams, and two Rx beams may contain the following information:

[00179] The selected NZP CSI-RS resource index CRI corresponding to the first Tx beam;

[00180] The RI and/or PMI and/or CQI of the first Tx beam;

[00181] The selected NZP CSI-RS resource index CRI corresponding to the second Tx beam;

[00182] The RI and/or PMI and/or CQI of the second Tx beam; and

[00183] The CQI of the second Tx beam may be encoded by its absolute value or by the difference with the CQI of the first Tx beam.

#### **D. Example wireless cellular communications system devices**

[00184] **Fig. 6** illustrates an embodiment of an eNB and an embodiment of a UE, in accordance with some embodiments of the disclosure. **Fig. 6** includes block diagrams of an eNB 610 and a UE 630 which are operable to co-exist with each other and other elements of an LTE network. High-level, simplified architectures of eNB 610 and UE 630 are described so as not to obscure the embodiments. It should be noted that in some embodiments, eNB 610 may be a stationary non-mobile device.

**[00185]** eNB 610 is coupled to one or more antennas 605, and UE 630 is similarly coupled to one or more antennas 625. However, in some embodiments, eNB 610 may incorporate or comprise antennas 605, and UE 630 in various embodiments may incorporate or comprise antennas 625.

**[00186]** In some embodiments, antennas 605 and/or antennas 625 may comprise one or more directional or omni-directional antennas, including monopole antennas, dipole antennas, loop antennas, patch antennas, microstrip antennas, coplanar wave antennas, or other types of antennas suitable for transmission of RF signals. In some MIMO (multiple-input and multiple output) embodiments, antennas 605 are separated to take advantage of spatial diversity.

**[00187]** eNB 610 and UE 630 are operable to communicate with each other on a network, such as a wireless network. eNB 610 and UE 630 may be in communication with each other over a wireless communication channel 650, which has both a downlink path from eNB 610 to UE 630 and an uplink path from UE 630 to eNB 610.

**[00188]** As illustrated in **Fig. 6**, in some embodiments, eNB 610 may include a physical layer circuitry 612, a MAC (media access control) circuitry 614, a processor 616, a memory 618, and a hardware processing circuitry 620. A person skilled in the art will appreciate that other components not shown may be used in addition to the components shown to form a complete eNB.

**[00189]** In some embodiments, physical layer circuitry 612 includes a transceiver 613 for providing signals to and from UE 630. Transceiver 613 provides signals to and from UEs or other devices using one or more antennas 605. In some embodiments, MAC circuitry 614 controls access to the wireless medium. Memory 618 may be, or may include, a storage media/medium such as a magnetic storage media (e.g., magnetic tapes or magnetic disks), an optical storage media (e.g., optical discs), an electronic storage media (e.g., conventional hard disk drives, solid-state disk drives, or flash-memory-based storage media), or any tangible storage media or non-transitory storage media. Hardware processing circuitry 620 may comprise logic devices or circuitry to perform various operations. In some embodiments, processor 616 and memory 618 are arranged to perform the operations of hardware processing circuitry 620, such as operations described herein with reference to logic devices and circuitry within eNB 610 and/or hardware processing circuitry 620.

**[00190]** As is also illustrated in **Fig. 6**, in some embodiments, UE 630 may include a physical layer circuitry 632, a MAC circuitry 634, a processor 636, a memory 638, a

hardware processing circuitry 640, a wireless interface 642, and a display 644. A person skilled in the art would appreciate that other components not shown may be used in addition to the components shown to form a complete UE.

**[00191]** In some embodiments, physical layer circuitry 632 includes a transceiver 633 for providing signals to and from eNB 610 (as well as other eNBs). Transceiver 633 provides signals to and from eNBs or other devices using one or more antennas 625. In some embodiments, MAC circuitry 634 controls access to the wireless medium. Memory 638 may be, or may include, a storage media/medium such as a magnetic storage media (e.g., magnetic tapes or magnetic disks), an optical storage media (e.g., optical discs), an electronic storage media (e.g., conventional hard disk drives, solid-state disk drives, or flash-memory-based storage media), or any tangible storage media or non-transitory storage media. Wireless interface 642 may be arranged to allow the processor to communicate with another device. Display 644 may provide a visual and/or tactile display for a user to interact with UE 630, such as a touch-screen display. Hardware processing circuitry 640 may comprise logic devices or circuitry to perform various operations. In some embodiments, processor 636 and memory 638 may be arranged to perform the operations of hardware processing circuitry 640, such as operations described herein with reference to logic devices and circuitry within UE 630 and/or hardware processing circuitry 640.

**[00192]** Elements of **Fig. 6**, and elements of other figures having the same names or reference numbers, can operate or function in the manner described herein with respect to any such figures (although the operation and function of such elements is not limited to such descriptions). For example, **Figs. 7-8, 11-12, and 15-16** also depict embodiments of eNBs, hardware processing circuitry of eNBs, UEs, and/or hardware processing circuitry of UEs, and the embodiments described with respect to **Fig. 6** and **Figs. 7-8, 11-12, and 15-16** can operate or function in the manner described herein with respect to any of the figures.

**[00193]** In addition, although eNB 610 and UE 630 are each described as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements and/or other hardware elements. In some embodiments of this disclosure, the functional elements can refer to one or more processes operating on one or more processing elements. Examples of software and/or hardware configured elements include Digital Signal Processors (DSPs), one or more microprocessors, DSPs, Field-Programmable Gate Arrays (FPGAs), Application Specific Integrated Circuits (ASICs), Radio-Frequency Integrated Circuits (RFICs), and so on.

**[00194]** Various methods that may relate to eNB 610, hardware processing circuitry 620, UE 630, and hardware processing circuitry 640 are discussed below. Although the actions in the flowchart with reference to **Figs. 9-10, 13-14, and 17-18** are shown in a particular order, the order of the actions can be modified. Thus, the illustrated embodiments can be performed in a different order, and some actions may be performed in parallel. Some of the actions and/or operations listed in **Figs. 9-10, 13-14, and 17-18** are optional in accordance with certain embodiments. The numbering of the actions presented is for the sake of clarity and is not intended to prescribe an order of operations in which the various actions must occur. Additionally, operations from the various flows may be utilized in a variety of combinations.

**[00195]** Moreover, in some embodiments, machine readable storage media may have executable instructions that, when executed, cause eNB 610 and/or hardware processing circuitry 620 to perform an operation comprising any of methods 900, 1300, and/or 1700. Similarly, in some embodiments, machine readable storage media may have executable instructions that, when executed, cause UE 610 and/or hardware processing circuitry 640 to perform an operation comprising any of method 1000, 1400, and/or 1800. Such machine readable storage media may include any of a variety of storage media, like magnetic storage media (e.g., magnetic tapes or magnetic disks), optical storage media (e.g., optical discs), electronic storage media (e.g., conventional hard disk drives, solid-state disk drives, or flash-memory-based storage media), or any other tangible storage media or non-transitory storage media.

#### **E. Example hardware processing circuitries and methods – SUST coding**

**[00196]** **Fig. 7** illustrates hardware processing circuitry for an eNB for enabling an SUST Transmission Mode (TM), in accordance with some embodiments of the disclosure. A hardware processing circuitry 700 may comprise logic devices and/or circuitry operable to perform various operations. For example, with reference to **Figs. 6 and 7**, eNB 610 (or various elements or components therein, such as hardware processing circuitry 620, or combinations of elements or components therein) may include part of, or all of, hardware processing circuitry 700. In some embodiments, processor 616 and memory 618 (and/or other elements or components of eNB 610) may be arranged to perform the operations of hardware processing circuitry 700, such as operations described herein with reference to devices and circuitry within hardware processing circuitry 700. For example, one or more

devices or circuits of hardware processing circuitry 700 may be implemented by combinations of software-configured elements and/or other hardware elements.

**[00197]** In some embodiments, hardware processing circuitry 700 may comprise one or more antenna ports 705 operable to provide various transmissions over a wireless communication channel (such as wireless communication channel 650). Antenna ports 705 may be coupled to one or more antennas 707 (which may be antennas 605). In some embodiments, hardware processing circuitry 700 may incorporate antennas 707, while in other embodiments, hardware processing circuitry 700 may merely be coupled to antennas 707.

**[00198]** Antenna ports 705 and antennas 707 may be operable to provide signals from an eNB to a wireless communications channel and/or a UE, and may be operable to provide signals from a UE and/or a wireless communications channel to an eNB. For example, antenna ports 705 and antennas 707 may be operable to provide transmissions from eNB 610 to wireless communication channel 650 (and from there to UE 630, or to another UE). Similarly, antennas 707 and antenna ports 705 may be operable to provide transmissions from a wireless communication channel 650 (and beyond that, from UE 630, or another UE) to eNB 610.

**[00199]** An apparatus of eNB 610 (or another eNB or base station) may be operable to communicate with a UE on a wireless network, and may comprise hardware processing circuitry 700. In some embodiments, the eNB (or other base station) may be a device comprising an application processor, a memory, one or more antenna ports, and an interface for allowing the application processor to communicate with another device.

**[00200]** With reference to **Fig. 7**, hardware processing circuitry 700 may comprise a first circuitry 710, a second circuitry 720, a third circuitry 730, and a fourth circuitry 740. First circuitry 710 may be configurable to enable an SUST TM. First circuitry 710 may provide an SUST TM indicator 715 to second circuitry 720, third circuitry 730, and/or fourth circuitry 740. First circuitry 710 may be configurable by RRC signaling to enable the SUST TM.

**[00201]** Second circuitry 720 may be operable to provide a plurality of codewords 725 for a DL shared channel transmission to a multiple-directional UE antenna-panel structure. Example DL shared channel transmissions may include a PDSCH transmission or an xPDSCH transmission. The shared channel transmission may include a first codeword for a first UE antenna panel of the multiple-directional UE antenna-panel structure and a second

codeword for a second UE antenna panel of the multiple-directional UE antenna-panel structure. A total power of the plurality of codewords may be 1.

**[00202]** Third circuitry 730 may be operable to provide a number of layers 735 assigned to at least two codewords of the plurality of codewords 725 for a DL assignment transmission. Third circuitry 730 may also be operable to provide an assignment of UE-RS antenna ports for at least two codewords of the plurality of codewords 725. In some embodiments, third circuitry 730 may be operable to provide a power allocation for at least two codewords of plurality of codewords 725 for a DL assignment transmission.

**[00203]** Fourth circuitry 740 may in turn be operable to transmit a DL assignment transmission, such as by transmitting the DL assignment transmission through antenna ports 705 and from there on to antennas 707.

**[00204]** In some embodiments, first circuitry 710, second circuitry 720, third circuitry 730, and fourth circuitry 740 may be implemented as separate circuitries. In other embodiments, one or more of first circuitry 710, second circuitry 720, third circuitry 730, and fourth circuitry 740 may be combined and implemented together in a circuitry without altering the essence of the embodiments. In various embodiments, processor 616 (and/or one or more other processors which eNB 610 may comprise) may be arranged to perform the operations of first circuitry 710, second circuitry 720, third circuitry 730, and/or fourth circuitry 740. In such embodiments, first circuitry 710, second circuitry 720, third circuitry 730, and/or fourth circuitry 740 may accordingly be implemented by various combinations of software-configured elements (e.g., processor 616, and/or one or more other processors) and/or other hardware elements. In various embodiments, processor 616 (and/or one or more other processors which eNB 610 may comprise) may be a baseband processor.

**[00205]** **Fig. 8** illustrates hardware processing circuitry for a UE for enabling an SUST Transmission Mode (TM), in accordance with some embodiments of the disclosure. A hardware processing circuitry 800 may comprise logic devices and/or circuitry operable to perform various operations. For example, with reference to **Figs. 6 and 8**, UE 630 (or various elements or components therein, such as hardware processing circuitry 640, or combinations of elements or components therein) may include part of, or all of, hardware processing circuitry 800. In some embodiments, processor 636 and memory 638 (and/or other elements or components of UE 630) may be arranged to perform various operations of hardware processing circuitry 800, such as operations described herein with reference to devices and circuitry within hardware processing circuitry 800. For example, one or more

devices or circuits of hardware processing circuitry 800 may be implemented by combinations of software-configured elements and/or other hardware elements.

**[00206]** In some embodiments, hardware processing circuitry 800 may comprise one or more antenna ports 805 operable to provide various transmissions over a wireless communication channel (such as wireless communication channel 650). Antenna ports 805 may be coupled to one or more antennas 807 (which may be antennas 605). In some embodiments, hardware processing circuitry 800 may incorporate antennas 807, while in other embodiments, hardware processing circuitry 800 may merely be coupled to antennas 807.

**[00207]** Antenna ports 805 and antennas 807 may be operable to provide signals from a UE to a wireless communications channel and/or an eNB, and may be operable to provide signals from an eNB and/or a wireless communications channel to a UE. For example, antenna ports 805 and antennas 807 may be operable to provide transmissions from UE 630 to wireless communication channel 650 (and from there to eNB 610, or to another eNB). Similarly, antennas 807 and antenna ports 805 may be operable to provide transmissions from a wireless communication channel 650 (and beyond that, from eNB 610, or another eNB) to UE 630.

**[00208]** An apparatus of UE 630 (or another UE or mobile handset) may be operable to communicate with an eNB on a wireless network, and may comprise hardware processing circuitry 800. In some embodiments, the UE (or other mobile handset) may be a device comprising an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate with another device, and a touch-screen display.

**[00209]** With reference to **Fig. 8**, hardware processing circuitry 800 may comprise a first circuitry 810, a second circuitry 820, a third circuitry 830, and a fourth circuitry 840. First circuitry 810 may be configurable to enable an SUST TM, such as by providing SUST TM indicator 815 to second circuitry 820, third circuitry 830, and/or fourth circuitry 840. First circuitry 810 may be configurable by RRC signaling to enable the SUST TM.

**[00210]** Second circuitry 820 may be operable to receive a plurality of codewords of a DL shared channel transmission, which may be received through antenna ports 805 and antennas 807. The DL shared channel transmission may include a first codeword for a first antenna panel of a multiple-directional antenna-panel structure and a second codeword for a

second antenna panel of the multiple-directional antenna-panel structure. A total power of the plurality of codewords may be 1.

**[00211]** Third circuitry 830 may be operable to receive a DL assignment transmission 825. Third circuitry 830 may also be operable to assign an RS antenna port for at least two codewords of the plurality of codewords.

**[00212]** Fourth circuitry 840 may be operable to parse a number of layers assigned to at least two codewords of the plurality of codewords from DL assignment transmission 825. In some embodiments, fourth circuitry 840 may be operable to parse a power allocation for at least two codewords of plurality of codewords from DL assignment transmission 825.

**[00213]** In some embodiments, first circuitry 810, second circuitry 820, third circuitry 830, and fourth circuitry 840 may be implemented as separate circuitries. In other embodiments, one or more of first circuitry 810, second circuitry 820, third circuitry 830, and fourth circuitry 840 may be combined and implemented together in a circuitry without altering the essence of the embodiments. In various embodiments, processor 636 (and/or one or more other processors which UE 630 may comprise) may be arranged to perform the operations of first circuitry 810, second circuitry 820, third circuitry 830, and/or fourth circuitry 840. In such embodiments, first circuitry 810, second circuitry 820, third circuitry 830, and/or fourth circuitry 840 may accordingly be implemented by various combinations of software-configured elements (e.g., processor 636, and/or one or more other processors) and/or other hardware elements. In various embodiments, processor 636 (and/or one or more other processors which UE 630 may comprise) may be a baseband processor.

**[00214]** **Fig. 9** illustrates methods for an eNB for enabling an SUST TM, in accordance with some embodiments of the disclosure. A method 900 includes an enabling 910 and a providing 920. In enabling 910, an SUST TM may be enabled for an eNB. In providing 920, a plurality of codewords may be provided for a downlink shared channel transmission to a multiple-directional UE antenna-panel structure. The downlink shared channel transmission may be a PDSCH transmission or an xPDSCH transmission, for example. The plurality of codewords may include a first codeword for a first UE antenna panel of the multiple-directional UE antenna-panel structure and a second codeword for a second UE antenna panel of the multiple-directional UE antenna-panel structure.

**[00215]** In some embodiments, method 900 may include an enabling 930. In enabling 930, the SUST TM may be enabled by RRC signaling.

**[00216]** Various embodiments of method 900 may comprise a providing 940 and a transmitting 950. In providing 940, a number of layers assigned to at least codewords of the plurality of codewords may be provided for a DL assignment transmission. In transmitting 950, the DL assignment transmission may be transmitted, such as through antenna ports and/or antennas coupled to the eNB.

**[00217]** Some embodiments of method 900 may comprise a providing 960. In providing 960, an assignment of UE-RS antenna ports may be provided for at least two codewords of the plurality of codewords. In some embodiments, a total power of the plurality of codewords may be 1.

**[00218]** **Fig. 10** illustrates methods for a UE for enabling an SUST TM, in accordance with some embodiments of the disclosure. Method 1000 may comprise an enabling 1010 and a receiving 1020. In enabling 1010, an SUST TM may be enabled for a UE. In receiving 1020, a plurality of codewords of a downlink shared channel transmission may be received. The downlink shared channel transmission may be a PDSCH transmission or an xPDSCH transmission, for example. The downlink shared channel transmission may include a first codeword for a first antenna panel of a multiple-directional antenna-panel structure, and may include a second codeword for a second antenna panel of the multiple-directional antenna-panel structure.

**[00219]** Some embodiments of method 1000 may include a receiving 1030 and a parsing 1040. In receiving 1030, a DL assignment transmission may be received. In parsing 1040, a number of layers assigned to at least two codewords of the plurality of codewords may be parsed from the DL assignment transmission.

**[00220]** In various embodiments, method 1000 may include an assigning 1050. In assigning 1050, an RS antenna port may be assigned for at least two codewords of the plurality of codewords. In some embodiments of method 1000, a total power of the plurality of codewords may be 1.

**[00221]** Some embodiments may comprise a receiving 1060 and a parsing 1070. In receiving 1060, a DL assignment transmission may be received. In parsing 1070, a power allocation for at least two codewords of the plurality of codewords may be parsed from the DL assignment transmission.

## **F. Example hardware processing circuitries and methods – measurement with simultaneous receiving beamforming**

**[00222]**        **Fig. 11** illustrates hardware processing circuitry for an eNB for determining a highest Beam Reference Signal (BRS) Receiving Power (BRS-RP) for a UE antenna panel, in accordance with some embodiments of the disclosure. A hardware processing circuitry 1100 may comprise logic devices and/or circuitry operable to perform various operations. For example, with reference to **Figs. 6 and 11**, eNB 610 (or various elements or components therein, such as hardware processing circuitry 620, or combinations of elements or components therein) may include part of, or all of, hardware processing circuitry 1100. In some embodiments, processor 616 and memory 618 (and/or other elements or components of eNB 610) may be arranged to perform the operations of hardware processing circuitry 1100, such as operations described herein with reference to devices and circuitry within hardware processing circuitry 1100. For example, one or more devices or circuits of hardware processing circuitry 1100 may be implemented by combinations of software-configured elements and/or other hardware elements.

