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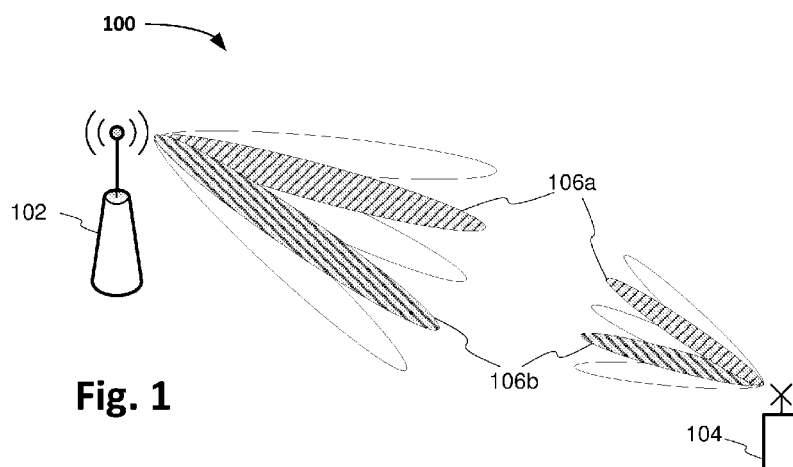
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(54) Title: **BEAMFORMED CSI-RS BASED MEASUREMENT FRAMEWORK**



(57) Abstract: There are disclosed methods and apparatus to facilitate beamformed CSI-RS based measurement including an apparatus for use in an eNB in a wireless communication network, the apparatus comprising transmitter circuitry; and control circuitry coupled to the transmitter circuitry, the control circuitry to configure a plurality of channel state information reference signals (CSI-RS), each CSI-RS associated with one of a plurality of virtualized sectors, and cause the transmitter circuitry to transmit the configured CSI-RS, wherein each of the plurality of virtualized sectors comprises a transmit beam beamformed to be vertically narrow and horizontally wide based on an associated vertical downtilt angle.

BEAMFORMED CSI-RS BASED MEASUREMENT FRAMEWORK

CROSS REFERENCE TO RELATED APPLICATIONS

5 The present application claims priority to U.S. Provisional Patent Application No. 62/255,865, filed November 16, 2015, entitled "BEAMFORMED CSI-RS BASED MEASUREMENT FRAMEWORK" the entire disclosure of which is hereby incorporated by reference.

TECHNICAL FIELD

10 Embodiments described herein generally relate to the field of wireless communications and, more particularly, to methods and apparatus for measurement of channel state information reference signals in beamformed transmit beams.

BACKGROUND

15 It is becoming more important to be able to provide telecommunication services to fixed and mobile subscribers as efficient and inexpensively as possible. Further, the increased use of mobile applications has resulted in much focus on developing wireless systems capable of delivering large amounts of data at high speed.

One approach under consideration for improving the efficient use of spectral resources is massive Multiple Input and Multiple output (MIMO) which allows reuse of frequencies to communicate with different users in the network through spatial multiplexing.

20 BRIEF DESCRIPTION OF THE DRAWING.

Aspects, features and advantages of embodiments of the present invention will become apparent from the following description of the invention in reference to the appended drawings in which like numerals denote like elements and in which:

Fig. 1 is diagram of an example wireless network according to various embodiments;

25 Fig. 2 is a block diagram of the example wireless network of Figure 2 according to various embodiments;

Fig. 3 is a sequence diagram of messaging for beamformed channel state information reference signals (CSI-RS) based measurement according to some embodiments;

30 Fig. 4 is a block diagram of a method performed in an eNB according to some embodiments;

Fig. 5 is a block diagram of a method performed in a UE according to some embodiments;

Fig. 6 is a block diagram of an example system operable to implement some embodiments; and

Fig. 7 is a block diagram of an example User Equipment device operable to implement some embodiments.

DETAILED DESCRIPTION OF EMBODIMENTS

Various aspects of the illustrative embodiments will be described using terms commonly employed by those skilled in the art to convey the substance of their work to others skilled in the art. However, it will be apparent to those skilled in the art that some alternate embodiments may be practiced using with portions of the described aspects. For purposes of explanation, specific numbers, materials, and configurations are set forth in order to provide a thorough understanding of the illustrative embodiments. However, it will be apparent to one skilled in the art that alternate embodiments may be practiced without the specific details. In other instances, well-known features are omitted or simplified in order to not obscure the illustrative embodiments.

Further, various operations will be described as multiple discrete operations, in turn, in a manner that is most helpful in understanding the illustrative embodiments; however, the order of description should not be construed as to imply that these operations are necessarily order dependent. In particular, these operations need not be performed in the order of presentation.

The phrase “in one embodiment” is used repeatedly. The phrase generally does not refer to the same embodiment; however, it may. The terms “comprising,” “having,” and “including” are synonymous, unless the context dictates otherwise. The phrase “A/B” means “A or B”. The phrase “A and/or B” means “(A), (B), or (A and B)”. The phrase “at least one of A, B and C” means “(A), (B), (C), (A and B), (A and C), (B and C) or (A, B and C)”. The phrase “(A) B” means “(B) or (A B)”, that is, A is optional.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that a wide variety of alternate and/or equivalent implementations may be substituted for the specific embodiments shown and described, without departing from the scope of the embodiments of the present disclosure. This application is intended to cover any adaptations or variations of the embodiments discussed herein. Therefore, it is manifestly intended that the embodiments of the present disclosure be limited only by the claims and the equivalents thereof.

As used herein, the term “module” may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and/or memory (shared, dedicated, or group) that execute one or more software or firmware instructions and/or programs, a combinational logic circuit, and/or other
5 suitable components that provide the described functionality.

The following inventive embodiments may be used in a variety of applications including transmitters and receivers of a radio system, although the present invention is not limited in this respect. Radio systems specifically included within the scope of the present invention include, but are not limited to, network interface cards (NICs), network
10 adaptors, fixed or mobile client devices, relays, base stations, femtocells, gateways, bridges, hubs, routers, access points, or other network devices. Further, the radio systems within the scope of the invention may be implemented in cellular radiotelephone systems, satellite systems, two-way radio systems as well as computing devices including such radio systems including personal computers (PCs), tablets and
15 related peripherals, personal digital assistants (PDAs), personal computing accessories, hand-held communication devices and all systems which may be related in nature and to which the principles of the inventive embodiments could be suitably applied.