**[00223]**        In some embodiments, hardware processing circuitry 1100 may comprise one or more antenna ports 1105 operable to provide various transmissions over a wireless communication channel (such as wireless communication channel 650). Antenna ports 1105 may be coupled to one or more antennas 1107 (which may be antennas 605). In some embodiments, hardware processing circuitry 1100 may incorporate antennas 1107, while in other embodiments, hardware processing circuitry 1100 may merely be coupled to antennas 1107.

**[00224]**        Antenna ports 1105 and antennas 1107 may be operable to provide signals from an eNB to a wireless communications channel and/or a UE, and may be operable to provide signals from a UE and/or a wireless communications channel to an eNB. For example, antenna ports 1105 and antennas 1107 may be operable to provide transmissions from eNB 610 to wireless communication channel 650 (and from there to UE 630, or to another UE). Similarly, antennas 1107 and antenna ports 1105 may be operable to provide transmissions from a wireless communication channel 650 (and beyond that, from UE 630, or another UE) to eNB 610.

**[00225]**        An apparatus of eNB 610 (or another eNB or base station) may be operable to communicate with a UE on a wireless network, and may comprise hardware processing circuitry 1100. In some embodiments, the eNB (or other base station) may be a device comprising an application processor, a memory, one or more antenna ports, and an interface for allowing the application processor to communicate with another device.

**[00226]** With reference to **Fig. 11**, hardware processing circuitry 1100 may comprise a first circuitry 1110, a second circuitry 1120, and a third circuitry 1130. First circuitry 1110 may be operable to provide a BRS transmission to an antenna for transmission to a UE.

Second circuitry 1120 may be operable to receive a BRS-RP reporting transmission 1135.

**[00227]** Third circuitry 1130 may be operable to parse a highest BRS-RP value for a first UE antenna panel from received BRS-RP reporting transmission 1135. In some embodiments, BRS-RP reporting transmission 1135 may include one or more of a Cell ID, a BRS ID for the BRS transmission, and a subframe index for the BRS transmission. In such embodiments, third circuitry 1130 may be operable to parse from BRS-RP reporting transmission 1135 one or more of the Cell ID, the BRS ID for the BRS transmission, and the subframe index for the BRS transmission.

**[00228]** In some embodiments, BRS-RP reporting transmission 1135 may include a highest BRS-RP value for a second UE antenna panel. In such embodiments, third circuitry 1130 may be operable to parse the highest BRS-RP value for the second UE antenna panel from BRS-RP reporting transmission 1135.

**[00229]** In various embodiments, BRS-RP reporting transmission 1135 may include a BRS-RP difference indicator based upon a difference between the highest BRS-RP value for the first UE antenna panel and a highest BRS-RP value for a second UE antenna panel. In such embodiments, third circuitry 1130 may be operable to parse the BRS-RP difference indicator from BRS-RP reporting transmission 1135. In such embodiments, BRS-RP reporting transmission 1135 may include a first Rx beam indicator identifying a first UE antenna corresponding to the highest BRS-RP value for the first UE antenna panel, and may include a second Rx beam indicator identifying a second UE antenna corresponding to the highest BRS-RP value for the second antenna panel. For such embodiments, third circuitry 1130 may be operable to parse the first Rx beam indicator and the second Rx beam indicator from BRS-RP reporting transmission 1135.

**[00230]** For various embodiments, BRS-RP reporting transmission 1135 may be a UCI transmission.

**[00231]** In some embodiments, first circuitry 1110, second circuitry 1120, and third circuitry 1130 may be implemented as separate circuitries. In other embodiments, one or more of first circuitry 1110, second circuitry 1120, and third circuitry 1130 may be combined and implemented together in a circuitry without altering the essence of the embodiments. In various embodiments, processor 616 (and/or one or more other processors which eNB 610

may comprise) may be arranged to perform the operations of first circuitry 1110, second circuitry 1120, and/or third circuitry 1130. In such embodiments, first circuitry 1110, second circuitry 1120, and/or third circuitry 1130 may accordingly be implemented by various combinations of software-configured elements (e.g., processor 616, and/or one or more other processors) and/or other hardware elements. In various embodiments, processor 616 (and/or one or more other processors which eNB 610 may comprise) may be a baseband processor.

**[00232]** **Fig. 12** illustrates hardware processing circuitry for a UE for determining a highest BRS-RP for a UE antenna panel, in accordance with some embodiments of the disclosure. A hardware processing circuitry 1200 may comprise logic devices and/or circuitry operable to perform various operations. For example, with reference to **Figs. 6 and 12**, UE 630 (or various elements or components therein, such as hardware processing circuitry 640, or combinations of elements or components therein) may include part of, or all of, hardware processing circuitry 1200. In some embodiments, processor 636 and memory 638 (and/or other elements or components of UE 630) may be arranged to perform various operations of hardware processing circuitry 1200, such as operations described herein with reference to devices and circuitry within hardware processing circuitry 1200. For example, one or more devices or circuits of hardware processing circuitry 1200 may be implemented by combinations of software-configured elements and/or other hardware elements.

**[00233]** In some embodiments, hardware processing circuitry 1200 may comprise one or more antenna ports 1205 operable to provide various transmissions over a wireless communication channel (such as wireless communication channel 650). Antenna ports 1205 may be coupled to one or more antennas 1207 (which may be antennas 605). In some embodiments, hardware processing circuitry 1200 may incorporate antennas 1207, while in other embodiments, hardware processing circuitry 1200 may merely be coupled to antennas 1207.

**[00234]** Antenna ports 1205 and antennas 1207 may be operable to provide signals from a UE to a wireless communications channel and/or an eNB, and may be operable to provide signals from an eNB and/or a wireless communications channel to a UE. For example, antenna ports 1205 and antennas 1207 may be operable to provide transmissions from UE 630 to wireless communication channel 650 (and from there to eNB 610, or to another eNB). Similarly, antennas 1207 and antenna ports 1205 may be operable to provide transmissions from a wireless communication channel 650 (and beyond that, from eNB 610, or another eNB) to UE 630.

**[00235]** An apparatus of UE 630 (or another UE or mobile handset) may be operable to communicate with an eNB on a wireless network, and may comprise hardware processing circuitry 1200. In some embodiments, the UE (or other mobile handset) may be a device comprising an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate with another device, and a touch-screen display.

**[00236]** With reference to **Fig. 12**, hardware processing circuitry 1200 may comprise a first circuitry 1210, a second circuitry 1220, and a third circuitry 1230. First circuitry 1210 may be operable to receive a plurality of first BRSSes, based on a BRS transmission as received through a plurality of first antennas of a first antenna panel, and may be operable to receive a plurality of second BRSSes, based on the BRS transmission as received through a plurality of second antennas of a second antenna panel.

**[00237]** First circuitry 1210 may be operable to provide various BRSSes 1215 (which may include one or more first BRSSes and/or one or more second BRSSes) to second circuitry 1220 and/or third circuitry 1230. Second circuitry 1220 may be operable to measure a BRS-RP value for at least one of the first BRSSes, and may be operable to measure a BRS-RP value for at least one of the second BRSSes.

**[00238]** Third circuitry 1230 may be operable to provide a BRS-RP reporting transmission 1235 including the highest BRS-RP value of the first BRSSes as a highest BRS-RP value for the first antenna panel. BRS-RP reporting transmission 1235 may include at least one of a Cell ID, a BRS ID for the measured BRS transmission, and a subframe index for the measured BRS transmission. The BRS-RP reporting transmission may, in various embodiments, be a UCI transmission.

**[00239]** In some embodiments, third circuitry 1230 may be operable to establish the highest BRS-RP value of the second BRSSes as a highest BRS-RP value for the second antenna panel. In such embodiments, BRS-RP reporting transmission 1235 may include the highest BRS-RP value for the second antenna panel.

**[00240]** Third circuitry 1230 may, in various embodiments, be operable to establish the highest BRS-RP value of the second BRSSes as a highest BRS-RP value for the second antenna panel, and may be operable to determine a BRS-RP difference indicator based upon a difference between the highest BRS-RP value for the first antenna panel and the highest BRS-RP value for the second antenna panel. In such embodiments, BRS-RP reporting transmission 1235 may include the BRS-RP difference indicator.

**[00241]** For some embodiments, third circuitry 1230 may be operable to establish a first Rx beam indicator identifying the first antenna corresponding to the highest BRS-RP value for the first antenna panel, and may be operable to establish a second Rx beam indicator identifying the second antenna corresponding to the highest BRS-RP value for the second antenna panel. In such embodiments, BRS-RP reporting transmission 1235 may include the first Rx beam indicator and the second Rx beam indicator.

**[00242]** In some embodiments, first circuitry 1210, second circuitry 1220, and third circuitry 1230 may be implemented as separate circuitries. In other embodiments, one or more of first circuitry 1210, second circuitry 1220, and third circuitry 1230 may be combined and implemented together in a circuitry without altering the essence of the embodiments. In various embodiments, processor 636 (and/or one or more other processors which UE 630 may comprise) may be arranged to perform the operations of first circuitry 1210, second circuitry 1220, and/or third circuitry 1230. In such embodiments, first circuitry 1210, second circuitry 1220, and/or third circuitry 1230 may accordingly be implemented by various combinations of software-configured elements (e.g., processor 636, and/or one or more other processors) and/or other hardware elements. In various embodiments, processor 636 (and/or one or more other processors which UE 630 may comprise) may be a baseband processor.

**[00243]** **Fig. 13** illustrates methods for an eNB for determining a highest BRS-RP for a UE antenna panel, in accordance with some embodiments of the disclosure. Method 1300 may comprise a providing 1310, a receiving 1320, and a parsing 1330. In providing 1310, a BRS transmission may, for an eNB, be provided to an antenna for transmission to a UE. In receiving 1320, a BRS-RP transmission may be received. In parsing 1330, a highest BRS-RP value for a first UE antenna panel may be parsed from the BRS-RP transmission.

**[00244]** Some embodiments of method 1300 may comprise a parsing 1340. In parsing 1340, at least one of a Cell ID, a BRS ID for the BRS transmission, and a subframe index for the BRS transmission may be parsed from the BRS-RP transmission.

**[00245]** Method 1300 may, in various embodiments, comprise a parsing 1350. In such embodiments, the BRS-RP reporting transmission may include a highest BRS-RP value for a second UE antenna panel. In parsing 1350, the highest BRS-RP value for the second UE antenna panel may be parsed from the BRS-RP transmission.

**[00246]** In some embodiments, method 1300 may comprise a parsing 1360, in which a BRS-RP difference indicator may be parsed from the BRS-RP transmission. The BRS-RP difference indicator may be based upon a difference between the highest BRS-RP value for

the first UE antenna panel and a highest BRS-RP value for a second UE antenna panel. In such embodiments, method 1300 may also comprise a parsing 1370, in which a first Rx beam indicator and a second Rx beam indicator may be parsed from the BRS-RP transmission. The first Rx beam indicator may identify a first UE antenna corresponding to the highest BRS-RP value for the first UE antenna panel, and the second Rx beam indicator may identify a second UE antenna corresponding to the highest BRS-RP value for the second antenna panel.

**[00247]** **Fig. 14** illustrates methods for a UE for determining a highest BRS-RP for a UE antenna panel, in accordance with some embodiments of the disclosure. Method 1400 may comprise a receiving 1410, a measuring 1420, and a providing 1430. In receiving 1410, a plurality of first BRSSes and a plurality of second BRSSes may be received for a UE. The first BRSSes may be based on a BRS transmission as received through a plurality of first antennas of a first antenna panel. The second BRSSes may be based on the BRS transmission as received through a plurality of second antennas of a second antenna panel. In measuring 1420, a BRS-RP value may be measured for at least one of the first BRSSes, and a BRS-RP value may be measured for at least one of the second BRSSes. In providing 1430, a BRS-RP reporting transmission may include the highest BRS-RP value of the first BRSSes as a highest BRS-RP value for the first antenna panel. For some embodiments of method 1400, the BRS-RP reporting transmission may include at least one of: a Cell ID, a BRS ID for the measured BRS transmission, and a subframe index for the measured BRS transmission.

**[00248]** Various embodiments of method 1400 may comprise an establishing 1440. In establishing 1440, the highest BRS-RP value of the second BRSSes may be established as a highest BRS-RP value for the second antenna panel. In such embodiments, the BRS-RP reporting transmission may include the highest BRS-RP value for the second antenna panel.

**[00249]** In some embodiments, method 1400 may comprise an establishing 1450 and a determining 1460. In establishing 1450, the highest BRS-RP value of the second BRSSes may be established as a highest BRS-RP value for the second antenna panel. In determining 1460, a BRS-RP difference indicator may be determined based upon a difference between the highest BRS-RP value for the first antenna panel and the highest BRS-RP value for the second antenna panel. The BRS-RP reporting transmission may then include the BRS-RP difference indicator. Such embodiments may also comprise an establishing 1470, in which a first Rx beam indicator and a second Rx beam indicator may be established. The first Rx beam indicator may identify the first antenna corresponding to the highest BRS-RP value for the first antenna panel, and the second Rx beam indicator may identify the second antenna

corresponding to the highest BRS-RP value for the second antenna panel. The BRS-RP reporting transmission may then include the first Rx beam indicator and the second Rx beam indicator.

**G. Example hardware processing circuitries and methods – channel quality measurement in an SUST transmission mode**

**[00250]** Fig. 15 illustrates hardware processing circuitry for an eNB for measuring channel quality for SUST transmissions, in accordance with some embodiments of the disclosure. A hardware processing circuitry 1500 may comprise logic devices and/or circuitry operable to perform various operations. For example, with reference to **Figs. 6 and 15**, eNB 610 (or various elements or components therein, such as hardware processing circuitry 620, or combinations of elements or components therein) may include part of, or all of, hardware processing circuitry 1500. In some embodiments, processor 616 and memory 618 (and/or other elements or components of eNB 610) may be arranged to perform the operations of hardware processing circuitry 1500, such as operations described herein with reference to devices and circuitry within hardware processing circuitry 1500. For example, one or more devices or circuits of hardware processing circuitry 1500 may be implemented by combinations of software-configured elements and/or other hardware elements.

**[00251]** In some embodiments, hardware processing circuitry 1500 may comprise one or more antenna ports 1505 operable to provide various transmissions over a wireless communication channel (such as wireless communication channel 650). Antenna ports 1505 may be coupled to one or more antennas 1507 (which may be antennas 605). In some embodiments, hardware processing circuitry 1500 may incorporate antennas 1507, while in other embodiments, hardware processing circuitry 1500 may merely be coupled to antennas 1507.

**[00252]** Antenna ports 1505 and antennas 1507 may be operable to provide signals from an eNB to a wireless communications channel and/or a UE, and may be operable to provide signals from a UE and/or a wireless communications channel to an eNB. For example, antenna ports 1505 and antennas 1507 may be operable to provide transmissions from eNB 610 to wireless communication channel 650 (and from there to UE 630, or to another UE). Similarly, antennas 1507 and antenna ports 1505 may be operable to provide transmissions from a wireless communication channel 650 (and beyond that, from UE 630, or another UE) to eNB 610.

**[00253]** An apparatus of eNB 610 (or another eNB or base station) may be operable to communicate with a UE on a wireless network, and may comprise hardware processing circuitry 1500. In some embodiments, the eNB (or other base station) may be a device comprising an application processor, a memory, one or more antenna ports, and an interface for allowing the application processor to communicate with another device.

**[00254]** With reference to **Fig. 15**, hardware processing circuitry 1500 may comprise a first circuitry 1510, a second circuitry 1520, a third circuitry 1540, and a fourth circuitry 1540. First circuitry 1510 may be operable to provide a CSI process configuration transmission 1515 for measurement of at least a first data symbol. Second circuitry 1520 may be operable to transmit CSI process configuration transmission 1515.

**[00255]** Third circuitry 1530 may be operable to transmit the first data symbol and a second data symbol in a downlink shared channel transmission, such as a PDSCH or an xPDSCH transmission. A power used to transmit the first data symbol may be less than half of a total power used to transmit the first data symbol and the second data symbol, and a power used to transmit the second data symbol may be greater than half of the total power. In some embodiments, third circuitry 1530 may be operable to transmit the second data symbol super-imposed with the first data symbol.

**[00256]** Fourth circuitry 1540 may be operable to receive a CSI measurement report transmission for at least the first symbol. In various embodiments, fourth circuitry 1540 may be operable to receive a second CSI measurement report for the second symbol.

**[00257]** In some embodiments, first circuitry 1510 may be operable to provide a first CSI process configuration transmission for measurement of the first data symbol and a second CSI process configuration transmission for measurement of the second data symbol. In such embodiments, second circuitry 1520 may be operable to transmit the first CSI process configuration transmission and the second CSI process configuration transmission. In addition, for such embodiments, the first CSI process configuration transmission and the second CSI process configuration transmission may specify the same list of NZPCSI-RS and IMR resources.

**[00258]** In various embodiments, the CSI measurement report transmission may include at least one of a BRS-RP, a CQI, an MCS, a CRI, and a PMI.

**[00259]** In some embodiments, first circuitry 1510, second circuitry 1520, third circuitry 1530, and fourth circuitry 1540 may be implemented as separate circuitries. In other embodiments, one or more of first circuitry 1510, second circuitry 1520, third circuitry 1530,

and fourth circuitry 1540 may be combined and implemented together in a circuitry without altering the essence of the embodiments. In various embodiments, processor 616 (and/or one or more other processors which eNB 610 may comprise) may be arranged to perform the operations of first circuitry 1510, second circuitry 1520, third circuitry 1530, and/or fourth circuitry 1540. In such embodiments, first circuitry 1510, second circuitry 1520, third circuitry 1530, and/or fourth circuitry 1540 may accordingly be implemented by various combinations of software-configured elements (e.g., processor 616, and/or one or more other processors) and/or other hardware elements. In various embodiments, processor 616 (and/or one or more other processors which eNB 610 may comprise) may be a baseband processor.

**[00260]**        **Fig. 16** illustrates hardware processing circuitry for a UE for measuring channel quality for SUST transmissions, in accordance with some embodiments of the disclosure. A hardware processing circuitry 1600 may comprise logic devices and/or circuitry operable to perform various operations. For example, with reference to **Figs. 6 and 16**, UE 630 (or various elements or components therein, such as hardware processing circuitry 640, or combinations of elements or components therein) may include part of, or all of, hardware processing circuitry 1600. In some embodiments, processor 636 and memory 638 (and/or other elements or components of UE 630) may be arranged to perform various operations of hardware processing circuitry 1600, such as operations described herein with reference to devices and circuitry within hardware processing circuitry 1600. For example, one or more devices or circuits of hardware processing circuitry 1600 may be implemented by combinations of software-configured elements and/or other hardware elements.

**[00261]**        In some embodiments, hardware processing circuitry 1600 may comprise one or more antenna ports 1605 operable to provide various transmissions over a wireless communication channel (such as wireless communication channel 650). Antenna ports 1605 may be coupled to one or more antennas 1607 (which may be antennas 605). In some embodiments, hardware processing circuitry 1600 may incorporate antennas 1607, while in other embodiments, hardware processing circuitry 1600 may merely be coupled to antennas 1607.

**[00262]**        Antenna ports 1605 and antennas 1607 may be operable to provide signals from a UE to a wireless communications channel and/or an eNB, and may be operable to provide signals from an eNB and/or a wireless communications channel to a UE. For example, antenna ports 1605 and antennas 1607 may be operable to provide transmissions from UE 630 to wireless communication channel 650 (and from there to eNB 610, or to

another eNB). Similarly, antennas 1607 and antenna ports 1605 may be operable to provide transmissions from a wireless communication channel 650 (and beyond that, from eNB 610, or another eNB) to UE 630.

**[00263]** An apparatus of UE 630 (or another UE or mobile handset) may be operable to communicate with an eNB on a wireless network, and may comprise hardware processing circuitry 1600. In some embodiments, the UE (or other mobile handset) may be a device comprising an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate with another device, and a touch-screen display.

**[00264]** With reference to **Fig. 16**, hardware processing circuitry 1600 may comprise a first circuitry 1610, a second circuitry 1620, a third circuitry 1630, and a fourth circuitry 1640. First circuitry 1610 may be operable to receive a CSI process configuration transmission for measurement of at least a first data symbol.

**[00265]** Second circuitry 1620 may be operable to receive the first data symbol and a second data symbol in a downlink shared channel transmission. Second circuitry 1620 may then provide the first data symbol and the second data symbol as data symbols 1625 to third circuitry 1630. In some embodiments, the second data symbol may be super-imposed with the first data symbol.

**[00266]** Third circuitry 1630 may be operable to take a first CSI measurement for the first data symbol and a second CSI measurement for the second data symbol. Third circuitry 1630 may also provide the first data symbol and the second data symbol as data symbols 1645 to fourth circuitry 1640, which in turn may be operable to prepare a CSI measurement report transmission for at least the first data symbol. In some embodiments, fourth circuitry 1640 may be operable to prepare a second CSI measurement report for the second symbol.

**[00267]** The CSI measurement report transmission may include at least one of a BRS-RP, a CQI, an MCS, a CRI), and a PMI.

**[00268]** In various embodiments, first circuitry 1610 may be operable to receive a first CSI process configuration transmission for measurement of the first data symbol and a second CSI process configuration transmission for measurement of the second data symbol. In such embodiments, the first CSI process configuration transmission and the second CSI process configuration transmission may specify the same list of Non-Zero Power NZPCSI-RS and IMR resources.

**[00269]** In some embodiments, first circuitry 1610, second circuitry 1620, third circuitry 1630, and fourth circuitry 1640 may be implemented as separate circuitries. In other embodiments, one or more of first circuitry 1610, second circuitry 1620, third circuitry 1630, and fourth circuitry 1640 may be combined and implemented together in a circuitry without altering the essence of the embodiments. In various embodiments, processor 636 (and/or one or more other processors which UE 630 may comprise) may be arranged to perform the operations of first circuitry 1610, second circuitry 1620, third circuitry 1630, and/or fourth circuitry 1640. In such embodiments, first circuitry 1610, second circuitry 1620, third circuitry 1630, and/or fourth circuitry 1640 may accordingly be implemented by various combinations of software-configured elements (e.g., processor 636, and/or one or more other processors) and/or other hardware elements. In various embodiments, processor 636 (and/or one or more other processors which UE 630 may comprise) may be a baseband processor.

**[00270]** **Fig. 17** illustrates methods for an eNB for measuring channel quality for SUST transmissions, in accordance with some embodiments of the disclosure. Method 1700 may comprise a providing 1710, a transmitting 1720, a transmitting 1730, and a receiving 1740. In providing 1710, a CSI process configuration transmission for measurement of at least a first data symbol may be provided for an eNB. In transmitting 1720, the CSI process configuration transmission may be transmitted. In transmitting 1730, the first data symbol and a second data symbol may be transmitted in a downlink shared channel transmission, such as a PDSCH transmission or an xPDSCH transmission. A power used to transmit the first data symbol may be less than half of a total power used to transmit the first data symbol and the second data symbol, and a power used to transmit the second data symbol may be greater than half of the total power. In receiving 1740, a CSI measurement report transmission for at least the first symbol may be received.

**[00271]** Method 1700 may also comprise a transmitting 1750, in which the second data symbol may be transmitted super-imposed with the first data symbol.

**[00272]** Some embodiments of method 1700 may comprise a providing 1760 and a transmitting 1770. In providing 1760, a first CSI process configuration transmission for measurement of the first data symbol and a second CSI process configuration transmission for measurement of the second data symbol may be provided. In transmitting 1770, the first CSI process configuration transmission and the second CSI process configuration transmission may be transmitted. In such embodiments, the first CSI process configuration

transmission and the second CSI process configuration transmission may specify the same list of NZP CSI-RS and IMR resources.

[00273] In various embodiments, method 1700 may comprise a receiving 1780, in which a second CSI measurement report for the second symbol may be received.

[00274] **Fig. 18** illustrates methods for a UE for measuring channel quality for SUST transmissions, in accordance with some embodiments of the disclosure. Method 1800 may comprise a receiving 1810, a receiving 1820, a taking 1830, and a preparing 1840. In receiving 1810, a CSI process configuration transmission for measurement of at least a first data symbol may be received for a User Equipment (UE). In receiving 1820, the first data symbol and a second data symbol may be received in a downlink shared channel transmission, such as a PDSCH transmission, or an xPDSCH transmission.

[00275] In taking 1830, a first CSI measurement for the first data symbol and a second CSI measurement for the second data symbol may be taken. In preparing 1840, a CSI measurement report transmission for at least the first data symbol may be prepared. In some embodiments of method 1800, the second data symbol may be superimposed with the first data symbol.

[00276] Method 1800 may in some embodiments include a receiving 1850, in which a first CSI process configuration transmission and a second CSI process configuration transmission may be received. The first CSI process configuration transmission may be for measurement of the first data symbol, and the second CSI process configuration transmission may be for measurement of the second data symbol. In such embodiments, the first CSI process configuration transmission and the second CSI process configuration transmission may specify the same list of NZP CSI-RS and IMR resources.

[00277] Various embodiments of method 1800 may also include a preparing 1860, in which a second CSI measurement report may be prepared for the second symbol.

#### **H. Example UE devices**

[00278] **Fig. 19** illustrates example components of a UE device 1900, in accordance with some embodiments of the disclosure. In some embodiments, the UE device 1900 may include application circuitry 1902, baseband circuitry 1904, Radio Frequency (RF) circuitry 1906, front-end module (FEM) circuitry 1908, a low-power wake-up receiver (LP-WUR), and one or more antennas 1910, coupled together at least as shown. In some embodiments, the UE device 1900 may include additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface.

**[00279]** The application circuitry 1902 may include one or more application processors. For example, the application circuitry 1902 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with and/or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications and/or operating systems to run on the system.

**[00280]** The baseband circuitry 1904 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 1904 may include one or more baseband processors and/or control logic to process baseband signals received from a receive signal path of the RF circuitry 1906 and to generate baseband signals for a transmit signal path of the RF circuitry 1906. Baseband processing circuitry 1904 may interface with the application circuitry 1902 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 1906. For example, in some embodiments, the baseband circuitry 1904 may include a second generation (2G) baseband processor 1904a, third generation (3G) baseband processor 1904b, fourth generation (4G) baseband processor 1904c, and/or other baseband processor(s) 1904d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 1904 (e.g., one or more of baseband processors 1904a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 1906. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 1904 may include Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 1904 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

**[00281]** In some embodiments, the baseband circuitry 1904 may include elements of a protocol stack such as, for example, elements of an EUTRAN protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), and/or RRC elements. A central processing unit (CPU) 1904e

of the baseband circuitry 1904 may be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP and/or RRC layers. In some embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (DSP) 1904f. The audio DSP(s) 1904f may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments. Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the baseband circuitry 1904 and the application circuitry 1902 may be implemented together such as, for example, on a system on a chip (SOC).

**[00282]** In some embodiments, the baseband circuitry 1904 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 1904 may support communication with an evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 1904 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

**[00283]** RF circuitry 1906 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 1906 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 1906 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 1908 and provide baseband signals to the baseband circuitry 1904. RF circuitry 1906 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 1904 and provide RF output signals to the FEM circuitry 1908 for transmission.

**[00284]** In some embodiments, the RF circuitry 1906 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 1906 may include mixer circuitry 1906a, amplifier circuitry 1906b and filter circuitry 1906c. The transmit signal path of the RF circuitry 1906 may include filter circuitry 1906c and mixer circuitry 1906a. RF circuitry 1906 may also include synthesizer circuitry 1906d for synthesizing a frequency for use by the mixer circuitry 1906a of the receive signal path and the transmit

signal path. In some embodiments, the mixer circuitry 1906a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 1908 based on the synthesized frequency provided by synthesizer circuitry 1906d. The amplifier circuitry 1906b may be configured to amplify the down-converted signals and the filter circuitry 1906c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be provided to the baseband circuitry 1904 for further processing. In some embodiments, the output baseband signals may be zero-frequency baseband signals, although this is not a requirement. In some embodiments, mixer circuitry 1906a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

**[00285]** In some embodiments, the mixer circuitry 1906a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 1906d to generate RF output signals for the FEM circuitry 1908. The baseband signals may be provided by the baseband circuitry 1904 and may be filtered by filter circuitry 1906c. The filter circuitry 1906c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

**[00286]** In some embodiments, the mixer circuitry 1906a of the receive signal path and the mixer circuitry 1906a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and/or upconversion respectively. In some embodiments, the mixer circuitry 1906a of the receive signal path and the mixer circuitry 1906a of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 1906a of the receive signal path and the mixer circuitry 1906a may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 1906a of the receive signal path and the mixer circuitry 1906a of the transmit signal path may be configured for super-heterodyne operation.

**[00287]** In some embodiments, the output baseband signals and the input baseband signals may be analog baseband signals, although the scope of the embodiments is not limited in this respect. In some alternate embodiments, the output baseband signals and the input baseband signals may be digital baseband signals. In these alternate embodiments, the RF circuitry 1906 may include analog-to-digital converter (ADC) and digital-to-analog converter

(DAC) circuitry and the baseband circuitry 1904 may include a digital baseband interface to communicate with the RF circuitry 1906.

**[00288]** In some dual-mode embodiments, a separate radio IC circuitry may be provided for processing signals for each spectrum, although the scope of the embodiments is not limited in this respect.

**[00289]** In some embodiments, the synthesizer circuitry 1906d may be a fractional-N synthesizer or a fractional  $N/N+1$  synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 1906d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

**[00290]** The synthesizer circuitry 1906d may be configured to synthesize an output frequency for use by the mixer circuitry 1906a of the RF circuitry 1906 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 1906d may be a fractional  $N/N+1$  synthesizer.

**[00291]** In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry 1904 or the applications processor 1902 depending on the desired output frequency. In some embodiments, a divider control input (e.g.,  $N$ ) may be determined from a look-up table based on a channel indicated by the applications processor 1902.

**[00292]** Synthesizer circuitry 1906d of the RF circuitry 1906 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either  $N$  or  $N+1$  (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into  $N_d$  equal packets of phase, where  $N_d$  is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

**[00293]** In some embodiments, synthesizer circuitry 1906d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four

times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency may be a LO frequency (fLO). In some embodiments, the RF circuitry 1906 may include an IQ/polar converter.

**[00294]** FEM circuitry 1908 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 1910, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 1906 for further processing. FEM circuitry 1908 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 1906 for transmission by one or more of the one or more antennas 1910.

**[00295]** In some embodiments, the FEM circuitry 1908 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 1906). The transmit signal path of the FEM circuitry 1908 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 1906), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 1910).

**[00296]** In some embodiments, the UE 1900 comprises a plurality of power saving mechanisms. If the UE 1900 is in an RRC\_Connected state, where it is still connected to the eNB as it expects to receive traffic shortly, then it may enter a state known as Discontinuous Reception Mode (DRX) after a period of inactivity. During this state, the device may power down for brief intervals of time and thus save power.

**[00297]** If there is no data traffic activity for an extended period of time, then the UE 1900 may transition off to an RRC\_Idle state, where it disconnects from the network and does not perform operations such as channel quality feedback, handover, etc. The UE 1900 goes into a very low power state and it performs paging where again it periodically wakes up to listen to the network and then powers down again. Since the device might not receive data in this state, in order to receive data, it should transition back to RRC\_Connected state.

**[00298]** An additional power saving mode may allow a device to be unavailable to the network for periods longer than a paging interval (ranging from seconds to a few hours). During this time, the device is totally unreachable to the network and may power down completely. Any data sent during this time incurs a large delay and it is assumed the delay is acceptable.

**[00299]** Reference in the specification to "an embodiment," "one embodiment," "some embodiments," or "other embodiments" means that a particular feature, structure, or characteristic described in connection with the embodiments is included in at least some embodiments, but not necessarily all embodiments. The various appearances of "an embodiment," "one embodiment," or "some embodiments" are not necessarily all referring to the same embodiments. If the specification states a component, feature, structure, or characteristic "may," "might," or "could" be included, that particular component, feature, structure, or characteristic is not required to be included. If the specification or claim refers to "a" or "an" element, that does not mean there is only one of the elements. If the specification or claims refer to "an additional" element, that does not preclude there being more than one of the additional element.

**[00300]** Furthermore, the particular features, structures, functions, or characteristics may be combined in any suitable manner in one or more embodiments. For example, a first embodiment may be combined with a second embodiment anywhere the particular features, structures, functions, or characteristics associated with the two embodiments are not mutually exclusive.

**[00301]** While the disclosure has been described in conjunction with specific embodiments thereof, many alternatives, modifications and variations of such embodiments will be apparent to those of ordinary skill in the art in light of the foregoing description. For example, other memory architectures e.g., Dynamic RAM (DRAM) may use the embodiments discussed. The embodiments of the disclosure are intended to embrace all such alternatives, modifications, and variations as to fall within the broad scope of the appended claims.

**[00302]** In addition, well known power/ground connections to integrated circuit (IC) chips and other components may or may not be shown within the presented figures, for simplicity of illustration and discussion, and so as not to obscure the disclosure. Further, arrangements may be shown in block diagram form in order to avoid obscuring the disclosure, and also in view of the fact that specifics with respect to implementation of such block

diagram arrangements are highly dependent upon the platform within which the present disclosure is to be implemented (i.e., such specifics should be well within purview of one skilled in the art). Where specific details (e.g., circuits) are set forth in order to describe example embodiments of the disclosure, it should be apparent to one skilled in the art that the disclosure can be practiced without, or with variation of, these specific details. The description is thus to be regarded as illustrative instead of limiting.

**[00303]** The following examples pertain to further embodiments. Specifics in the examples may be used anywhere in one or more embodiments. All optional features of the apparatus described herein may also be implemented with respect to a method or process.

**[00304]** An example apparatus of an Evolved Node B (eNB) operable to communicate with a User Equipment (UE) on a wireless network, comprising: one or more processors to: enable a Single User Superimposed Transmission (SUST) Transmission Mode (TM); and generate a plurality of codewords for a downlink shared channel transmission to a multiple-directional UE antenna-panel structure, including a first codeword for a first UE antenna panel of the multi-directional UE antenna-panel structure and a second codeword for a second UE antenna panel of the multiple-directional UE antenna-panel structure.

**[00305]** In some embodiments, the eNB is configurable by Radio Resource Control (RRC) signaling to enable the SUST TM. In some embodiments, the one or more processors are further to: generate a number of layers assigned to at least two codewords of the plurality of codewords for a Downlink (DL) assignment transmission. In some embodiments, the one or more processors are further to: generate an assignment of UE-specific Reference Signal (UE-RS) antenna ports for at least two codewords of the plurality of codewords. In some embodiments, a total power of the plurality of codewords is 1. In some embodiments, the one or more processors are further to: generate a power allocation for at least two codewords of the plurality of codewords for a Downlink (DL) assignment transmission.

**[00306]** An example eNB device comprises an application processor, a memory, one or more antenna ports, and an interface for allowing the application processor to

communicate with another device, the eNB device including any of the exemplary apparatus described above.

**[00307]** An example machine readable storage media has machine executable instructions that, when executed, cause one or more processors to perform an operation comprising: enable, for an Evolved Node B (eNB), a Single User Superimposed Transmission (SUST) Transmission Mode (TM); and generate a plurality of codewords for a downlink shared channel transmission to a multiple-directional UE antenna-panel structure, including a first codeword for a first UE antenna panel of the multiple-directional UE antenna-panel structure and a second codeword for a second UE antenna panel of the multiple-directional UE antenna-panel structure.

**[00308]** In some embodiments, the operation comprises: enable the SUST TM by Radio Resource Control (RRC) signaling. In some embodiments, the operation comprises: generate a number of layers assigned to at least two codewords of the plurality of codewords for a Downlink (DL) assignment transmission. In some embodiments, the operation comprises: generate an assignment of UE-specific Reference Signal (UE-RS) antenna ports for at least two codewords of the plurality of codewords. In some embodiments, a total power of the plurality of codewords is 1.

**[00309]** An example method comprises: enabling, for an Evolved Node B (eNB), a Single User Superimposed Transmission (SUST) Transmission Mode (TM); and generating a plurality of codewords for a downlink shared channel transmission to a multiple-directional UE antenna-panel structure, including a first codeword for a first UE antenna panel of the multiple-directional UE antenna-panel structure and a second codeword for a second UE antenna panel of the multiple-directional UE antenna-panel structure.

**[00310]** In some embodiments, a method comprises: enabling the SUST TM by Radio Resource Control (RRC) signaling. In some embodiments, a method comprises: generating a

number of layers assigned to at least two codewords of the plurality of codewords for a Downlink (DL) assignment transmission. In some embodiments, a method comprises: generating an assignment of UE-specific Reference Signal (UE-RS) antenna ports for at least two codewords of the plurality of codewords. In some embodiments, a total power of the plurality of codewords is 1.

**[00311]** An example machine readable storage media has machine executable instructions stored thereon that, when executed, cause one or more processors to perform any of the exemplary methods described above.

**[00312]** An example apparatus of an Evolved Node B (eNB) operable to communicate with a User Equipment (UE) on a wireless network, comprising: means for enabling a Single User Superimposed Transmission (SUST) Transmission Mode (TM); and means for generating a plurality of codewords for a downlink shared channel transmission to a multiple-directional UE antenna-panel structure, including a first codeword for a first UE antenna panel of the multiple-directional UE antenna-panel structure and a second codeword for a second UE antenna panel of the multiple-directional UE antenna-panel structure.

**[00313]** In some embodiments, an apparatus comprises: means for enabling the SUST TM by Radio Resource Control (RRC) signaling. In some embodiments, an apparatus comprises: means for generating a number of layers assigned to at least two codewords of the plurality of codewords for a Downlink (DL) assignment transmission. In some embodiments, an apparatus comprises: means for generating an assignment of UE-specific Reference Signal (UE-RS) antenna ports for at least two codewords of the plurality of codewords. In some embodiments, a total power of the plurality of codewords is 1.

**[00314]** An example apparatus of a User Equipment (UE) operable to communicate with an Evolved Node B (eNB) on a wireless network, comprising: one or more processors to: enable a Single User Superimposed Transmission (SUST) Transmission Mode (TM); process

a plurality of codewords of a downlink shared channel transmission, including a first codeword for a first antenna panel of a multiple-directional antenna-panel structure and a second codeword for a second antenna panel of the multiple-directional antenna-panel structure.