In a system implementing massive Multiple Input and Multiple output (MIMO), or Full Dimension MIMO (FD-MIMO), a large number of service antennas may be used to
20 provide a number of virtual beams that may provide a high degree of spatial separation between terminals in a wireless network. Thus, using massive MIMO, a system may be able to support a large number of users on the same bandwidth simultaneously.

According to an example massive MIMO implementation, an evolved NodeB (“eNodeB” or “eNB”) may transmit a number of analog sector transmitting (Tx) beams, and each
25 sector Tx beam may be generated based on different vertical down tilting angles. That is, a single eNB may provide a plurality of virtualized sectors that are horizontally wide and vertically narrow. The eNB may transmit multiple antenna ports from each sector Tx beam. Within each virtualized sector Tx beam, a digital precoder may be applied to provide further horizontal Tx beamforming.

A user equipment (UE) served by the eNB may select one sector Tx beam and report the Channel State Information (CSI) measured from this sector Tx beam. In particular, the UE may report a Reference Signal Receiving Power (RSRP) of one sector Tx beam. Then the UE may report the CSI for the selected sector Tx beam which may contain a Channel Quality Indicator (CQI), Rank Indicator (RI), and Precoder Matrix Indicator (PMI). The eNB
30 usually relies on the PMI to create a Tx beam for data transmission on the selected sector Tx beam.
35

However, in systems that implement receiving (Rx) beam beamforming and multiple Rx antenna panels at the UE side, different serving Tx beams for data transmission may be observed from different Rx beams of the same or different antenna panels. In this case, the best Tx beams for data transmission may be within the same or different sector Tx beams.

Figure 1 illustrates one example arrangement of a wireless network 100 including an eNB 102 and a UE 104 configured to use different Tx beam and Rx beam pairs for data transmission. According to the example illustrated in Figure 1, the eNB 102 and UE 104 may have identified a first Tx beam – Rx beam pair 106a for transmission of data and control information, and a second, candidate, Tx beam – Rx beam pair 106b.

As a result of UE rotation, movement, or Doppler Effect, the active antenna panel or active Rx beam on the UE side may change so that the Tx beams for data transmission may need to be updated. The Tx beam change for data transmission may include a sector Tx beam change, horizontal digital Tx beam change within a sector Tx beam, or both. As the CSI-RS may be beamformed within a sector Tx beam, it may be beneficial in some embodiments to measure the receiving power from the narrow vertical and narrow horizontal beams to allow beam switching from any two Tx beams for data transmission from either the same or different sector Tx beams.

Example embodiments provide systems, apparatuses, and methods for beamformed CSI-RS based measurement framework with the UE side Rx beamforming to enable beam mobility in millimeter wave (mmWave) systems.

Figure 2 schematically illustrates the wireless communication network 100 in accordance with various embodiments. Wireless communication network 100 (hereinafter “network 100”) may be an access network of a 3rd Generation Partnership Project (3GPP) long-term evolution (LTE), long-term evolution- advanced (LTE-A) network such as an evolved universal mobile telecommunication system (UMTS) terrestrial radio access network (E-UTRAN) or 5G network.

The network 100 may include a base station, e.g., evolved node base station (eNB) 102, configured to wirelessly communicate with one or more mobile device(s) or terminal(s), e.g., user equipment (UE) 104. In various embodiments, the eNB 102 may be a fixed station (e.g., a fixed node) or a mobile station/node.

The eNB 104 may include receiver circuitry 120 with which to receive signals from UE 104 via one or more antennas 130. eNB 104 may include transmitter circuitry 124 with which to transmit signals to UE 104 via one or more antennas 130. eNB 104 may also include controller circuitry 128 in communication with receiver module 120 and transmitter module 124 and configured to encode and decode information communicated by the

signals. Controller module 128 also includes CSI-RS configuration circuitry 126 to facilitate configuration and report processing of beamformed CSI-RS messages in the network 100.

In various embodiments, the control circuitry 128 may be comprised in a separate device from the receiver circuitry 120 and/or the transmitter circuitry 124. For example, the eNB
5 104 may be implemented as part of a cloud-RAN (C-RAN).

In various embodiments, the UE 104 and/or the eNB 102 may include a plurality of antennas 156, 130 to implement a multiple-input-multiple-output (MIMO) transmission system, which may operate in a variety of MIMO modes, including single-user MIMO (SU-MIMO), multi-user MIMO (MU-MIMO), close loop MIMO, open loop MIMO or variations
10 of smart antenna processing.

In various embodiments, UE 104 comprises transmitter circuitry 148 for transmitting signals to eNB 102 and receiver circuitry 144 for receiving signals from the eNB 102. UE 104 further comprises controller circuitry 152 coupled between receiver circuitry 144 and transmitter circuitry 148 and including communication circuitry 154 to encode and
15 decode information communicated by the signals. Controller circuitry 152 may also include CSI reporting circuitry 158 to facilitate measurement and reporting of channel state information by the UE 102.

According to embodiments, the UE 104 may attempt to receive channel state information reference signals (CSI-RS) for each sector Tx beam using receiver circuitry
20 144 and then measure a reference signal received power (RSRP) for each sector Tx beam received based on the CSI-RS beamformed within each sector Tx beam. The RSRP may be used as an indication of the signal quality for each sector Tx beam being received by the UE, and therefore the UE may select the sector Tx beam having the highest measured RSRP value. The UE 104 may then report the selected Tx beam to the eNB 102, and may
25 include the measured RSRP value associated with the selected sector Tx beam.

According to some embodiments, the UE 104 may report all measured RSRP values and their associated sector Tx beams to the eNB 102, and selection of a sector Tx beam may then be performed in the eNB 102.

Once sector Tx selection has been performed, the UE may then attempt to receive UE
30 specific CSI-RS on the selected sector Tx beam and to determine based on the received CSI-RS a precoder matrix indicator to signal to the eNB 102 a horizontal Tx beam within the selected Tx sector to be used to communicate data.

Based on the information provided by the UE 104 to the eNB 102, a two-dimensional narrow Tx beam may be defined. Further CSI-RS may be transmitted on this two-
35 dimensional narrow beam to allow the UE to determine a channel quality indicator, rank indicator, etc. for the beamformed link.