**[00315]** In some embodiments, the one or more processors are further to: process a Downlink (DL) assignment transmission; and parse from the DL assignment transmission a number of layers assigned to at least two codewords of the plurality of codewords. In some embodiments, the one or more processors are further to: assign a Reference Signal (RS) antenna port for at least two codewords of the plurality of codewords. In some embodiments, a total power of the plurality of codewords is 1. In some embodiments, the one or more processors are further to: process a Downlink (DL) assignment transmission; and parse from the DL assignment transmission a power allocation for at least two codewords of the plurality of codewords.

**[00316]** An example UE device comprises an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate with another device, and a touch-screen display, the UE device including any of the exemplary apparatus described above.

**[00317]** An example machine readable storage media has machine executable instructions that, when executed, cause one or more processors to perform an operation comprising: enable, for a User Equipment (UE), a Single User Superimposed Transmission (SUST) Transmission Mode (TM); process a plurality of codewords of a downlink shared channel transmission, including a first codeword for a first antenna panel of a multiple-directional antenna-panel structure and a second codeword for a second antenna panel of the multiple-directional antenna-panel structure.

**[00318]** In some embodiments, the operation comprises: process a Downlink (DL) assignment transmission; and parse from the DL assignment transmission a number of layers assigned to at least two codewords of the plurality of codewords. In some embodiments, the operation comprises: assign a Reference Signal (RS) antenna port for at least two codewords of the plurality of codewords. In some embodiments, a total power of the plurality of codewords is 1. In some embodiments, the operation comprises: process a Downlink (DL) assignment transmission; and parse from the DL assignment transmission a power allocation for at least two codewords of the plurality of codewords.

**[00319]** An example method comprises: enabling, for a User Equipment (UE), a Single User Superimposed Transmission (SUST) Transmission Mode (TM); processing a plurality of codewords of a downlink shared channel transmission, including a first codeword for a first antenna panel of a multiple-directional antenna-panel structure and a second codeword for a second antenna panel of the multiple-directional antenna-panel structure.

**[00320]** In some embodiments, a method comprises: processing a Downlink (DL) assignment transmission; and parsing from the DL assignment transmission a number of layers assigned to at least two codewords of the plurality of codewords. In some embodiments, a method comprises: assigning a Reference Signal (RS) antenna port for at least two codewords of the plurality of codewords. In some embodiments, a total power of the plurality of codewords is 1. In some embodiments, a method comprises: processing a Downlink (DL) assignment transmission; and parsing from the DL assignment transmission a power allocation for at least two codewords of the plurality of codewords.

**[00321]** An example machine readable storage media has machine executable instructions stored thereon that, when executed, cause one or more processors to perform any of the exemplary methods described above.

**[00322]** An example apparatus of a User Equipment (UE) operable to communicate with an Evolved Node B (eNB) on a wireless network, comprising: means for enabling a Single User Superimposed Transmission (SUST) Transmission Mode (TM); means for processing a plurality of codewords of a downlink shared channel transmission, including a first codeword for a first antenna panel of a multiple-directional antenna-panel structure and a second codeword for a second antenna panel of the multiple-directional antenna-panel structure.

**[00323]** In some embodiments, an apparatus comprises: means for processing a Downlink (DL) assignment transmission; and means for parsing from the DL assignment transmission a number of layers assigned to at least two codewords of the plurality of codewords. In some embodiments, an apparatus comprises: means for assigning a Reference Signal (RS) antenna port for at least two codewords of the plurality of codewords. In some embodiments, a total power of the plurality of codewords is 1. In some embodiments, an apparatus comprises: means for processing a Downlink (DL) assignment transmission; and means for parsing from the DL assignment transmission a power allocation for at least two codewords of the plurality of codewords.

**[00324]** An example apparatus of an Evolved Node B (eNB) operable to communicate with a User Equipment (UE) on a wireless network, comprising: one or more processors to: generate a Beam Reference Signal (BRS) transmission to an antenna for transmission to the UE; process a BRS Receiving Power (BRS-RP) reporting transmission; and parse a highest BRS-RP value for a first UE antenna panel from the BRS-RP reporting transmission.

**[00325]** In some embodiments, the BRS-RP reporting transmission includes at least one of: a Cell ID, a BRS ID for the BRS transmission, or a subframe index for the BRS transmission; and the one or more processors are further to parse, from the BRS-RP reporting transmission, at least one of: the Cell ID, the BRS ID for the BRS transmission, or the

subframe index for the BRS transmission. In some embodiments, the BRS-RP reporting transmission includes a highest BRS-RP value for a second UE antenna panel; and the one or more processors are further to parse the highest BRS-RP value for the second UE antenna panel from the BRS-RP reporting transmission. In some embodiments, the BRS-RP reporting transmission includes a BRS-RP difference indicator based upon a difference between the highest BRS-RP value for the first UE antenna panel and a highest BRS-RP value for a second UE antenna panel; and the one or more processors are further to parse the BRS-RP difference indicator from the BRS-RP reporting transmission. In some embodiments, the BRS-RP reporting transmission includes a first Rx beam indicator identifying a first UE antenna corresponding to the highest BRS-RP value for the first UE antenna panel, and includes a second Rx beam indicator identifying a second UE antenna corresponding to the highest BRS-RP value for the second antenna panel; and the one or more processors are further to parse the first Rx beam indicator and the second Rx beam indicator from the BRS-RP reporting transmission. In some embodiments, an apparatus comprises: the BRS-RP reporting transmission may be an Uplink Control Information (UCI) transmission.

**[00326]** An example eNB device comprises an application processor, a memory, one or more antenna ports, and an interface for allowing the application processor to communicate with another device, the eNB device including any of the exemplary apparatus described above.

**[00327]** An example machine readable storage media has machine executable instructions that, when executed, cause one or more processors to perform an operation comprising: generate, for an Evolved Node B (eNB), a Beam Reference Signal (BRS) transmission to an antenna for transmission to the UE; process a BRS Receiving Power

(BRS-RP) transmission; and parse a highest BRS-RP value for a first UE antenna panel from the BRS-RP transmission.

**[00328]** In some embodiments, the operation comprises: parse, from the BRS-RP transmission, at least one of: a Cell ID, a BRS ID for the BRS transmission, or a subframe index for the BRS transmission. In some embodiments, the BRS-RP reporting transmission includes a highest BRS-RP value for a second UE antenna panel, the operation comprising: parse the highest BRS-RP value for the second UE antenna panel from the BRS-RP transmission. In some embodiments, the operation comprises: parse a BRS-RP difference indicator from the BRS-RP transmission, the BRS-RP difference indicator based upon a difference between the highest BRS-RP value for the first UE antenna panel and a highest BRS-RP value for a second UE antenna panel. In some embodiments, the operation comprises: parse, from the BRS-RP transmission, a first Rx beam indicator identifying a first UE antenna corresponding to the highest BRS-RP value for the first UE antenna panel, and a second Rx beam indicator identifying a second UE antenna corresponding to the highest BRS-RP value for the second antenna panel.

**[00329]** An example method comprises: generating, for an Evolved Node B (eNB), a Beam Reference Signal (BRS) transmission to an antenna for transmission to the UE; processing a BRS Receiving Power (BRS-RP) transmission; and parsing a highest BRS-RP value for a first UE antenna panel from the BRS-RP transmission.

**[00330]** In some embodiments, a method comprises: parsing, from the BRS-RP transmission, at least one of: a Cell ID, a BRS ID for the BRS transmission, or a subframe index for the BRS transmission. In some embodiments, the BRS-RP reporting transmission includes a highest BRS-RP value for a second UE antenna panel, comprising: parsing the highest BRS-RP value for the second UE antenna panel from the BRS-RP transmission. In some embodiments, a method comprises: parsing a BRS-RP difference indicator from the

BRS-RP transmission, the BRS-RP difference indicator based upon a difference between the highest BRS-RP value for the first UE antenna panel and a highest BRS-RP value for a second UE antenna panel. In some embodiments, a method comprises: parsing, from the BRS-RP transmission, a first Rx beam indicator identifying a first UE antenna corresponding to the highest BRS-RP value for the first UE antenna panel, and a second Rx beam indicator identifying a second UE antenna corresponding to the highest BRS-RP value for the second antenna panel.

**[00331]** An example machine readable storage media has machine executable instructions stored thereon that, when executed, cause one or more processors to perform any of the exemplary methods described above.

**[00332]** An example apparatus of an Evolved Node B (eNB) operable to communicate with a User Equipment (UE) on a wireless network, comprising: means for generating a Beam Reference Signal (BRS) transmission to an antenna for transmission to the UE; means for processing a BRS Receiving Power (BRS-RP) transmission; and means for parsing a highest BRS-RP value for a first UE antenna panel from the BRS-RP transmission.

**[00333]** In some embodiments, an apparatus comprises: means for parsing, from the BRS-RP transmission, at least one of: a Cell ID, a BRS ID for the BRS transmission, or a subframe index for the BRS transmission. In some embodiments, the BRS-RP reporting transmission includes a highest BRS-RP value for a second UE antenna panel, comprising: means for parsing the highest BRS-RP value for the second UE antenna panel from the BRS-RP transmission. In some embodiments, an apparatus comprises: means for parsing a BRS-RP difference indicator from the BRS-RP transmission, the BRS-RP difference indicator based upon a difference between the highest BRS-RP value for the first UE antenna panel and a highest BRS-RP value for a second UE antenna panel. In some embodiments, an apparatus comprises: means for parsing, from the BRS-RP transmission, a first Rx beam

indicator identifying a first UE antenna corresponding to the highest BRS-RP value for the first UE antenna panel, and a second Rx beam indicator identifying a second UE antenna corresponding to the highest BRS-RP value for the second antenna panel.

**[00334]** An example apparatus of a User Equipment (UE) operable to communicate with an Evolved Node B (eNB) on a wireless network, comprising: one or more processors to: process a plurality of first Beam Reference Signals (BRSes), based on a BRS transmission as received through a plurality of first antennas of a first antenna panel, and to process a plurality of second BRSes, based on the BRS transmission as received through a plurality of second antennas of a second antenna panel; measure a BRS Receiving Power (BRS-RP) value for at least one of the first BRSes, and to measure a BRS-RP value for at least one of the second BRSes; and generate a BRS-RP reporting transmission including the highest BRS-RP value of the first BRSes as a highest BRS-RP value for the first antenna panel.

**[00335]** In some embodiments, the BRS-RP reporting transmission includes at least one of: a Cell ID, a BRS ID for the measured BRS transmission, or a subframe index for the measured BRS transmission. In some embodiments, the one or more processors are further to establish the highest BRS-RP value of the second BRSes as a highest BRS-RP value for the second antenna panel; and the BRS-RP reporting transmission includes the highest BRS-RP value for the second antenna panel. In some embodiments, the one or more processors are further to establish the highest BRS-RP value of the second BRSes as a highest BRS-RP value for the second antenna panel, and are further to determine a BRS-RP difference indicator based upon a difference between the highest BRS-RP value for the first antenna panel and the highest BRS-RP value for the second antenna panel; and the BRS-RP reporting transmission includes the BRS-RP difference indicator. In some embodiments, the one or more processors are further to establish a first Rx beam indicator identifying the first antenna corresponding to the highest BRS-RP value for the first antenna panel, and are further to

establish a second Rx beam indicator identifying the second antenna corresponding to the highest BRS-RP value for the second antenna panel; and the BRS-RP reporting transmission includes the first Rx beam indicator and the second Rx beam indicator. In some embodiments, the BRS-RP reporting transmission may be an Uplink Control Information (UCI) transmission.

**[00336]** An example UE device comprises an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate with another device, and a touch-screen display, the UE device including any of the exemplary apparatus described above.

**[00337]** An example machine readable storage media has machine executable instructions that, when executed, cause one or more processors to perform an operation comprising: process, for a User Equipment (UE), a plurality of first Beam Reference Signals (BRSes) based on a BRS transmission as received through a plurality of first antennas of a first antenna panel, and a plurality of second BRSes based on the BRS transmission as received through a plurality of second antennas of a second antenna panel; measure a BRS Receiving Power (BRS-RP) value for at least one of the first BRSes, and a BRS-RP value for at least one of the second BRSes; and generate a BRS-RP reporting transmission including the highest BRS-RP value of the first BRSes as a highest BRS-RP value for the first antenna panel. In some embodiments, the BRS-RP reporting transmission includes at least one of: a Cell ID, a BRS ID for the measured BRS transmission, or a subframe index for the measured BRS transmission. In some embodiments, the operation comprises: establish the highest BRS-RP value of the second BRSes as a highest BRS-RP value for the second antenna panel, the BRS-RP reporting transmission includes the highest BRS-RP value for the second antenna panel. In some embodiments, the operation comprises: establish the highest BRS-RP value of the second BRSes as a highest BRS-RP value for the second antenna panel; and

determine a BRS-RP difference indicator based upon a difference between the highest BRS-RP value for the first antenna panel and the highest BRS-RP value for the second antenna panel, the BRS-RP reporting transmission includes the BRS-RP difference indicator. In some embodiments, the operation comprises: establish a first Rx beam indicator identifying the first antenna corresponding to the highest BRS-RP value for the first antenna panel, a second Rx beam indicator identifying the second antenna corresponding to the highest BRS-RP value for the second antenna panel, the BRS-RP reporting transmission includes the first Rx beam indicator and the second Rx beam indicator.

**[00338]** An example method comprises: processing, for a User Equipment (UE), a plurality of first Beam Reference Signals (BRSes) based on a BRS transmission as received through a plurality of first antennas of a first antenna panel, and a plurality of second BRSes based on the BRS transmission as received through a plurality of second antennas of a second antenna panel; measuring a BRS Receiving Power (BRS-RP) value for at least one of the first BRSes, and a BRS-RP value for at least one of the second BRSes; and generating a BRS-RP reporting transmission including the highest BRS-RP value of the first BRSes as a highest BRS-RP value for the first antenna panel.

**[00339]** In some embodiments, the BRS-RP reporting transmission includes at least one of: a Cell ID, a BRS ID for the measured BRS transmission, or a subframe index for the measured BRS transmission. In some embodiments, a method comprises: establishing the highest BRS-RP value of the second BRSes as a highest BRS-RP value for the second antenna panel, the BRS-RP reporting transmission includes the highest BRS-RP value for the second antenna panel. In some embodiments, a method comprises: establishing the highest BRS-RP value of the second BRSes as a highest BRS-RP value for the second antenna panel; and determining a BRS-RP difference indicator based upon a difference between the highest BRS-RP value for the first antenna panel and the highest BRS-RP value for the second

antenna panel, the BRS-RP reporting transmission includes the BRS-RP difference indicator. In some embodiments, a method comprises: establishing a first Rx beam indicator identifying the first antenna corresponding to the highest BRS-RP value for the first antenna panel, a second Rx beam indicator identifying the second antenna corresponding to the highest BRS-RP value for the second antenna panel, the BRS-RP reporting transmission includes the first Rx beam indicator and the second Rx beam indicator.

**[00340]** An example machine readable storage media has machine executable instructions stored thereon that, when executed, cause one or more processors to perform any of the exemplary methods described above.

**[00341]** An example apparatus of a User Equipment (UE) operable to communicate with an Evolved Node B (eNB) on a wireless network, comprising: means for processing a plurality of first Beam Reference Signals (BRSes) based on a BRS transmission as received through a plurality of first antennas of a first antenna panel, and a plurality of second BRSes based on the BRS transmission as received through a plurality of second antennas of a second antenna panel; means for measuring a BRS Receiving Power (BRS-RP) value for at least one of the first BRSes, and a BRS-RP value for at least one of the second BRSes; and means for generating a BRS-RP reporting transmission including the highest BRS-RP value of the first BRSes as a highest BRS-RP value for the first antenna panel.

**[00342]** In some embodiments, the BRS-RP reporting transmission includes at least one of: a Cell ID, a BRS ID for the measured BRS transmission, or a subframe index for the measured BRS transmission. In some embodiments, an apparatus comprises: means for establishing the highest BRS-RP value of the second BRSes as a highest BRS-RP value for the second antenna panel, the BRS-RP reporting transmission includes the highest BRS-RP value for the second antenna panel. In some embodiments, an apparatus comprises: means for establishing the highest BRS-RP value of the second BRSes as a highest BRS-RP value

for the second antenna panel; and means for determining a BRS-RP difference indicator based upon a difference between the highest BRS-RP value for the first antenna panel and the highest BRS-RP value for the second antenna panel, the BRS-RP reporting transmission includes the BRS-RP difference indicator. In some embodiments, an apparatus comprises: means for establishing a first Rx beam indicator identifying the first antenna corresponding to the highest BRS-RP value for the first antenna panel, a second Rx beam indicator identifying the second antenna corresponding to the highest BRS-RP value for the second antenna panel, the BRS-RP reporting transmission includes the first Rx beam indicator and the second Rx beam indicator.

**[00343]** An example apparatus of an Evolved Node B (eNB) operable to communicate with a User Equipment (UE) on a wireless network, the apparatus comprising: one or more processors to: generate a Channel State Information (CSI) process configuration transmission for measurement of at least a first data symbol; generate the first data symbol and a second data symbol in a downlink shared channel transmission, the first data symbol being transmitted using less than half of a total power used to transmit the first data symbol and the second data symbol, and the second data symbol being transmitted using greater than half of the total power; and process a CSI measurement report transmission for at least the first symbol.

**[00344]** In some embodiments, the one or more processors are further to generate the second data symbol superimposed with the first data symbol. In some embodiments, the one or more processors are further to generate a first CSI process configuration transmission for measurement of the first data symbol and a second CSI process configuration transmission for measurement of the second data symbol. In some embodiments, the first CSI process configuration transmission and the second CSI process configuration transmission specify the same list of Non-Zero Power (NZP) CSI Reference Signal (CSI-RS) and Interference

Measurement Resource (IMR) resources. In some embodiments, the one or more processors are further to process a second CSI measurement report for the second symbol. In some embodiments, the CSI measurement report transmission may include at least one of a Beam Reference Signal (BRS) Receiving Power (BRS-RP), a Channel Quality Indication (CQI), a Modulation and Coding Scheme (MCS), a CSI Reference Signal (CSI-RS) Resource Indicator (CRI), or a Pre-coding Matrix Indicator (PMI).

**[00345]** An example eNB device comprises an application processor, a memory, one or more antenna ports, and an interface for allowing the application processor to communicate with another device, the eNB device including any of the exemplary apparatus described above.

**[00346]** An example machine readable storage media has machine executable instructions that, when executed, cause one or more processors to perform an operation comprising: generate, for an Evolved Node-B (eNB), a Channel State Information (CSI) process configuration transmission for measurement of at least a first data symbol; generate the CSI process configuration transmission; generate the first data symbol and a second data symbol in a downlink shared channel transmission, the first data symbol being transmitted using less than half of a total power used to transmit the first data symbol and the second data symbol, and the second data symbol being transmitted using greater than half of the total power; and process a CSI measurement report transmission for at least the first symbol.

**[00347]** In some embodiments, the operation comprises: generate the second data symbol superimposed with the first data symbol. In some embodiments, the operation comprises: generate a first CSI process configuration transmission for measurement of the first data symbol and a second CSI process configuration transmission for measurement of the second data symbol. In some embodiments, the first CSI process configuration transmission and the second CSI process configuration transmission specify the same list of

Non-Zero Power (NZP) CSI Reference Signal (CSI-RS) and Interference Measurement Resource (IMR) resources. In some embodiments, the operation comprises: process a second CSI measurement report for the second symbol.