Thus, the UE 104 may select its sector Tx beam based on the CSI-RS Receiving Power (CSIRS-RP) of each sector Tx beam, as the CSI-RS may be beamformed with different sector Tx beams. The UE may report the horizontal Tx beam directions by the PMI. Then the eNodeB may further transmit one additional beamformed CSI-RS using the Tx beam for data transmission. UE may further measure this additional CSI-RS from this Tx beam to derive CQI RI etc.

At the eNB 102, the active Tx beam may be defined as the one digital narrow beam with the highest reported CQI from the sector Tx beam having highest reported CSIRS-RP. According to some embodiments, a candidate Tx beam can be defined as the digital narrow beam with the highest CQI from the sector beam which is cannot be measured by UE simultaneously as the active Tx beam.

Table 1 illustrates one example for the CSIRS-RPs measured by UE 104 using different Rx beams. In the example of Table 2, Tx beam 2 has the highest reported received power and may be designated to be the active Tx beam and the Tx beam 4 has the second highest reported received power and may be designated to be the candidate Tx beam by the eNB 102.

BRS-RP [dBm]		Sector Tx beam				
		1	2	3	4	5
Rx beam	1				-89	
	2			-88	-77	-93
	3		-88		-92	
	4	-83	-71	-82		
	5		-80			

Table 1: one example for RSRP measurement result

In some embodiments, the active Tx beam and candidate Tx beam can be the same sector Tx beam.

To support a narrow vertical and horizontal beamformed data transmission within the vertical narrow and horizontal wide beam sector Tx beam, the basic procedure may contain the sector Tx beam selection, digital beam selection and CSIRS-RP measurement and report as illustrated in Figure 3.

According to the method 200 illustrated in the sequence diagram of Figure 3, eNB 102 begins by transmitting 202 multiple CSI-RS(s) on a plurality of vertically narrow, horizontally wide sector Tx beams. These sector Tx beams are monitored by the UE 104,

and RSRP values for one or more sector Tx beams are reported 204 to the eNB to facilitate sector Tx beam selection.

The eNB 102 then transmits 206 UE specific CSI-RS within the selected sector Tx beam. In some embodiments, multiple horizontally narrow beams within the selected sector Tx beam may be used. The UE 104, uses the received CSI-RS information to provide 208 a precoder matrix indicator to the eNB 102 defining a horizontally narrow beam within the Tx sector. The eNB 102 then transmits 210 further UE specific CSI-RS using the defined two-dimensional narrow beam to allow channel state information to be determined by the UE and reported 212 to the eNB 102.

Figure 4 illustrates a method 400 performed by an eNB 102 according to some embodiments. According to the illustrated method, the eNB 102 first configures 402 CSI-RS for each of a number of virtualized, horizontally wide but vertically narrow, sector Tx beams. The eNB 102 then receives 404 at least one RSRP value associated with a sector Tx beam. A selection 406 is then made based on the received RSRP value.

Figure 5 illustrates a method 500 performed at UE 104 according to some embodiments. According to the illustrated method, the UE 104 receives 502 CSI-RS associated with virtualized, horizontally wide but vertically narrow, sector Tx beams. A reference signal received power value is then determined 504 for a virtualized sector based on the associated received CSI-RS. Determined RSRP values are then reported 506 to the eNB 102.

CSIRS-RP Measurement for sector Tx beam selection

According to some embodiments, the UE 104 may need to report an RSRP value for each sector Tx beam, which may help the eNodeB 102 to decide the best sector Tx beam for the UE.

In some embodiments, the UE 104 may maintain two non-simultaneous Rx beam(s), and may report the RSRP value with an indicator to show whether this RSRP value is measured from active Rx beam or candidate Rx beam. A current Rx beam is defined as the Rx beam used for current downlink control and signal receiving. This current Rx beam may switch between active Rx beam and candidate Rx beam according to channel conditions. Hence, in some embodiments, the context for RSRP may contain the following information:

- Cell ID;
- RSRP value;
- Rx beam Indicator;
- Subframe index or CSI-RS process ID; and
- Beam index or CSI-RS port index.

According to some embodiments, the Cell ID may be used to indicate the cell ID which used to generate the CSI-RS. RSRP value may be quantized by several bits. Subframe index may indicate the subframe index for the CSI-RS where the RSRP is measured. The Rx beam indicator may contain 1 bit, where value 0 may indicate the CSIRS-RP is measured from active Rx beam and value 1 may indicate it is measured from candidate Rx beam. Alternatively the Rx beam indicator may not be used and the UE may report two RSRPs values measured from two Rx beams per sector Tx beam to the eNodeB.

The beam index may be equal to the sector Tx beam index. Sometimes, sector Tx beam index is transparent to UE, so CSI-RS port index may be used to implicitly indicate which sector Tx beam is chosen based on the corresponding Rx beam. Two ports may be paired for vertical and horizontal channel measurement, and be equipped with the same sector Tx beam. In this case, report of only one CSI-RS port index may be sufficient. CSI-RS process ID may indicate the RSRP is measured on which CSI-RS symbols.

CSI Feedback for digital beam selection

After sector Tx beam selection, the UE may further select the Tx beam within the selected sector Tx beam. In some embodiments, if more than one simultaneous Rx beam can be applied for CSI-RS receiving, the UE may measure the same CSI-RS in the selected sector Tx beam and report more than one digital beam selection based CSI, e.g. using one PMI for one digital precoder.

According to some embodiments, two PMIs may be restricted to be measured from a rank 1 precoder codebook for N Tx antenna ports based sector Tx beam, where N is equal to the number of antenna ports for sector beam based CSI-RS. The codebook for the two PMIs may be defined by the system.

In embodiments, if the UE cannot use simultaneous Rx beams for receiving the CSI-RS, the PMI for the active Rx beam and candidate Rx beam may be measured in two CSI-RS subframes and reported individually or jointly as in the embodiment above.

CSI-RS Tx beam for CSI measurement

After receiving the PMI for active Rx beam and PMI for candidate Rx beam, the eNodeB may be able to generate the narrow Tx beam based on the feedback PMIs and the sector Tx beam.

In some embodiments, the CSI-RS may be divided into several groups, and each CSI-RS group may include K antenna ports. In one example, K may be equal to 2. Different narrow Tx beams may be applied to different CSI-RS groups. In one example, a narrow Tx beam can be generated as follow.

$$P_{i,j} = P_c^i P_d^j \quad (1)$$

Where P_c^i may indicate the $N_{tx} \times N_p$ analog beamforming weight for sector Tx beam i ; P_d^j may denote the $N_p \times K$ digital precoder for PMI j ; $P_{i,j}$ may refer to the narrow Tx beam for sector i and PMI j ; N_{tx} is the number of Tx antenna; N_p is the number of CSI-RS antenna ports.

The UE may then measure a number of narrow Tx beams of one sector Tx beam in one CSI-RS subframe, and may report the CSI containing the following items:

- Beam Index (BI);
- 10 • Rank Indicator (RI);
- Precoding Matrix Indicator (PMI);
- Channel Quality Indicator (CQI); and
- Rx beam Indicator.
- 15 In some embodiments, not all the above items in CSI may be transmitted, and the Uplink Control Information (UCI) may contain more than one of the above CSI blocks.

In some embodiments, the UE may measure and report the CSIRS-RP based on each CSI-RS group. Then the UE may report the CSIRS-RP with the following pattern:

- Cell ID;
- RSRP value;
- 20 • Rx beam Indicator;
- Subframe index for the measured CSI-RS; and
- Beam index or CSI-RS group index corresponded to active beam.

In another embodiment, the UE may report up to X CSIRS-RPs, where X can be configured by the system or Radio Resource Control (RRC) signaling, e.g. $X=8$. Further the UE may only include a report for valid beams where a valid beam can be defined as a beam with

30 the following condition in (2) is valid.

$$r_a - r_{c,k} < \Delta \quad (2)$$

Where r_a may indicate the CSIRS-RP measured from active Tx beam with the current Rx beam; $r_{c,k}$ may indicate the CSIRS-RP measured from the Tx beam c with Rx beam k . The Rx beam k can be either the current Rx beam or candidate Rx beam. Threshold Δ

35 denotes the CSIRS-RP threshold, which may be configured via RRC signaling.

Various embodiments have been described in the context of transmit or receive beams that are beamformed to be horizontally and/or vertically narrow as opposed to wide. Such beamforming rely on the use of a plurality of antenna elements with a narrower beam being achievable through the use of a greater number of antenna elements.

According to some embodiments, an antenna port used to transmit a transmit beam for a virtualized sector beamformed to be vertically narrow and horizontally wide is associated with a first number, N_v , of vertical antenna elements and a second number, N_h , of horizontal antenna elements, where N_v is greater than N_h . Furthermore, according to
5 some embodiments N_v is greater than or equal to 8 while N_h is less than or equal to 2.

Throughout the disclosure, the term eNB may loosely refer to a cell or RAN (Radio Access Network) node or transmission point (TP). The relay UE may belong to the same or different eNB or entity. When it belongs to different entity than the direct path of the remote UE, then additional signaling and context transfer might need to happen for the
10 remote UE to switch between the direct path and relay UE path. Furthermore, the remote UE may be receiving data from multiple relay UEs, each associated with the same eNB/entity or different eNB/entity than the remote UE itself.

Embodiments of the technology herein may be described as related to the third generation partnership project (3GPP) long term evolution (LTE) or LTE-advanced (LTE-A)
15 standards. For example, terms or entities such as eNodeB (eNB), mobility management entity (MME), user equipment (UE), etc. may be used that may be viewed as LTE-related terms or entities. However, in other embodiments the technology may be used in or related to other wireless technologies such as the Institute of Electrical and Electronic Engineers (IEEE) 802.16 wireless technology (WiMax), IEEE 802.11 wireless technology
20 (WiFi), various other wireless technologies such as global system for mobile communications (GSM), enhanced data rates for GSM evolution (EDGE), GSM EDGE radio access network (GERAN), universal mobile telecommunications system (UMTS), UMTS terrestrial radio access network (UTRAN), or other 2G, 3G, 4G, 5G, etc. technologies either already developed or to be developed. In those embodiments, where LTE-related
25 terms such as eNB, MME, UE, etc. are used, one or more entities or components may be used that may be considered to be equivalent or approximately equivalent to one or more of the LTE-based terms or entities.

As used herein, the term "circuitry" may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or
30 group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable hardware components that provide the described functionality. In some embodiments, the circuitry may be implemented in, or functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may
35 include logic, at least partially operable in hardware.

Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. Figure 6 illustrates, for one embodiment, example components of an electronic device 600. In embodiments, the electronic device 600 may

be, implement, be incorporated into, or otherwise be a part of a user equipment (UE), an evolved NodeB (eNB), or any other suitable electronic device. In some embodiments, the electronic device 600 may include application circuitry 602, baseband circuitry 604, Radio Frequency (RF) circuitry 606, front-end module (FEM) circuitry 608 and one or more
5 antennas 610, coupled together at least as shown.

The application circuitry 602 may include one or more application processors. For example, the application circuitry 602 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
10 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.

The baseband circuitry 604 may include circuitry such as, but not limited to, one or more
15 single-core or multi-core processors. The baseband circuitry 604 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 606 and to generate baseband signals for a transmit signal path of the RF circuitry 606. Baseband processing circuitry 604 may interface with the application circuitry 602 for generation and processing of the
20 baseband signals and for controlling operations of the RF circuitry 606. For example, in some embodiments, the baseband circuitry 604 may include a second generation (2G) baseband processor 604a, third generation (3G) baseband processor 604b, fourth generation (4G) baseband processor 604c, and/or other baseband processor(s) 604d for other existing generations, generations in development or to be developed in the future
25 (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 604 (e.g., one or more of baseband processors 604a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 606. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some
30 embodiments, modulation/demodulation circuitry of the baseband circuitry 604 may include Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 604 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder/decoder functionality.
35 Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

In some embodiments, the baseband circuitry 604 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access

network (EUTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), and/or radio resource control (RRC) elements. A central processing unit (CPU) 604e of the baseband circuitry 604 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) 604f. The audio DSP(s) 604f may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments.

The baseband circuitry 604 may further include memory/storage 604g. The memory/storage 604g may be used to load and store data and/or instructions for operations performed by the processors of the baseband circuitry 604. Memory/storage for one embodiment may include any combination of suitable volatile memory and/or non-volatile memory. The memory/storage 604g may include any combination of various levels of memory/storage including, but not limited to, read-only memory (ROM) having embedded software instructions (e.g., firmware), random access memory (e.g., dynamic random access memory (DRAM)), cache, buffers, etc. The memory/storage 604g may be shared among the various processors or dedicated to particular processors.