**[00348]** An example method comprises: generating, for an Evolved Node-B (eNB), a Channel State Information (CSI) process configuration transmission for measurement of at least a first data symbol; generating the CSI process configuration transmission; generating the first data symbol and a second data symbol in a downlink shared channel transmission, the first data symbol being transmitted using less than half of a total power used to transmit the first data symbol and the second data symbol, and the second data symbol being transmitted using greater than half of the total power; and processing a CSI measurement report transmission for at least the first symbol.

**[00349]** In some embodiments, a method comprises: generating the second data symbol superimposed with the first data symbol. In some embodiments, a method comprises: generating a first CSI process configuration transmission for measurement of the first data symbol and a second CSI process configuration transmission for measurement of the second data symbol. In some embodiments, the first CSI process configuration transmission and the second CSI process configuration transmission specify the same list of Non-Zero Power (NZP) CSI Reference Signal (CSI-RS) and Interference Measurement Resource (IMR) resources. In some embodiments, a method comprises: processing a second CSI measurement report for the second symbol.

**[00350]** An example machine readable storage media has machine executable instructions stored thereon that, when executed, cause one or more processors to perform any of the exemplary methods described above.

**[00351]** An example apparatus of an Evolved Node B (eNB) operable to communicate with a User Equipment (UE) on a wireless network, the apparatus comprising: means for

generating a Channel State Information (CSI) process configuration transmission for measurement of at least a first data symbol; means for generating the CSI process configuration transmission; means for generating the first data symbol and a second data symbol in a downlink shared channel transmission, the first data symbol being transmitted using less than half of a total power used to transmit the first data symbol and the second data symbol, and the second data symbol being transmitted using greater than half of the total power; and means for processing a CSI measurement report transmission for at least the first symbol.

**[00352]** In some embodiments, an apparatus comprises: means for generating the second data symbol superimposed with the first data symbol. In some embodiments, an apparatus comprises: means for generating a first CSI process configuration transmission for measurement of the first data symbol and a second CSI process configuration transmission for measurement of the second data symbol. In some embodiments, the first CSI process configuration transmission and the second CSI process configuration transmission specify the same list of Non-Zero Power (NZP) CSI Reference Signal (CSI-RS) and Interference Measurement Resource (IMR) resources. In some embodiments, an apparatus comprises: means for processing a second CSI measurement report for the second symbol.

**[00353]** An example apparatus of a User Equipment (UE) operable to communicate with an Evolved Node B (eNB) on a wireless network, the apparatus comprising: one or more processors to: process a Channel State Information (CSI) process configuration transmission for measurement of at least a first data symbol; process the first data symbol and a second data symbol in a downlink shared channel transmission; take a first CSI measurement for the first data symbol and a second CSI measurement for the second data symbol; and prepare a CSI measurement report transmission for at least the first data symbol.

**[00354]** In some embodiments, the second data symbol is superimposed with the first data symbol. In some embodiments, the one or more processors are further to process a first CSI process configuration transmission for measurement of the first data symbol and a second CSI process configuration transmission for measurement of the second data symbol. In some embodiments, the first CSI process configuration transmission and the second CSI process configuration transmission specify the same list of Non-Zero Power (NZP) CSI Reference Signal (CSI-RS) and Interference Measurement Resource (IMR) resources. In some embodiments, the one or more processors are further to prepare a second CSI measurement report for the second symbol. In some embodiments, the CSI measurement report transmission may include at least one of a Beam Reference Signal (BRS) Receiving Power (BRS-RP), a Channel Quality Indication (CQI), a Modulation and Coding Scheme (MCS), a CSI Reference Signal (CSI-RS) Resource Indicator (CRI), or a Pre-coding Matrix Indicator (PMI).

**[00355]** An example UE device comprises an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate with another device, and a touch-screen display, the UE device including any of the exemplary apparatus described above.

**[00356]** An example machine readable storage media has machine executable instructions that, when executed, cause one or more processors to perform an operation comprising: process, for a User Equipment (UE), a Channel State Information (CSI) process configuration transmission for measurement of at least a first data symbol; process the first data symbol and a second data symbol in a downlink shared channel transmission; take a first CSI measurement for the first data symbol and a second CSI measurement for the second data symbol; and prepare a CSI measurement report transmission for at least the first data symbol.

**[00357]** In some embodiments, the second data symbol is superimposed with the first data symbol. In some embodiments, the operation comprises: process a first CSI process configuration transmission for measurement of the first data symbol and a second CSI process configuration transmission for measurement of the second data symbol. In some embodiments, the first CSI process configuration transmission and the second CSI process configuration transmission specify the same list of Non-Zero Power (NZIP) CSI Reference Signal (CSI-RS) and Interference Measurement Resource (IMR) resources. In some embodiments, the operation comprises: prepare a second CSI measurement report for the second symbol.

**[00358]** An example method comprises: processing, for a User Equipment (UE), a Channel State Information (CSI) process configuration transmission for measurement of at least a first data symbol; processing the first data symbol and a second data symbol in a downlink shared channel transmission; taking a first CSI measurement for the first data symbol and a second CSI measurement for the second data symbol; and preparing a CSI measurement report transmission for at least the first data symbol.

**[00359]** In some embodiments, the second data symbol is superimposed with the first data symbol. In some embodiments, a method comprises: processing a first CSI process configuration transmission for measurement of the first data symbol and a second CSI process configuration transmission for measurement of the second data symbol. In some embodiments, the first CSI process configuration transmission and the second CSI process configuration transmission specify the same list of Non-Zero Power (NZIP) CSI Reference Signal (CSI-RS) and Interference Measurement Resource (IMR) resources. In some embodiments, a method comprises: preparing a second CSI measurement report for the second symbol.

**[00360]** An example machine readable storage media has machine executable instructions stored thereon that, when executed, cause one or more processors to perform any of the exemplary methods described above.

**[00361]** An example apparatus of a User Equipment (UE) operable to communicate with an Evolved Node B (eNB) on a wireless network, the apparatus comprising: means for processing a Channel State Information (CSI) process configuration transmission for measurement of at least a first data symbol; means for processing the first data symbol and a second data symbol in a downlink shared channel transmission; means for taking a first CSI measurement for the first data symbol and a second CSI measurement for the second data symbol; and means for preparing a CSI measurement report transmission for at least the first data symbol.

**[00362]** In some embodiments, the second data symbol is superimposed with the first data symbol. In some embodiments, an apparatus comprises: means for processing a first CSI process configuration transmission for measurement of the first data symbol and a second CSI process configuration transmission for measurement of the second data symbol. In some embodiments, the first CSI process configuration transmission and the second CSI process configuration transmission specify the same list of Non-Zero Power (NZP) CSI Reference Signal (CSI-RS) and Interference Measurement Resource (IMR) resources. In some embodiments, an apparatus comprises: means for preparing a second CSI measurement report for the second symbol.

**[00363]** In various embodiments, the one or more processors of an apparatus may comprise a baseband processor.

**[00364]** An abstract is provided that will allow the reader to ascertain the nature and gist of the technical disclosure. The abstract is submitted with the understanding that it will not be used to limit the scope or meaning of the claims. The following claims are hereby

incorporated into the detailed description, with each claim standing on its own as a separate embodiment.

**CLAIMS**

We claim:

1. An apparatus of an Evolved Node-B (eNB) operable to communicate with a User Equipment (UE) on a wireless network, comprising:
  - one or more processors to:
    - enable a Single User Superimposed Transmission (SUST) Transmission Mode (TM); and
    - generate a plurality of codewords for a downlink shared channel transmission to a multiple-directional UE antenna-panel structure, including a first codeword for a first UE antenna panel of the multi-directional UE antenna-panel structure and a second codeword for a second UE antenna panel of the multiple-directional UE antenna-panel structure.
2. The apparatus of claim 1,
  - wherein the eNB is configurable by Radio Resource Control (RRC) signaling to enable the SUST TM.
3. The apparatus of claim 1, wherein the one or more processors are further to:
  - generate a number of layers assigned to at least two codewords of the plurality of codewords for a Downlink (DL) assignment transmission.
4. The apparatus of claim 1, wherein the one or more processors are further to:
  - generate an assignment of UE-specific Reference Signal (UE-RS) antenna ports for at least two codewords of the plurality of codewords.
5. The apparatus of claim 1,
  - wherein a total power of the plurality of codewords is 1.
6. The apparatus of claim 1, wherein the one or more processors are further to:
  - generate a power allocation for at least two codewords of the plurality of codewords for a Downlink (DL) assignment transmission.

7. An eNB device comprising an application processor, a memory, one or more antenna ports, and an interface for allowing the application processor to communicate with another device, the eNB device including the apparatus of any of claims 1 through 6.
8. Machine readable storage media having machine executable instructions that, when executed, cause one or more processors to perform an operation comprising:  
enable, for an Evolved Node B (eNB), a Single User Superimposed Transmission (SUST) Transmission Mode (TM); and  
generate a plurality of codewords for a downlink shared channel transmission to a multiple-directional UE antenna-panel structure, including a first codeword for a first UE antenna panel of the multiple-directional UE antenna-panel structure and a second codeword for a second UE antenna panel of the multiple-directional UE antenna-panel structure.
9. The machine readable storage media of claim 8, the operation comprising:  
enable the SUST TM by Radio Resource Control (RRC) signaling.
10. The machine readable storage media of claim 8, the operation comprising:  
generate a number of layers assigned to at least two codewords of the plurality of codewords for a Downlink (DL) assignment transmission.
11. The machine readable storage media of claim 8, the operation comprising:  
generate an assignment of UE-specific Reference Signal (UE-RS) antenna ports for at least two codewords of the plurality of codewords.
12. The machine readable storage media of claim 8,  
wherein a total power of the plurality of codewords is 1.
13. An apparatus of a User Equipment (UE) operable to communicate with an Evolved Node B (eNB) on a wireless network, comprising:  
one or more processors to:  
enable a Single User Superimposed Transmission (SUST) Transmission Mode (TM);  
process a plurality of codewords of a downlink shared channel transmission, including a first codeword for a first antenna panel of a multiple-directional antenna-panel structure and a

second codeword for a second antenna panel of the multiple-directional antenna-panel structure.

14. The apparatus of claim 13, wherein the one or more processors are further to: process a Downlink (DL) assignment transmission; and parse from the DL assignment transmission a number of layers assigned to at least two codewords of the plurality of codewords.

15. The apparatus of claim 13, wherein the one or more processors are further to: assign a Reference Signal (RS) antenna port for at least two codewords of the plurality of codewords.

16. The apparatus of claim 13, wherein a total power of the plurality of codewords is 1.

17. The apparatus of claim 13, wherein the one or more processors are further to: process a Downlink (DL) assignment transmission; and parse from the DL assignment transmission a power allocation for at least two codewords of the plurality of codewords.

18. A UE device comprising an application processor, a memory, one or more antennas, a wireless interface for allowing the application processor to communicate with another device, and a touch-screen display, the UE device including the apparatus of any of claims 13 through 17.

19. Machine readable storage media having machine executable instructions that, when executed, cause one or more processors to perform an operation comprising: enable, for a User Equipment (UE), a Single User Superimposed Transmission (SUST) Transmission Mode (TM); process a plurality of codewords of a downlink shared channel transmission, including a first codeword for a first antenna panel of a multiple-directional antenna-panel structure and a second codeword for a second antenna panel of the multiple-directional antenna-panel structure.

20. The machine readable storage media of claim 19, the operation comprising:  
process a Downlink (DL) assignment transmission; and  
parse from the DL assignment transmission a number of layers assigned to at least two  
codewords of the plurality of codewords.
21. The machine readable storage media of claim 19, the operation comprising:  
assign a Reference Signal (RS) antenna port for at least two codewords of the plurality of  
codewords.
22. The machine readable storage media of claim 19, wherein a total power of the  
plurality of codewords is 1.
23. The machine readable storage media of claim 19, the operation comprising:  
process a Downlink (DL) assignment transmission; and  
parse from the DL assignment transmission a power allocation for at least two codewords of  
the plurality of codewords.