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 604 and the application circuitry 602 may be implemented together such as, for example, on a system on a chip (SOC).

In some embodiments, the baseband circuitry 604 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 604 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 604 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

RF circuitry 606 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 606 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 606 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 608 and provide baseband signals to the baseband circuitry 604. RF circuitry 606 may also include a transmit signal path which may include circuitry to up-

convert baseband signals provided by the baseband circuitry 604 and provide RF output signals to the FEM circuitry 608 for transmission.

In some embodiments, the RF circuitry 606 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 606 may include mixer circuitry 606a, amplifier circuitry 606b and filter circuitry 606c. The transmit signal path of the RF circuitry 606 may include filter circuitry 606c and mixer circuitry 606a. RF circuitry 606 may also include synthesizer circuitry 606d for synthesizing a frequency for use by the mixer circuitry 606a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 606a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 608 based on the synthesized frequency provided by synthesizer circuitry 606d. The amplifier circuitry 606b may be configured to amplify the down-converted signals and the filter circuitry 606c 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 604 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 606a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

In some embodiments, the mixer circuitry 606a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 606d to generate RF output signals for the FEM circuitry 608. The baseband signals may be provided by the baseband circuitry 604 and may be filtered by filter circuitry 606c. The filter circuitry 606c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

In some embodiments, the mixer circuitry 606a of the receive signal path and the mixer circuitry 606a 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 606a of the receive signal path and the mixer circuitry 606a 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 606a of the receive signal path and the mixer circuitry 606a may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 606a of the receive signal path and the mixer circuitry 606a of the transmit signal path may be configured for super-heterodyne operation.

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 606 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 604 may include a digital baseband interface to communicate with the RF circuitry 606.

- 5 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.

- 10 In some embodiments, the synthesizer circuitry 606d 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 606d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

- 15 The synthesizer circuitry 606d may be configured to synthesize an output frequency for use by the mixer circuitry 606a of the RF circuitry 606 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 606d may be a fractional N/N+1 synthesizer.

- 20 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 604 or the applications processor 602 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 602.

- 25 Synthesizer circuitry 606d of the RF circuitry 606 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
30 embodiments, the delay elements may be configured to break a VCO period up into Nd equal packets of phase, where Nd 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.

- 35 In some embodiments, synthesizer circuitry 606d 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 606 may include an IQ/polar converter.

FEM circuitry 608 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 610, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 606 for further processing. FEM circuitry 608 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 606 for transmission by one or more of the one or more antennas 610.

In some embodiments, the FEM circuitry 608 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 606). The transmit signal path of the FEM circuitry 608 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 606), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 610).

In some embodiments, the electronic device 600 may include additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface.

In some embodiments, the electronic device 600 of Figure 6 may be configured to perform one or more processes, techniques, and/or methods as described herein, or portions thereof. Such processes may include one or more of the following examples.

Figure 7 shows an embodiment in which the electronic device 600 implements a UE 102 in the specific form of a mobile device 700.

In various embodiments, user interfaces could include, but are not limited to, a display 740 (e.g., a liquid crystal display, a touch screen display, etc.), a speaker 730, a microphone 790, one or more cameras 780 (e.g., a still camera and/or a video camera), a flashlight (e.g., a light emitting diode flash), and a keyboard 770.

In various embodiments, the peripheral component interfaces may include, but are not limited to, a non-volatile memory port, an audio jack, and a power supply interface.

In various embodiments, the sensors may include, but are not limited to, a gyro sensor, an accelerometer, a proximity sensor, an ambient light sensor, and a positioning unit. The positioning unit may also be part of, or interact with, a network interface to communicate with components of a positioning network, e.g., a global positioning system (GPS) satellite.

In various embodiments, the electronic device 600 may be a mobile computing device such as, but not limited to, a laptop computing device, a tablet computing device, a netbook, a mobile phone, etc. In various embodiments, system 700 may have more or less components, and/or different architectures.

In embodiments, the implemented wireless network may be a 3rd Generation Partnership Project's long term evolution (LTE) advanced wireless communication standard, which may include, but is not limited to releases 8, 9, 10, 11, 12, 13, and 14 or later, of the 3GPP's LTE-A or 5G standards.

Although certain embodiments have been illustrated and described herein for purposes of description, a wide variety of alternate and/or equivalent embodiments or implementations calculated to achieve the same purposes may be substituted for the embodiments shown and described without departing from the scope of the present disclosure. This application is intended to cover any adaptations or variations of the embodiments discussed herein. Therefore, it is manifestly intended that embodiments described herein be limited only by the claims and the equivalents thereof.

EXAMPLES

Example 1 may include a method comprising: configuring beamformed Channel State Information Reference Signal (CSI-RS), wherein the CSI-RS is transmitted with a vertical narrow and horizontal wide sector transmitting (Tx) beam, and each Tx beam is considered as a virtualized sector.

Example 2 may include the method of example 1 or some other example herein, wherein the UE measures and reports the Reference Signal Receiving Power (RSRP) based on the beamformed CSI-RS to indicate the signal quality of one sector Tx beam.

Example 3 may include the method of example 2 or some other example herein, wherein the UE reports a receiving (Rx) beam indicator associated with the RSRP, where value 0 indicates the RSRP is measured from an active Rx beam and value 1 indicates the RSRP is measured from a candidate Rx beam, and wherein the UE cannot receive data from both active Rx beam and candidate Rx beam simultaneously, wherein the Rx beam is defined as an Rx beam used for data and control receiving and is initially set to be either active Rx beam and can be switched to candidate Rx beam.

Example 4 may include the method of example 1 or 3 or some other example herein, wherein the UE reports a digital beam selection Channel State Information (CSI), wherein a Precoder Matrix Indicator (PMI) for the active Rx beam and the PMI for the candidate Rx beam may be reported.

- 5 Example 5 may include the method of example 4 or some other example herein, wherein the PMI is measured using a codebook from the CSI-RS transmitted on sector beam, which is defined by the system.

Example 6 may include the method of example 4 or some other example herein, wherein the PMI is selected from a rank 1 codebook.

- 10 Example 7 may include the method of example 1 or some other example herein, wherein a UE-specific CSI-RS is transmitted as several groups and each group of the several groups is transmitted using a two dimensional narrow Tx beam.