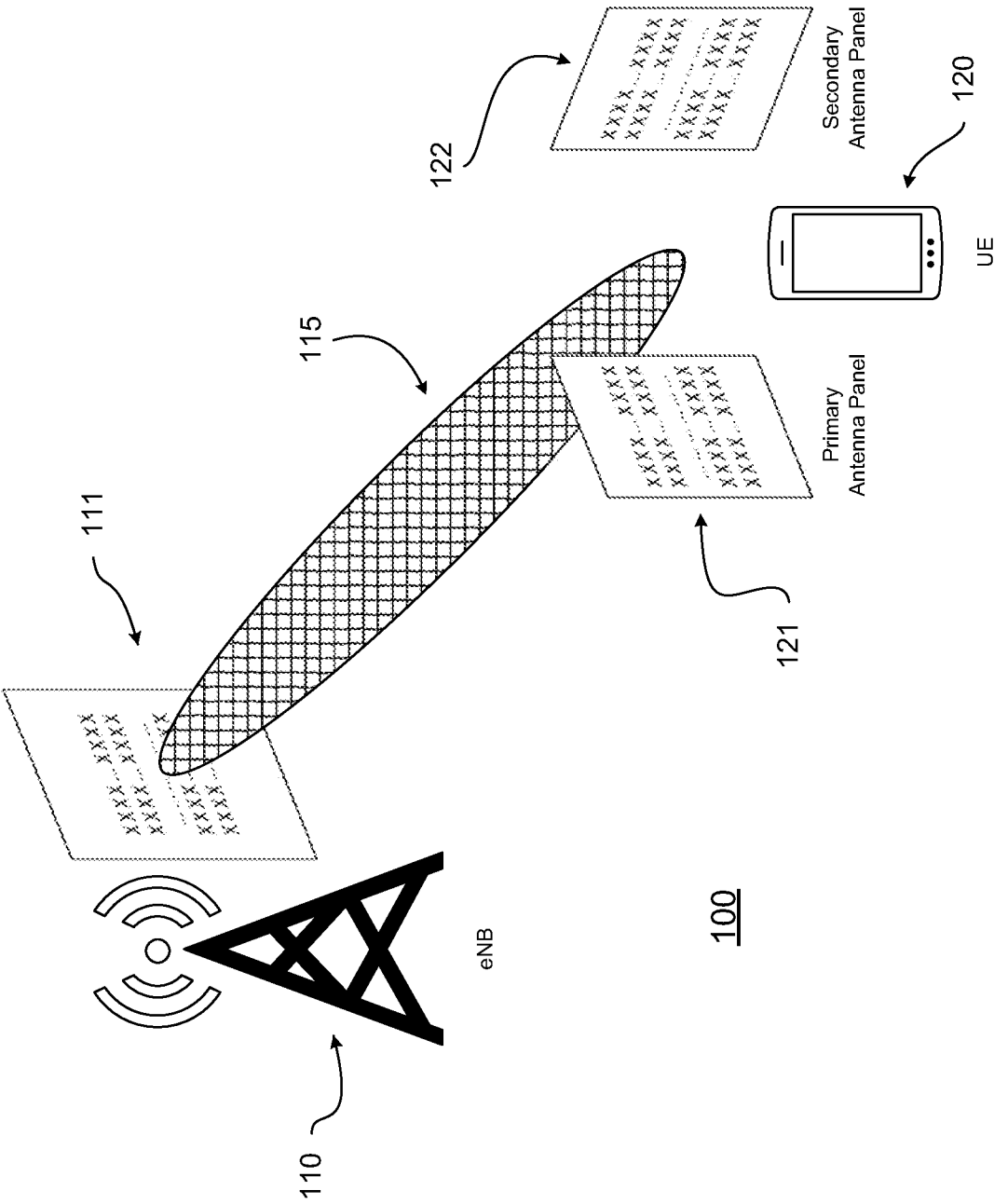


Fig. 1

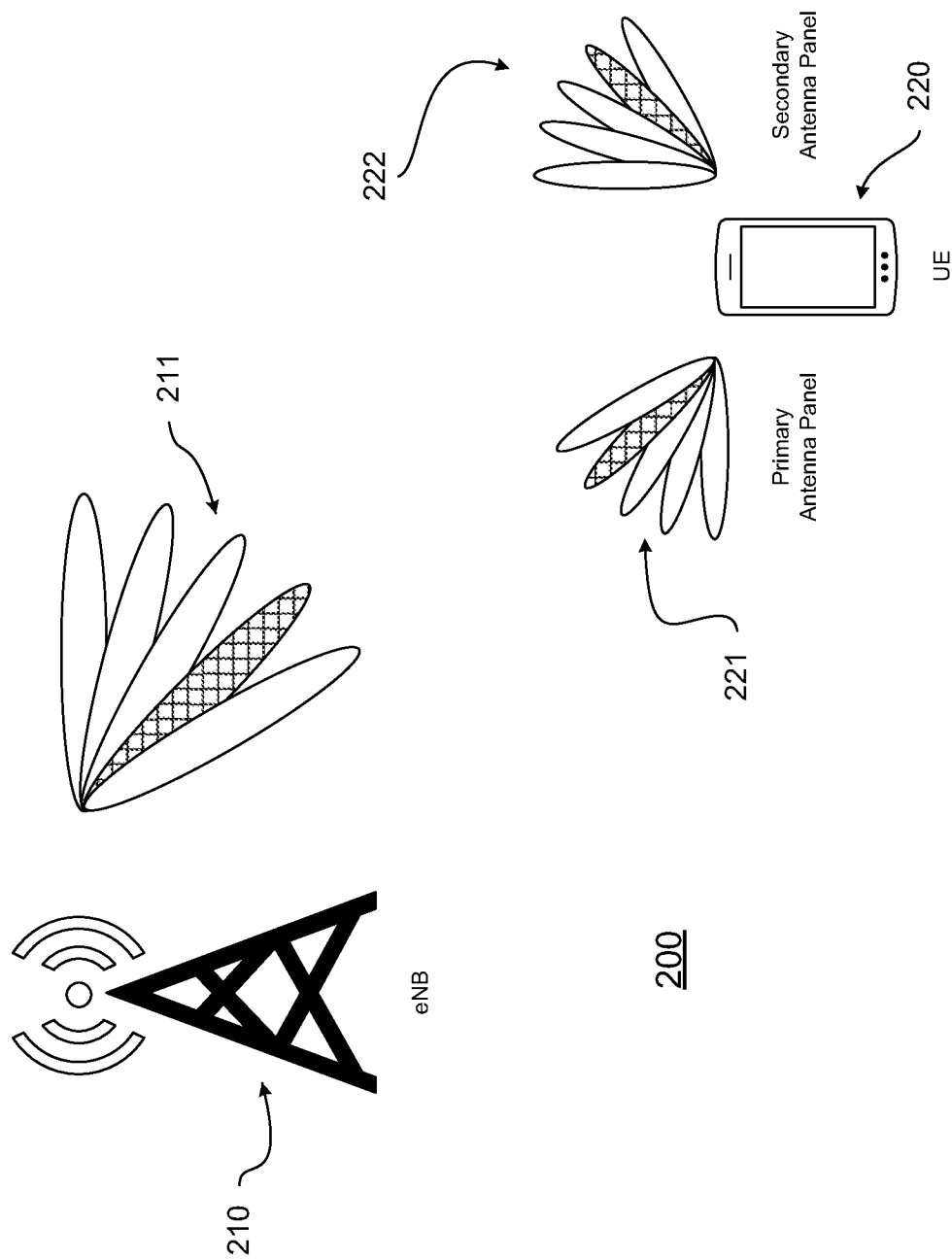


Fig. 2

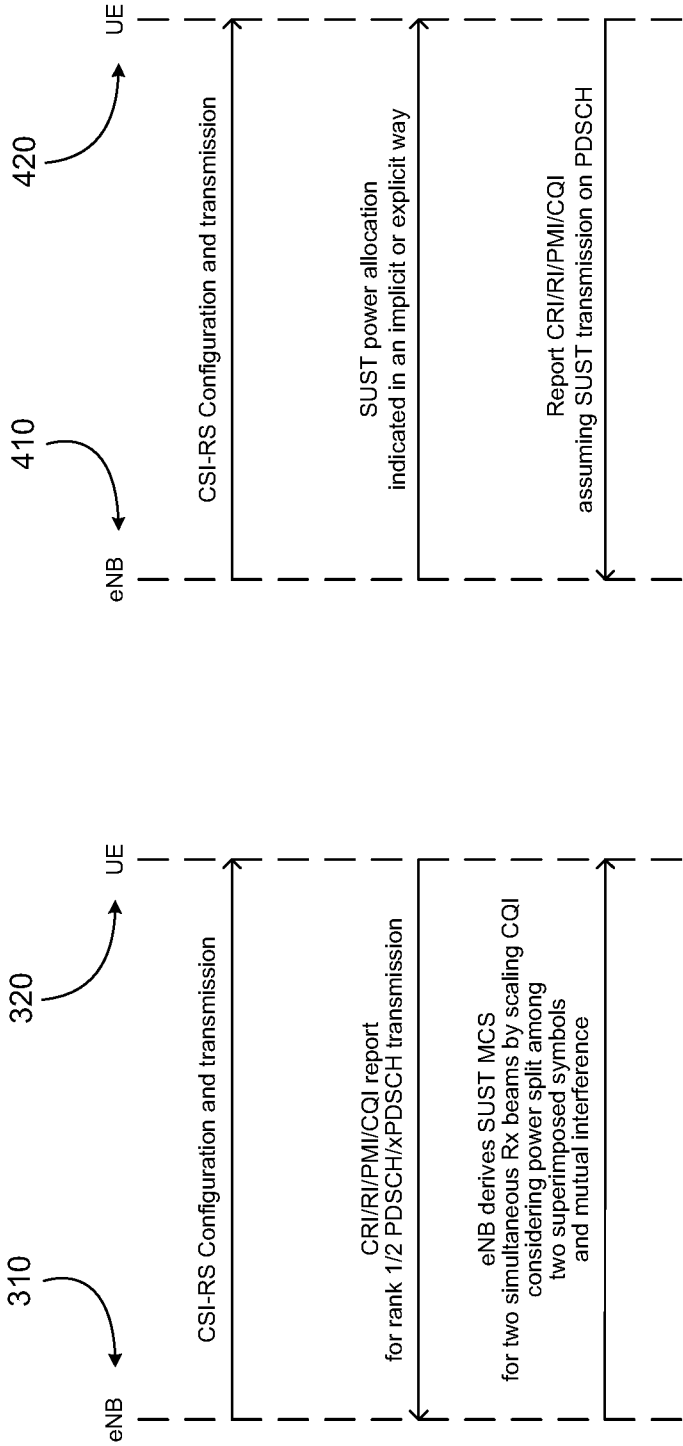


**Fig. 3**

300

**Fig. 4**

400

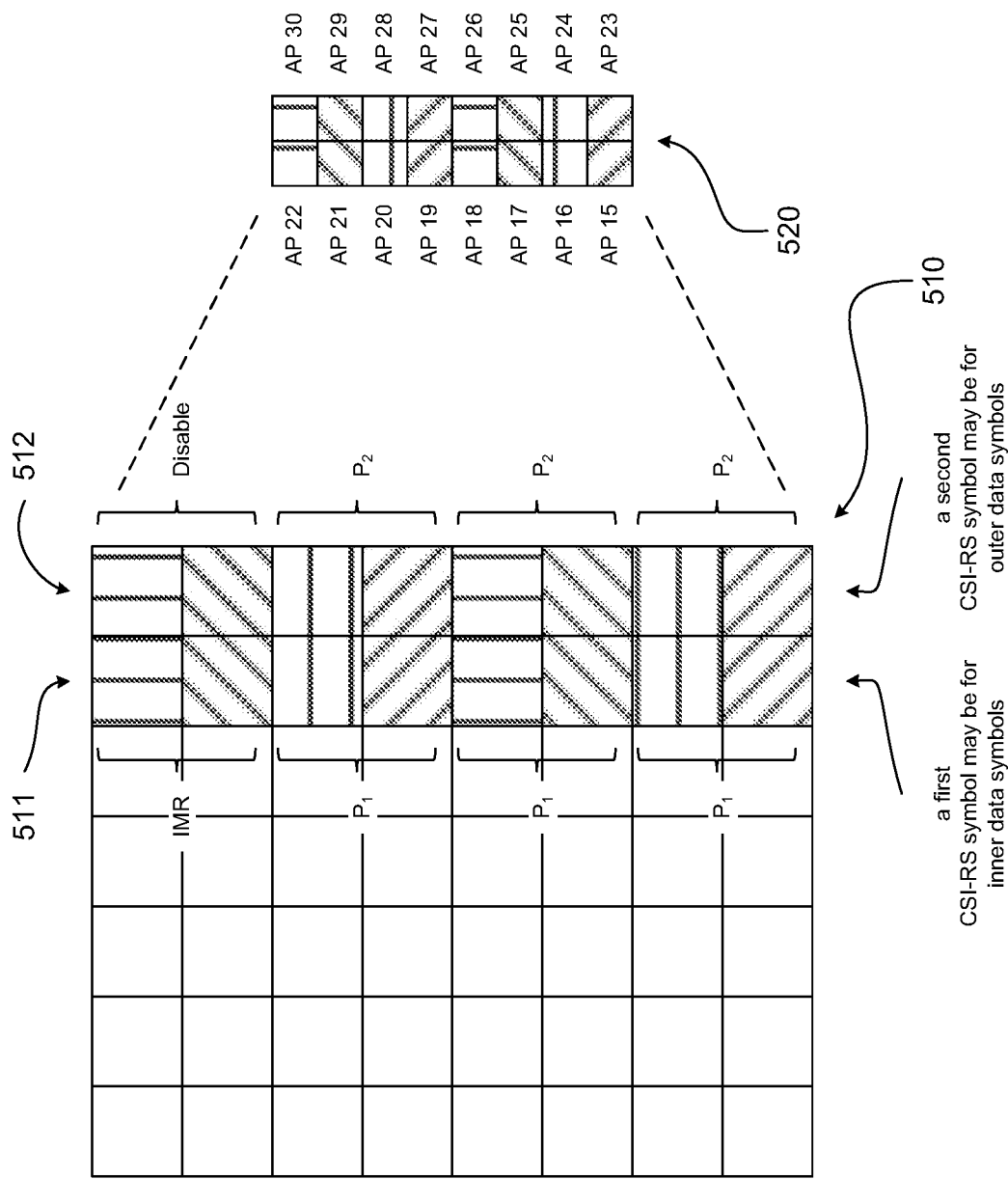


Fig. 5

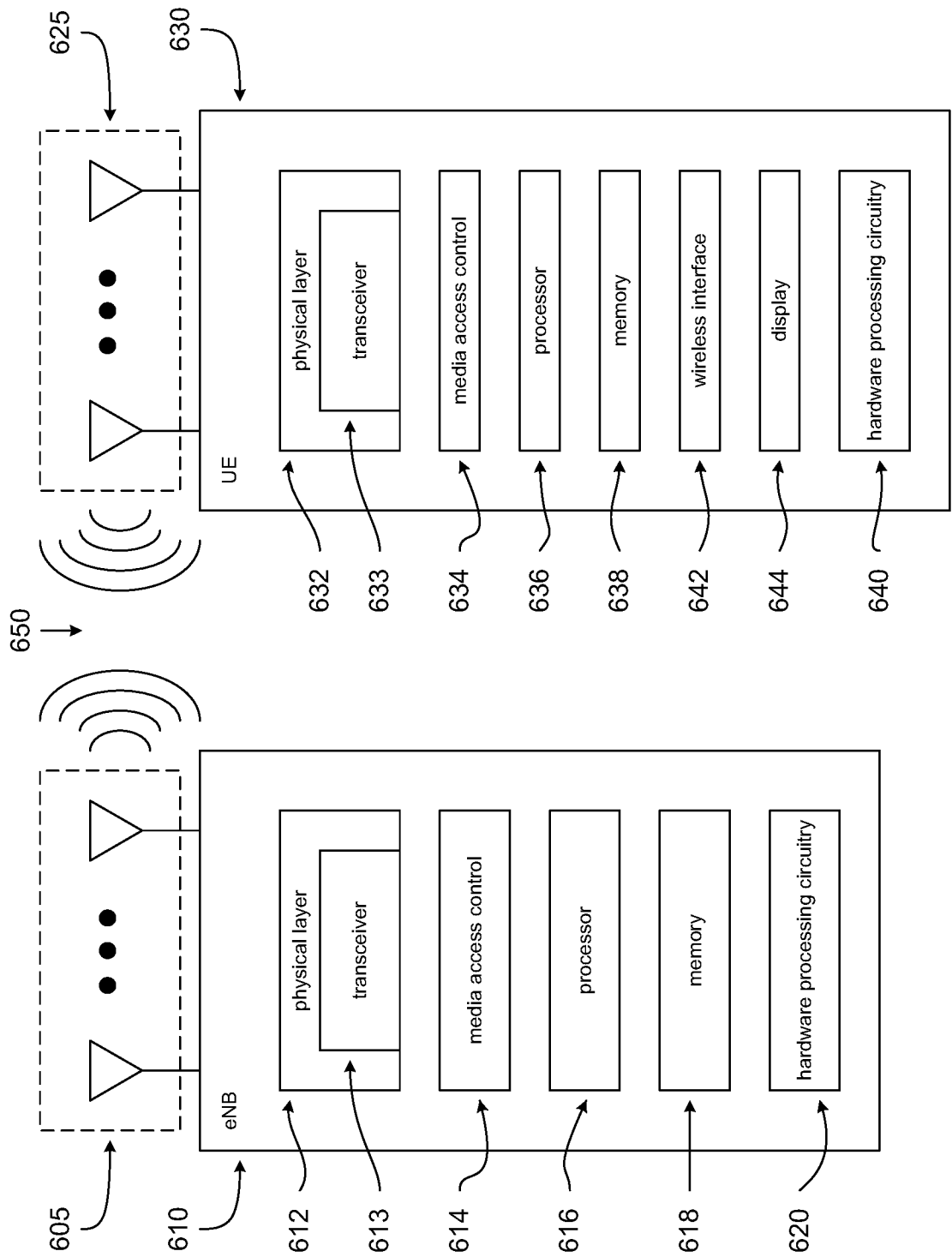


Fig. 6

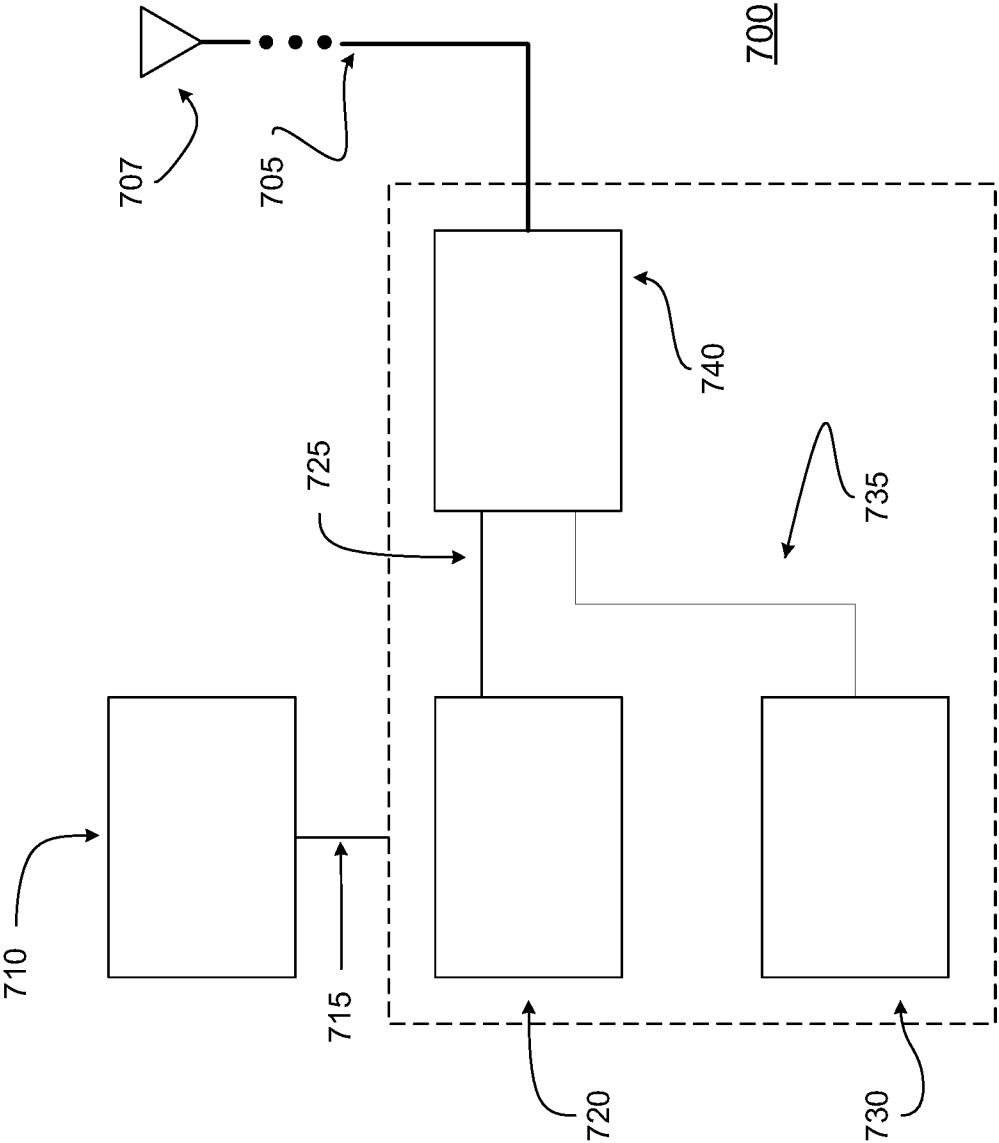


Fig. 7

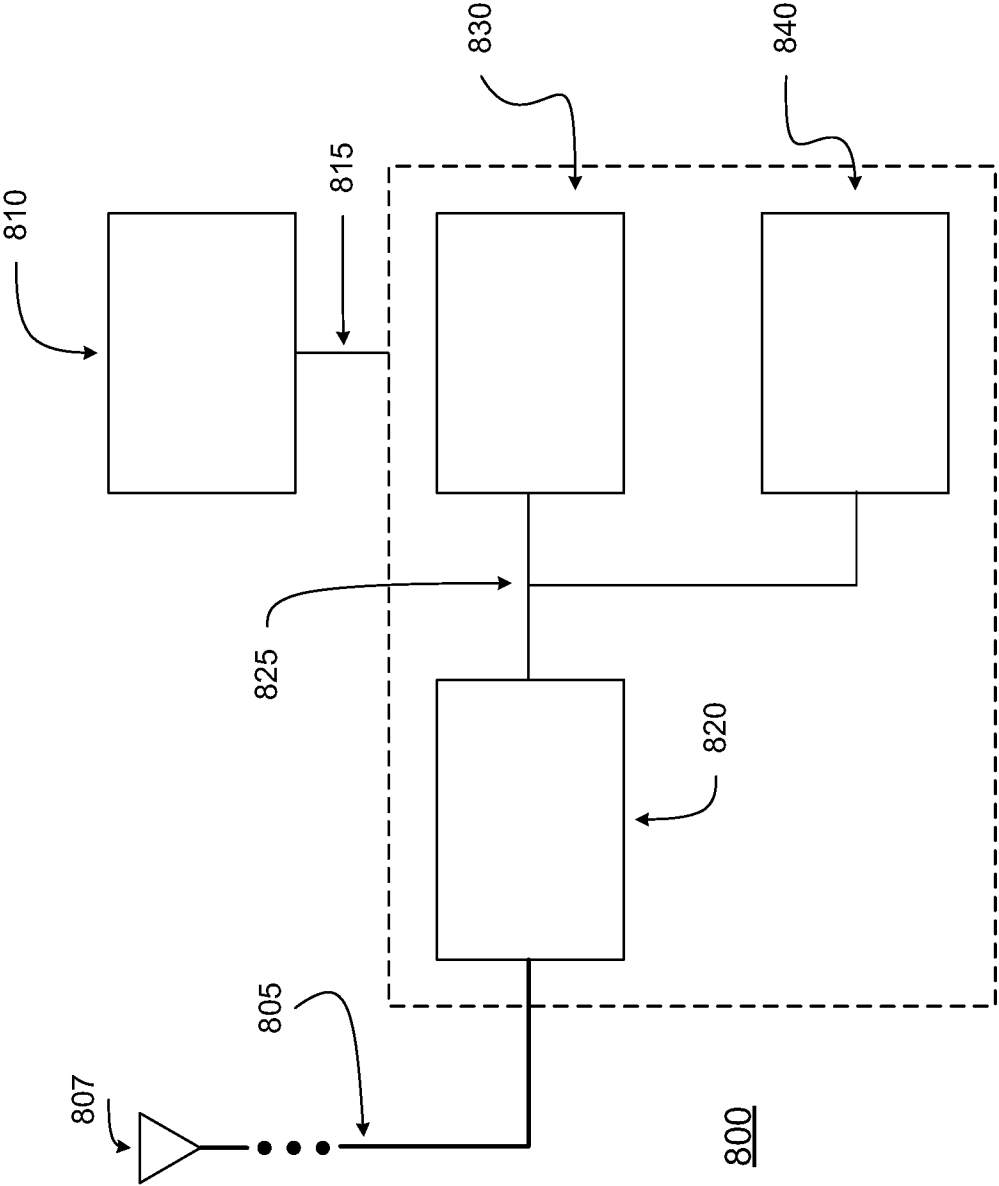
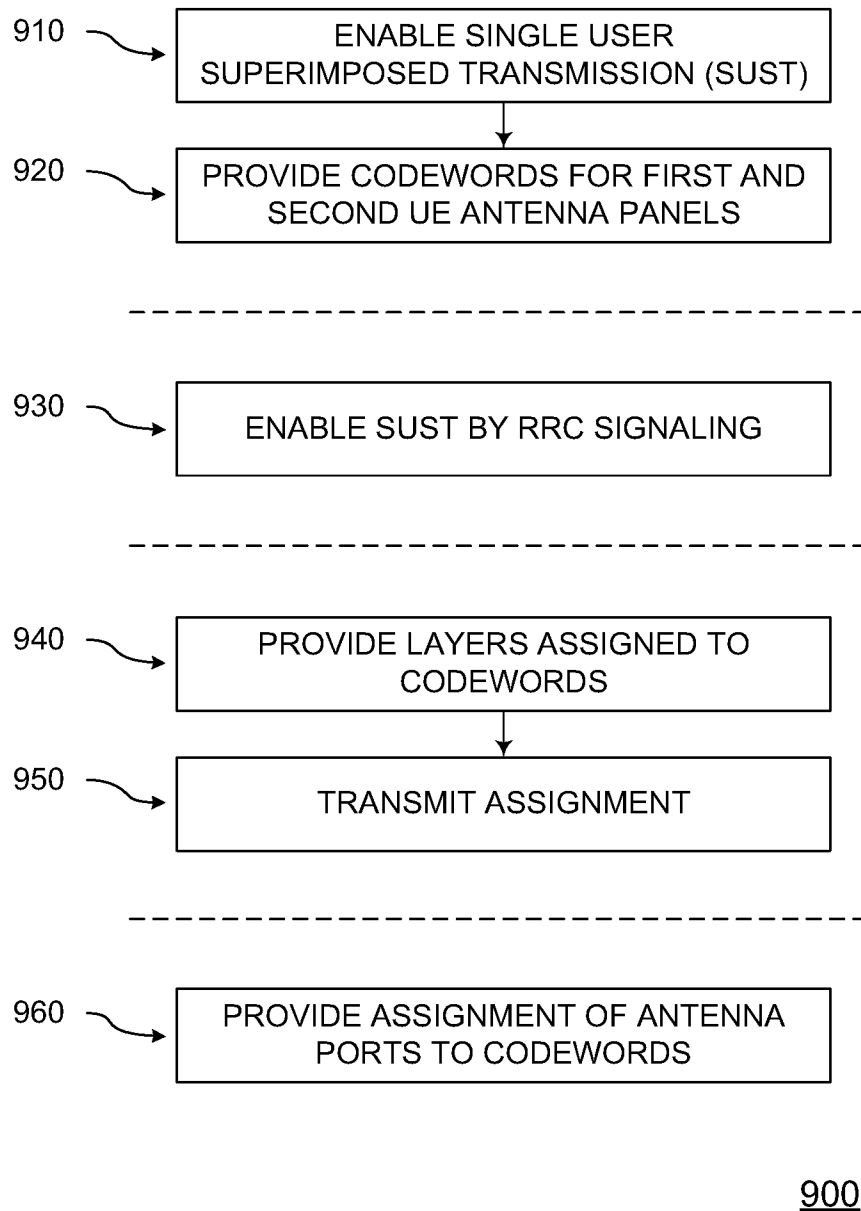
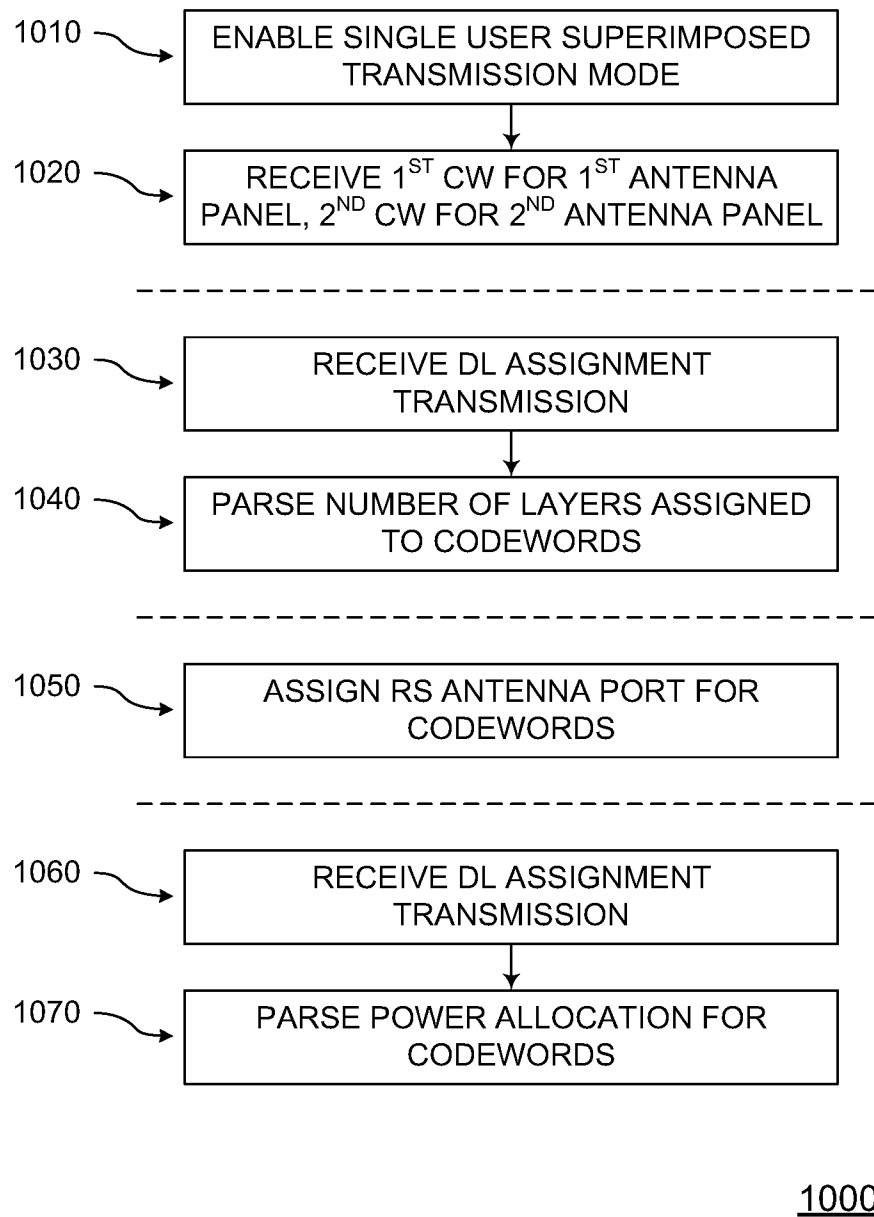


Fig. 8

**Fig. 9**

**Fig. 10**

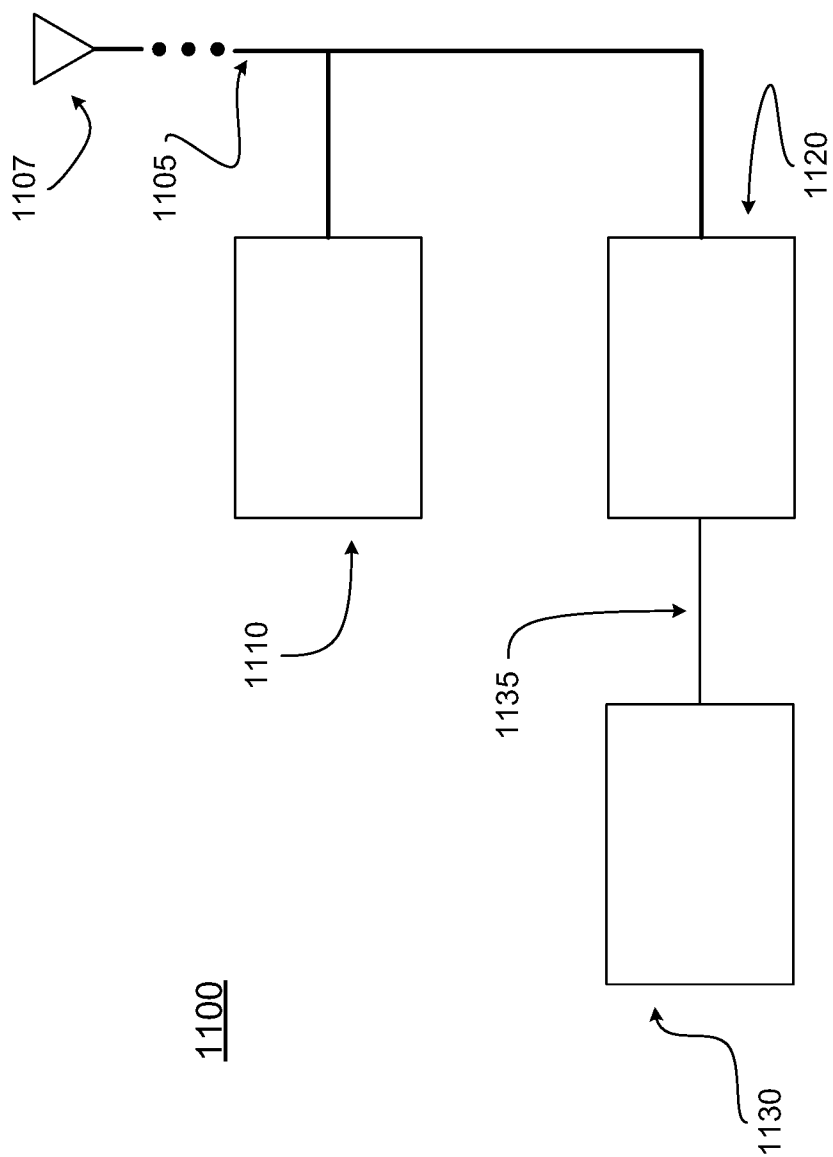


Fig. 11

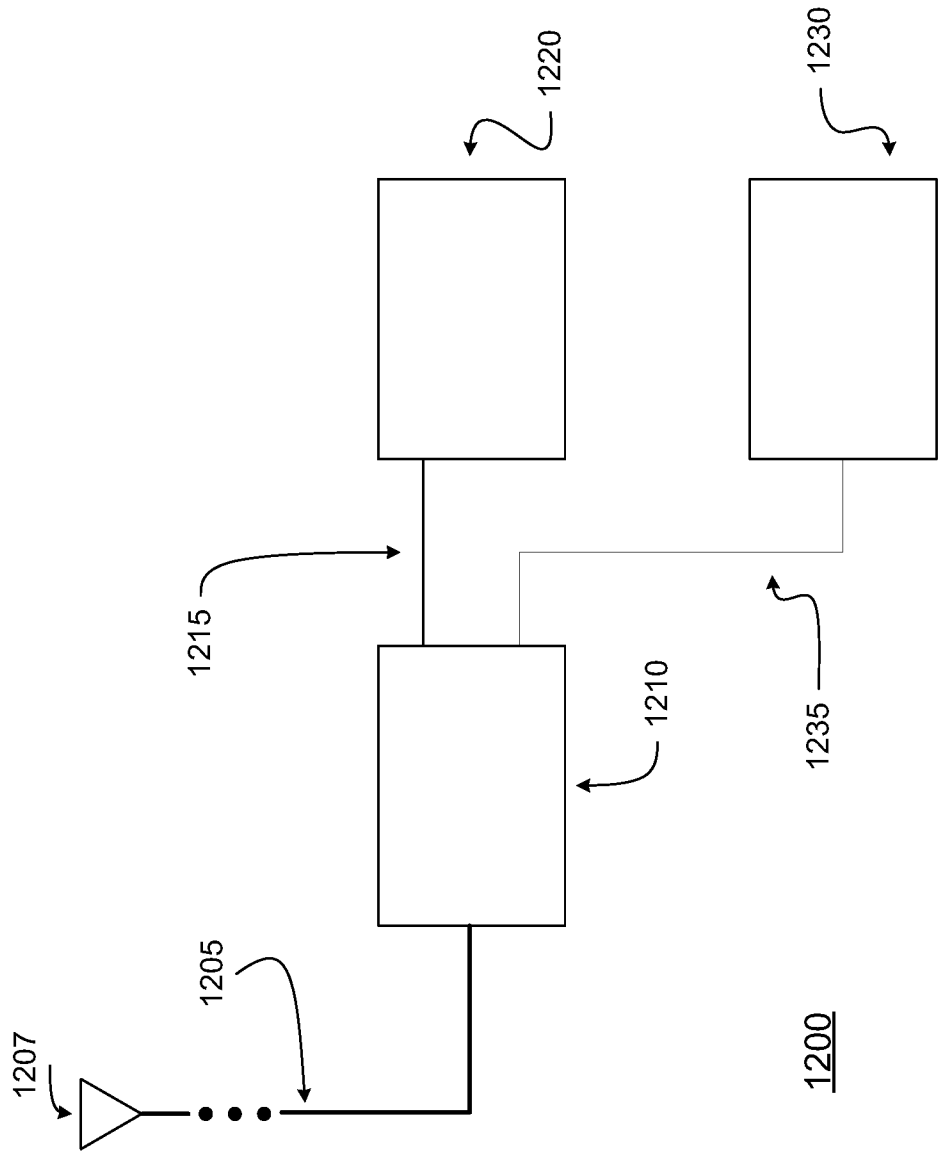
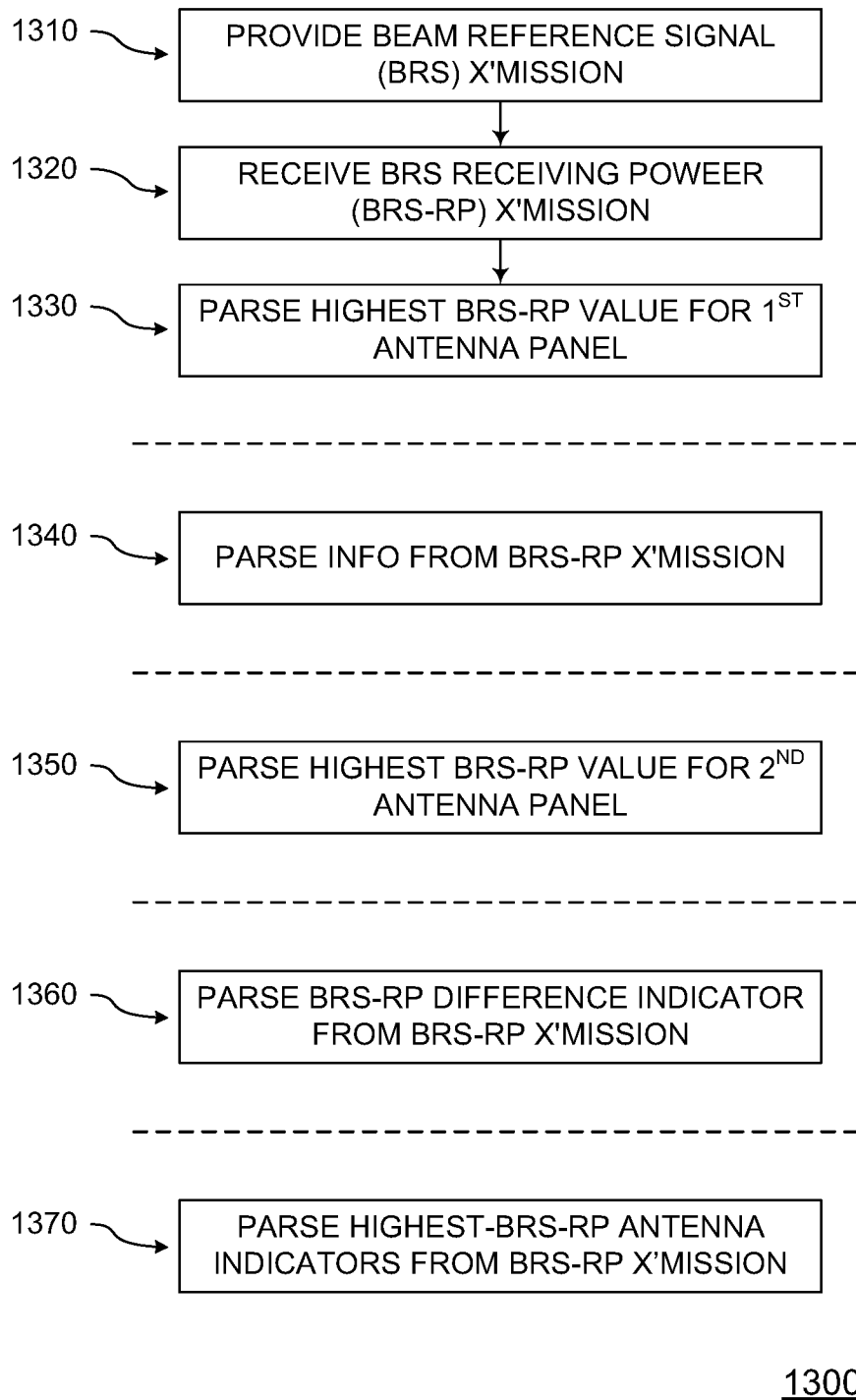
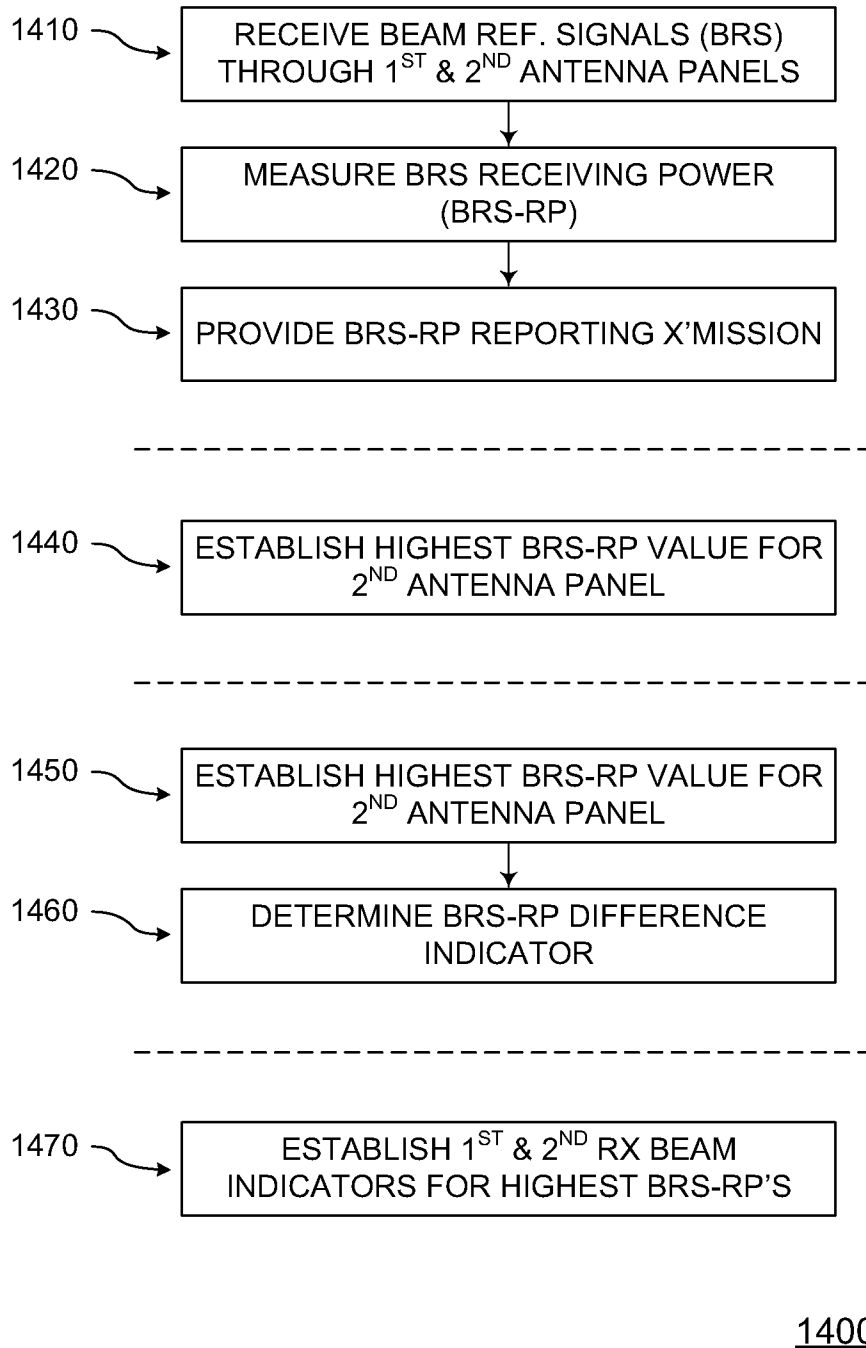