- Example 8 may include the method of example 7 or some other example herein, wherein each of the several groups use two antenna ports sent from both horizontal and vertical
15 polarizations.

Example 9 may include the method of example 7 or some other example herein, wherein the UE measures the CSI-RS Receiving Power (CSIRS-RP) for each CSI-RS group.

- Example 10 may include the method of example 9 or some other example herein, wherein the UE reports the CSIRS-RP comprising the value of CSIRS-RP, Rx beam
20 indicator, CSI-RS group index and subframe index, wherein the Rx beam indicator is used to indicate whether this CSIRS-RP is measured from active Rx beam or candidate Rx beam.

- Example 11 may include the method of example 10 or some other example herein, wherein the UE may report up to N CSIRS-RPs, where N is to be configured by the system
25 or radio resource control (RRC) signaling.

Example 12 may include the method of example 11 or some other example herein, wherein only a valid CSIRS-RP may be reported and a valid CSIRS-RP is defined as a CSIRS-RP within the CSIRS-RP threshold, which is configured by the system or RRC signaling.

- Example 13 may include an apparatus comprising means to perform one or more
30 elements of a method described in or related to any of examples 1-12, or any other method or process described herein.

Example 14 may include one or more non-transitory computer-readable media comprising instructions to cause an electronic device, upon execution of the instructions by one or more processors of the electronic device, to perform one or more elements of

a method described in or related to any of examples 1-12, or any other method or process described herein.

Example 15 may include an apparatus comprising logic, modules, and/or circuitry to perform one or more elements of a method described in or related to any of examples 1-12, or any other method or process described herein.

Example 16 may include a method, technique, or process as described in or related to any of examples 1-12, or portions or parts thereof.

Example 17 may include an apparatus comprising: one or more processors and one or more computer readable media comprising instructions that, when executed by the one or more processors, cause the one or more processors to perform the method, techniques, or process as described in or related to any of examples 1-12, or portions thereof.

Example 18 may include a method of communicating in a wireless network as shown and described herein.

Example 19 may include a system for providing wireless communication as shown and described herein.

Example 20 may include a device for providing wireless communication as shown and described herein.

Example 21 may include an apparatus for use in an eNB in a wireless communication network, the apparatus comprising transmitter circuitry; and control circuitry coupled to the transmitter circuitry, the control circuitry to: configure a plurality of channel state information reference signals (CSI-RS), each CSI-RS associated with one of a plurality of virtualized sectors; and cause the transmitter circuitry to transmit the configured CSI-RS; wherein each of the plurality of virtualized sectors comprises a transmit beam beamformed to be vertically narrow and horizontally wide based on an associated vertical downtilt angle.

Example 22 may include the apparatus of example 21, wherein each of the plurality of virtualized sectors is associated with a different vertical downtilt angle.

Example 23 may include the apparatus of example 21 or example 22 example further comprising receiver circuitry coupled to the control circuitry, the receiver circuitry to receive an indication of a reference signal received power (RSRP) value associated with one of the virtualized sectors from a User Equipment (UE), the indication of RSRP value based on the CSI-RS associated with the one of the virtualized sectors.

Example 24 may include the apparatus of example 23, wherein the indication of RSRP value comprises an indication of a receiving beam associated with the RSRP value.

5 Example 25 may include the apparatus of example 24, wherein the indication of a receiving beam comprises a first value to indicate that the RSRP value was measured from an active receiving beam and a second value to indicate that the RSRP value was measure from a candidate receiving beam.

Example 26 may include the apparatus of example 23, wherein the control circuitry is further to select a virtualized sector beam for communicating with the UE based on the received indication of RSRP value.

10 Example 27 may include the apparatus of example 26, wherein the control circuitry is further to configure UE specific CSI-RS associated with the selected virtualized sector and cause the transmitter circuitry to transmit the UE specific CSI-RS to the UE in the selected virtualized sector.

15 Example 28 may include the apparatus of example 27, wherein the receiver circuitry is further to receive a digital beam selection channel state information (CSI) from the UE in response to the UE specific CSI-RS, the digital beam selection CSI comprising a first precoder matrix indicator (PMI) associated with an active receiving beam.

Example 29 may include the apparatus of example 28, wherein the digital beam selection CSI further comprises a second PMI associated with a candidate receiving beam.

20 Example 30 may include the apparatus of examples 28 or 29, wherein the PMI is selected from a rank 1 codebook.

Example 31 may include the apparatus of examples 28 or 29, wherein the PMI is measured using a codebook defined by the network.

25 Example 32 may include the apparatus of any of examples 8 to 10, wherein the control circuitry is further to generate a two dimensional narrow transmit beam within the selected virtualized sector based on a received PMI.

30 Example 33 may include the apparatus of any of examples 27 to 32, wherein the transmitter circuitry is further to transmit the US specific CSI-RS a plurality of CSI-RS groups, wherein each CSI-RS group of the plurality of CSI-RS groups is associated with a two dimensional narrow transmit beam within the selected virtualized sector.

Example 34 may include the apparatus of example 33, wherein each of the plurality of CSI-RS groups is associated with two antenna ports sent from both horizontal and vertical polarizations.

Example 35 may include the apparatus of example 33 or example 34, the receiver circuitry further to receive a CSI-RS report from the UE, the report comprising: CSI-RS receiving power (CSIRS-RP) value; a receiving beam indicator comprising a first value to indicate the CSIRS-RP value was measured using an active receive beam and a second value to indicate that the CSIRS-RP value was measured using a candidate receive beam; a CSI-RS group index; and a subframe index.

Example 36 may include the apparatus of example 35, the receiver circuitry further to receive a plurality of CSI-RS reports from the UE, each CSI-RS report associated with a CSI-RS group of the plurality of CSI-RS groups.

Example 37 may include the apparatus of example 36, wherein the plurality of CSI-RS reports may comprise N CSI-RP reports, where N is configured by the network or using radio resource control signalling (RRC).

Example 38 may include the apparatus of example 36 or example 37, wherein the plurality of CSI-RS reports comprises CSI-RS reports having a CSIRS-RP value greater than a threshold CSIRS-RP value.

Example 39 may include the apparatus of example 38, wherein the threshold CSIRS-RP value is configured by the network or using radio resource control signalling (RRC).