Fig. 12

**Fig. 13**

**Fig. 14**

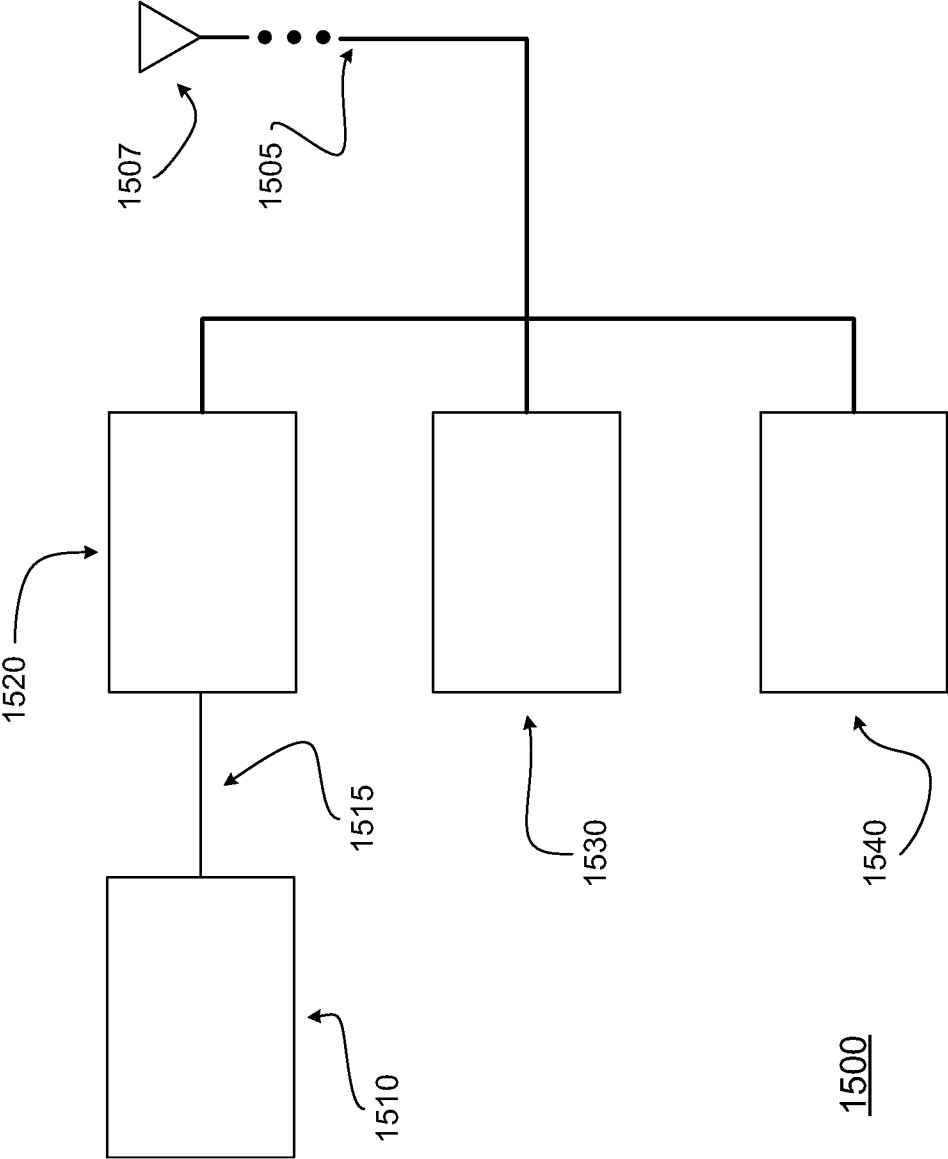


Fig. 15

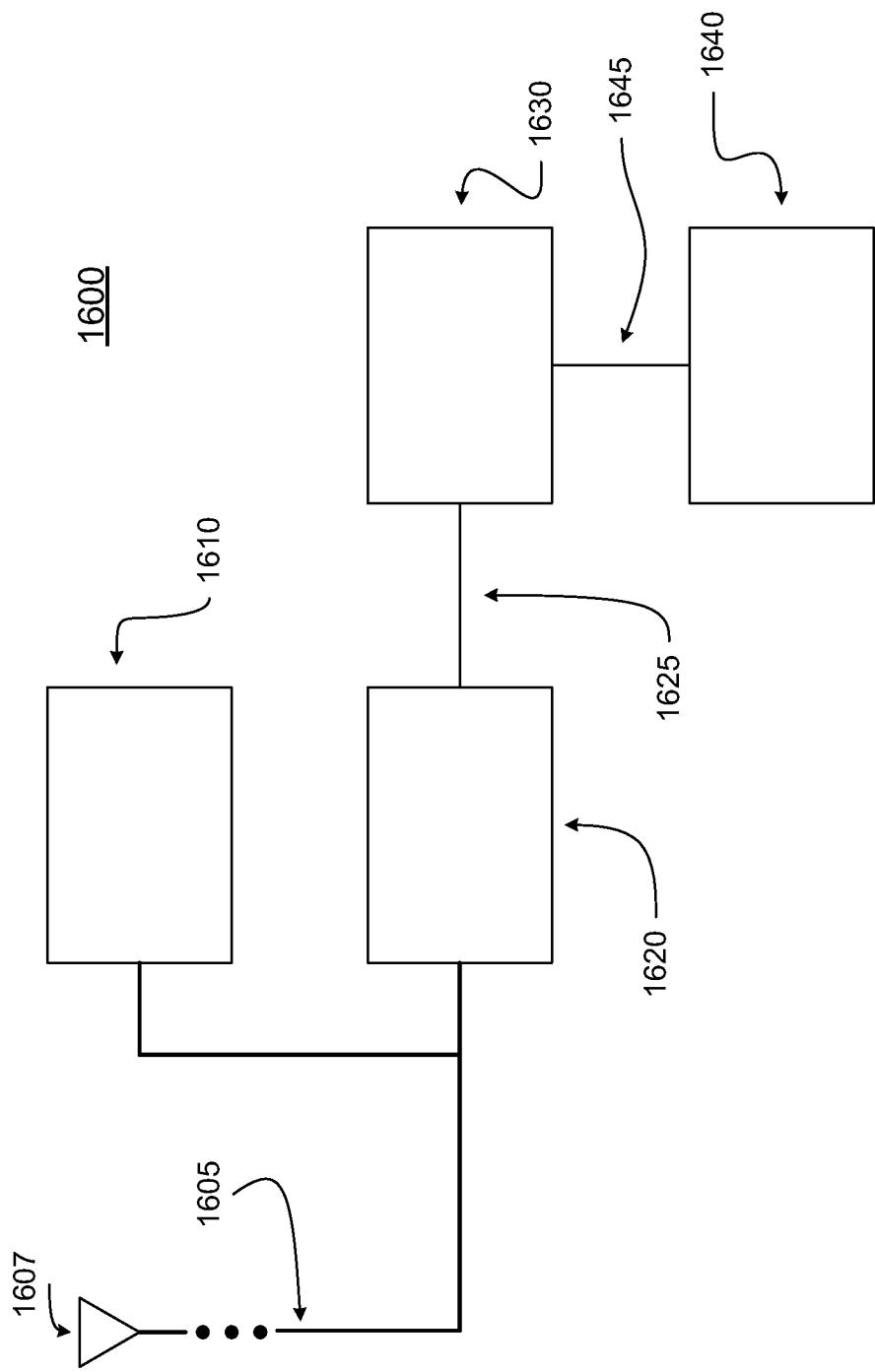
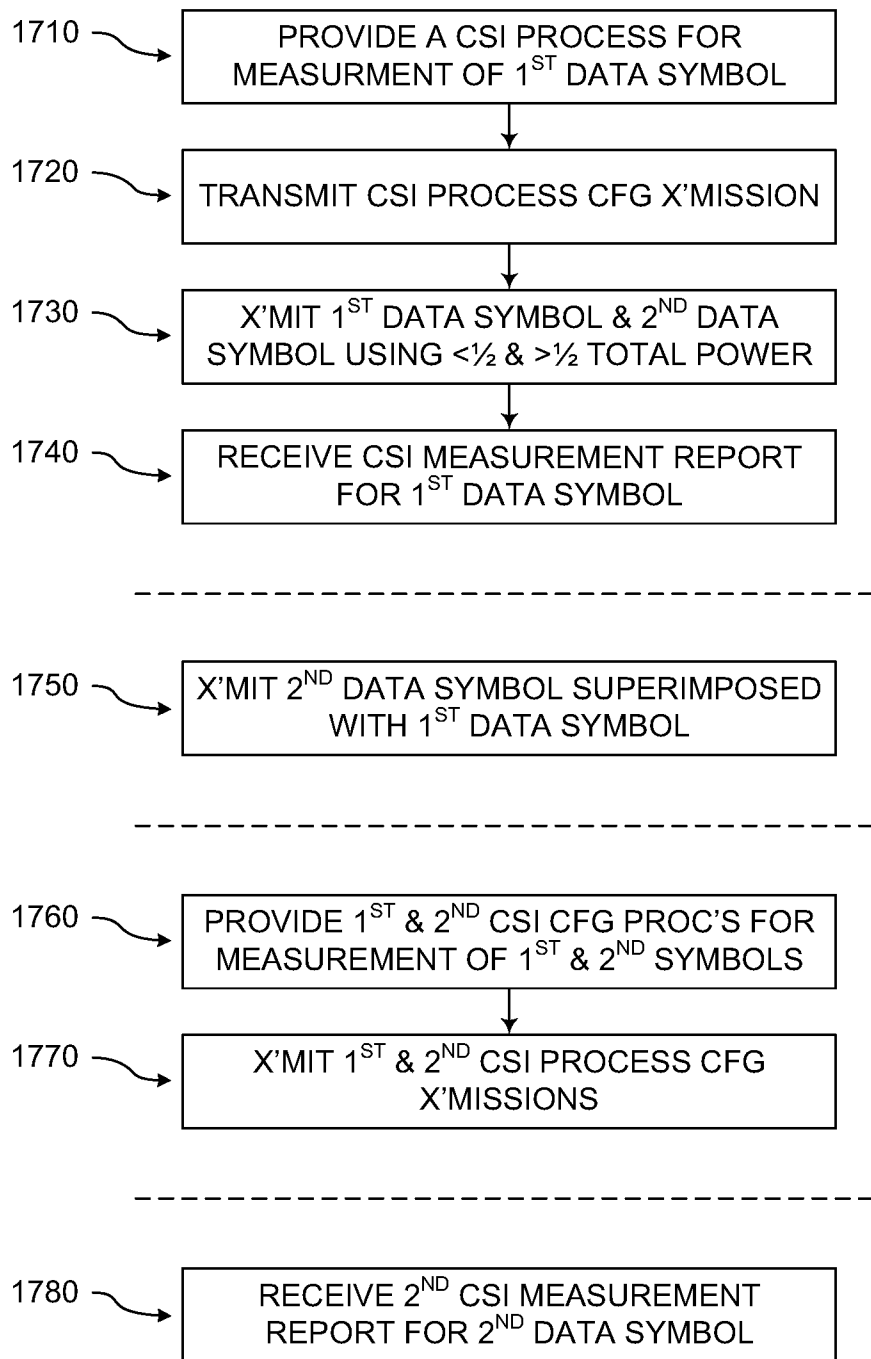
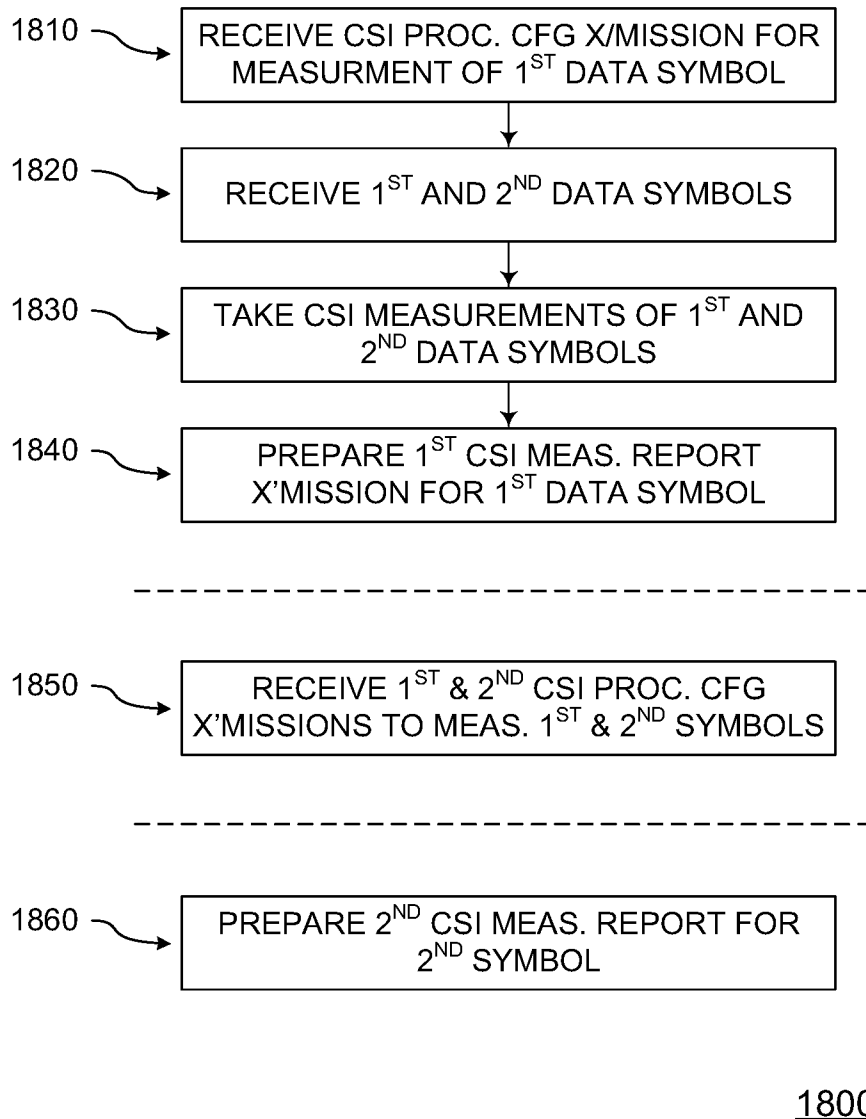


Fig. 16

1700**Fig. 17**

**Fig. 18**

1900

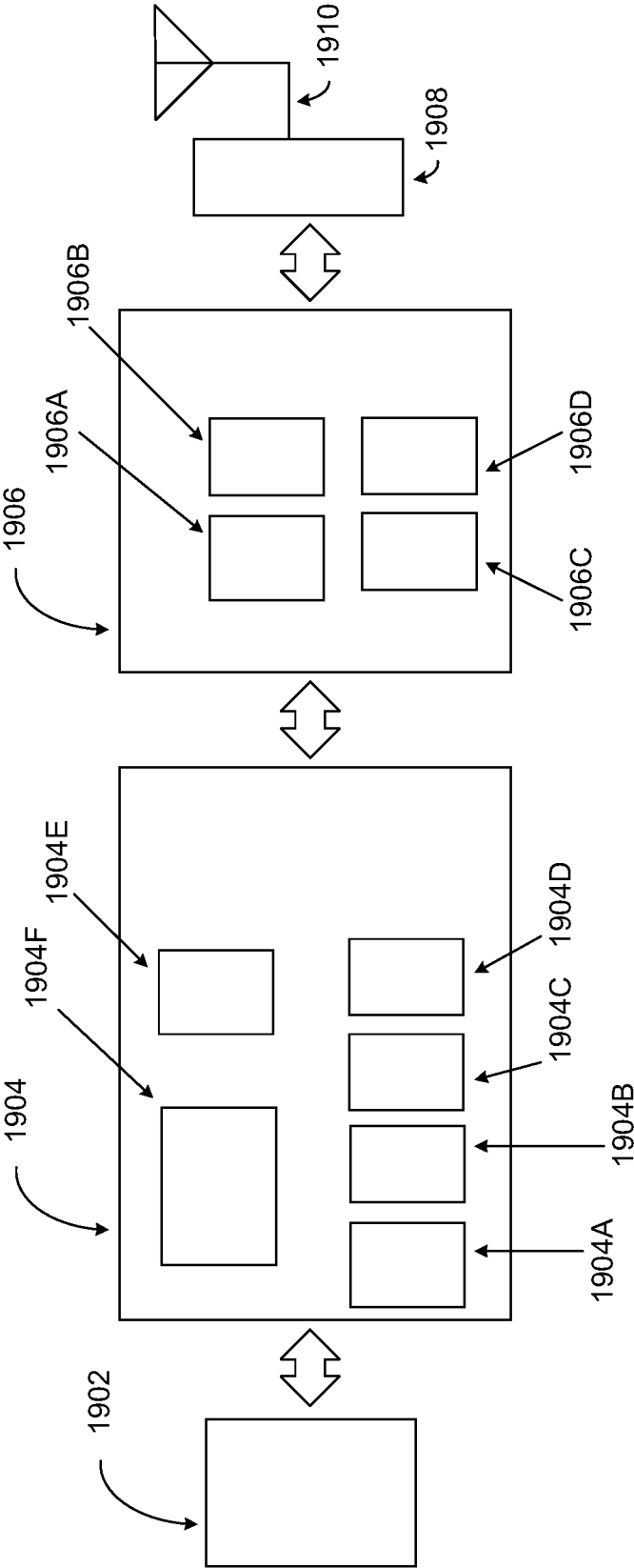


Fig. 19

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2016/078409

**A. CLASSIFICATION OF SUBJECT MATTER**

H04B 7/005(2006.01)i; H04B 7/04(2006.01)i

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

H04L, H04B, H04W

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

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

CPRSABS, CNTXT, WOTXT, USTXT, SIPOABS, DWPI, CNKI: singl+, user+, UE+, super+, codeword+, impos+, structure+, super?impos+, code?word+, multi?direction+, superimpos+, antenna+, panel+, SUST, SUST+, evolve+, equipment+, node? B+, transmi+, mode+, eNB+,multi+, direction+

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                       | Relevant to claim No. |
|-----------|----------------------------------------------------------------------------------------------------------|-----------------------|
| A         | CN 101485103 A (FUJITSU LTD) 15 July 2009 (2009-07-15)<br>The whole document                             | 1-23                  |
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☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

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Date of the actual completion of the international search

12 July 2016

Date of mailing of the international search report

26 July 2016

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**INTERNATIONAL SEARCH REPORT**  
**Information on patent family members**

International application No.

**PCT/CN2016/078409**

| Patent document<br>cited in search report |            |    | Publication date<br>(day/month/year) | Patent family member(s) |             |    | Publication date<br>(day/month/year) |
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