Example 40 may include an apparatus for use in a user equipment in a wireless communication network, the apparatus comprising receiver circuitry to receive a plurality of channel state information reference signals (CSI-RS) from an eNB, each CSI-RS associated with one of a plurality of virtualized sectors; controller circuitry coupled to the receiver circuitry, the controller circuitry to: obtain a plurality of reference signal receiver power (RSRP) values, each of the plurality of RSRP values associated with one of the received CSI-RS; and generate an indication of RSRP associated with one of the virtualized sectors; and transmitter circuitry to transmit the indication of RSRP to the eNB; and wherein each of the plurality of virtualized sectors comprises a transmit beam beamformed to be vertically narrow and horizontally wide based on an associated vertical downtilt angle.

Example 41 may include the apparatus of example 40, the controller circuitry further to determine a highest RSRP value of the plurality of RSRP values wherein the generated indication comprises an indication of the determined highest RSRP value and the associated virtualized sector.

Example 42 may include the apparatus of example 40 or example 41, wherein the receiver circuitry is operable to receive an active receiving beam and a candidate receiving beam; and wherein the generated indication of RSRP further comprises an indication of a receiving beam associated with the RSRP value, wherein the indication of

a receiving beam comprises a first value to indicate that the RSRP value was measured from the active receiving beam and a second value to indicate that the RSRP value was measure from the candidate receiving beam.

5 Example 43 may include the apparatus of example 42, wherein the receiver circuitry is operable to receive one of the active receiving beam and the candidate receiving beam at one time.

10 Example 44 may include the apparatus of any of examples 40 to 43, wherein the receiver circuitry is further to receive UE specific CSI-RS on a first virtualized sector of the plurality of virtualized sectors; and wherein the controller circuitry is further to generate a digital beam selection Channel State Information (CSI) in dependence on the received UE specific CSI-RS.

15 Example 45 may include the apparatus of example 44, wherein the UE specific CSI-RS comprises a plurality of CSI-RS groups, wherein each CSI-RS group of the plurality of CSI-RS groups is associated with a two dimensional narrow transmit beam within the selected virtualized sector.

Example 46 may include the apparatus of example 44 or example 45, wherein the digital beam selection CSI comprises a first precoder matrix indicator (PMI) associated with an active receiving beam.

20 Example 47 may include the apparatus of example 46, wherein the digital beam selection CSI further comprises a second PMI associated with a candidate receiving beam.

Example 48 may include the apparatus of example 44 to example 47, wherein the PMI is selected from a rank 1 codebook.

25 Example 49 may include the apparatus of example 45, the control circuitry to generate a CSI-RS report, the CSI-RP report comprising CSI-RS receiving power (CSIRS-RP) value; a receiving beam indicator comprising a first value to indicate the CSIRS-RP value was measured using an active receive beam and a second value to indicate that the CSIRS-RP value was measured using a candidate receive beam; a CSI-RS group index; and a subframe index.

30 Example 50 may include the apparatus of example 49, the control circuitry to generate a plurality of CSI-RS reports from the UE, each CSI-RS report associated with a CSI-RS group of the plurality of CSI-RS groups.

Example 51 may include the apparatus of example 50, wherein the plurality of CSI-RS reports may comprise N CSI-RP reports, where N is configured by the network or using radio resource control signalling (RRC).

Example 52 may include the apparatus of example 50 or example 51, wherein the plurality of CSI-RS reports comprises CSI-RS reports having a CSIRS-RP value greater than a threshold CSIRS-RP value.

5 Example 53 may include the apparatus of example 52, wherein the threshold CSIRS-RP value is configured by the network or using radio resource control signalling (RRC).

Example 54 may include a user equipment comprising an apparatus according to any of examples 20 to 33, the user equipment further comprising at least one of a display; a keyboard; and a touchscreen.

10 Example 55 may include a computer readable medium comprising computer program code that when executed implements the method of receiving a plurality of channel state information reference signals (CSI-RS) from an eNB, each CSI-RS associated with one of a plurality of virtualized sectors; obtaining a plurality of reference signal receiver power (RSRP) values, each of the plurality of RSRP values associated with one of the received CSI-RS; and generating an indication of RSRP associated with one of the virtualized
15 sectors; and transmitting the indication of RSRP to the eNB; wherein each of the plurality of virtualized sectors comprises a transmit beam beamformed to be vertically narrow and horizontally wide based on an associated vertical downtilt angle.

20 Example 56 may include a computer readable medium comprising computer program code that when executed implements the method of configuring a plurality of channel state information reference signals (CSI-RS), each CSI-RS associated with one of a plurality of virtualized sectors; and transmitting the configured CSI-RS; wherein each of the plurality of virtualized sectors comprises a transmit beam beamformed to be vertically narrow and horizontally wide based on an associated vertical downtilt angle.

25 Example 57 may include the apparatus of example 21, wherein a transmit beam associated with a virtualized sector is transmitted using a first antenna port, the first antenna port associated with a first number of vertical antenna elements and a second number of horizontal antenna elements wherein the first number of vertical antenna elements is greater than the second number of horizontal antenna elements.

30 Example 58 may include the apparatus of example 57, wherein the first number of vertical antenna elements is greater than or equal to 8, and wherein the second number of horizontal antenna elements is less than or equal to 2.

35 The foregoing description of one or more implementations provides illustration and description, but is not intended to be exhaustive or to limit the scope of the example embodiments to the precise form disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from practice of various implementations of the example embodiments.

CLAIMS

1. An apparatus for use in an eNB in a wireless communication network, the apparatus comprising:

transmitter circuitry; and

5 control circuitry coupled to the transmitter circuitry, the control circuitry to:
configure a plurality of channel state information reference signals (CSI-RS), each CSI-RS associated with one of a plurality of virtualized sectors;
and

cause the transmitter circuitry to transmit the configured CSI-RS;

10 wherein each of the plurality of virtualized sectors comprises a transmit beam beamformed to be vertically narrow and horizontally wide based on an associated vertical downtilt angle.

2. The apparatus of claim 1, wherein each of the plurality of virtualized sectors is associated with a different vertical downtilt angle.

15 3. The apparatus of any preceding claim further comprising:
receiver circuitry coupled to the control circuitry, the receiver circuitry to receive an indication of a reference signal received power (RSRP) value associated with one of the virtualized sectors from a User Equipment (UE), the indication of RSRP value based on the CSI-RS associated with the one of the
20 virtualized sectors.

4. The apparatus of claim 3, wherein the control circuitry is further to select a virtualized sector beam for communicating with the UE based on the received indication of RSRP value.

5. The apparatus of claim 4, wherein the control circuitry is further to configure
25 UE specific CSI-RS associated with the selected virtualized sector and cause the transmitter circuitry to transmit the UE specific CSI-RS to the UE in the selected virtualized sector.

6. The apparatus of claim 5, wherein the receiver circuitry is further to receive a digital beam selection channel state information (CSI) from the UE in response

to the UE specific CSI-RS, the digital beam selection CSI comprising a first precoder matrix indicator (PMI) associated with an active receiving beam.

7. The apparatus of claim 6, wherein the digital beam selection CSI further comprises a second PMI associated with a candidate receiving beam.

5 8. The apparatus of claims 6 or 7, wherein the PMI is selected from a rank 1 codebook defined by the network.

9. The apparatus of any of claims 6 to 8, wherein the control circuitry is further to generate a two dimensional narrow transmit beam within the selected virtualized sector based on a received PMI.

10 10. The apparatus of any of claims 6 to 9, wherein the transmitter circuitry is further to transmit the UE specific CSI-RS a plurality of CSI-RS groups, wherein each CSI-RS group of the plurality of CSI-RS groups is associated with a two dimensional narrow transmit beam within the selected virtualized sector;
wherein each of the plurality of CSI-RS groups is associated with two
15 antenna ports sent from both horizontal and vertical polarizations.

11. The apparatus of any of claims 1 to 10, wherein a transmit beam associated with a virtualized sector is transmitted using a first antenna port, the first antenna port associated with a first number of vertical antenna elements and a second number of horizontal antenna elements wherein the first number of
20 vertical antenna elements is greater than the second number of horizontal antenna elements.

12. The apparatus of claim 10 or claim 11, the receiver circuitry further to: receive a CSI-RS report from the UE, the report comprising:

CSI-RS receiving power (CSIRS-RP) value;

25 a receiving beam indicator comprising a first value to indicate the CSIRS-RP value was measured using an active receive beam and a second value to indicate that the CSIRS-RP value was measured using a candidate receive beam;

a CSI-RS group index; and

30 a subframe index.

13. The apparatus of claim 12, the receiver circuitry further to receive a plurality of CSI-RS reports from the UE, each CSI-RS report associated with a CSI-RS group of the plurality of CSI-RS groups.

14. An apparatus for use in a user equipment (UE) in a wireless

5 communication network, the apparatus comprising:

receiver circuitry to receive a plurality of channel state information reference signals (CSI-RS) from an eNB, each CSI-RS associated with one of a plurality of virtualized sectors;

10 controller circuitry coupled to the receiver circuitry, the controller circuitry to:
obtain a plurality of reference signal receiver power (RSRP) values, each of the plurality of RSRP values associated with one of the received CSI-RS;
and

generate an indication of RSRP associated with one of the virtualized sectors; and

15 transmitter circuitry to transmit the indication of RSRP to the eNB; and
wherein each of the plurality of virtualized sectors comprises a transmit beam beamformed to be vertically narrow and horizontally wide based on an associated vertical downtilt angle.

15. The apparatus of claim 14, the controller circuitry further to determine a
20 highest RSRP value of the plurality of RSRP values wherein the generated indication comprises an indication of the determined highest RSRP value and the associated virtualized sector.

16. The apparatus of claim 14 or claim 15, wherein the receiver circuitry is operable to receive an active receiving beam and a candidate receiving beam;
25 and

wherein the generated indication of RSRP further comprises an indication of a receiving beam associated with the RSRP value, wherein the indication of a receiving beam comprises a first value to indicate that the RSRP value was measured from the active receiving beam and a second value to indicate that the
30 RSRP value was measure from the candidate receiving beam.

17. The apparatus of claim 16, wherein the receiver circuitry is operable to receive only one of the active receiving beam and the candidate receiving beam at one time.

18. The apparatus of any of claims 14 to 17, wherein the receiver circuitry is further to receive UE specific CSI-RS on a first virtualized sector of the plurality of virtualized sectors; and

wherein the controller circuitry is further to generate a digital beam selection Channel State Information (CSI) in dependence on the received UE specific CSI-RS.

19. The apparatus of claim 18, wherein the UE specific CSI-RS comprises a plurality of CSI-RS groups, wherein each CSI-RS group of the plurality of CSI-RS groups is associated with a two dimensional narrow transmit beam within the selected virtualized sector.

20. The apparatus of claim 18 or claim 19, wherein the digital beam selection CSI comprises a first precoder matrix indicator (PMI) associated with an active receiving beam and a second PMI associated with a candidate receiving beam.

21. The apparatus of claim 19, the control circuitry to generate a CSI-RS report, the CSI-RP report comprising:

CSI-RS receiving power (CSIRS-RP) value;

a receiving beam indicator comprising a first value to indicate the CSIRS-RP value was measured using an active receive beam and a second value to indicate that the CSIRS-RP value was measured using a candidate receive beam;

a CSI-RS group index; and

a subframe index.

22. The apparatus of claim 21, the control circuitry to generate a plurality of CSI-RS reports from the UE, each CSI-RS report associated with a CSI-RS group of the plurality of CSI-RS groups.

23. A user equipment comprising an apparatus according to any of claims 20 to 33, the user equipment further comprising at least one of a display; a keyboard; and a touchscreen.

24. A computer readable medium comprising computer program code that
5 when executed implements the method of:

receiving a plurality of channel state information reference signals (CSI-RS) from an eNB, each CSI-RS associated with one of a plurality of virtualized sectors;

obtaining a plurality of reference signal receiver power (RSRP) values, each of the plurality of RSRP values associated with one of the received CSI-RS;

10 and

generating an indication of RSRP associated with one of the virtualized sectors; and

transmitting the indication of RSRP to the eNB;

15 wherein each of the plurality of virtualized sectors comprises a transmit beam beamformed to be vertically narrow and horizontally wide based on an associated vertical downtilt angle.

25. A computer readable medium comprising computer program code that when executed implements the method of:

20 configuring a plurality of channel state information reference signals (CSI-RS), each CSI-RS associated with one of a plurality of virtualized sectors; and transmitting the configured CSI-RS;

wherein each of the plurality of virtualized sectors comprises a transmit beam beamformed to be vertically narrow and horizontally wide based on an associated vertical downtilt angle.

25

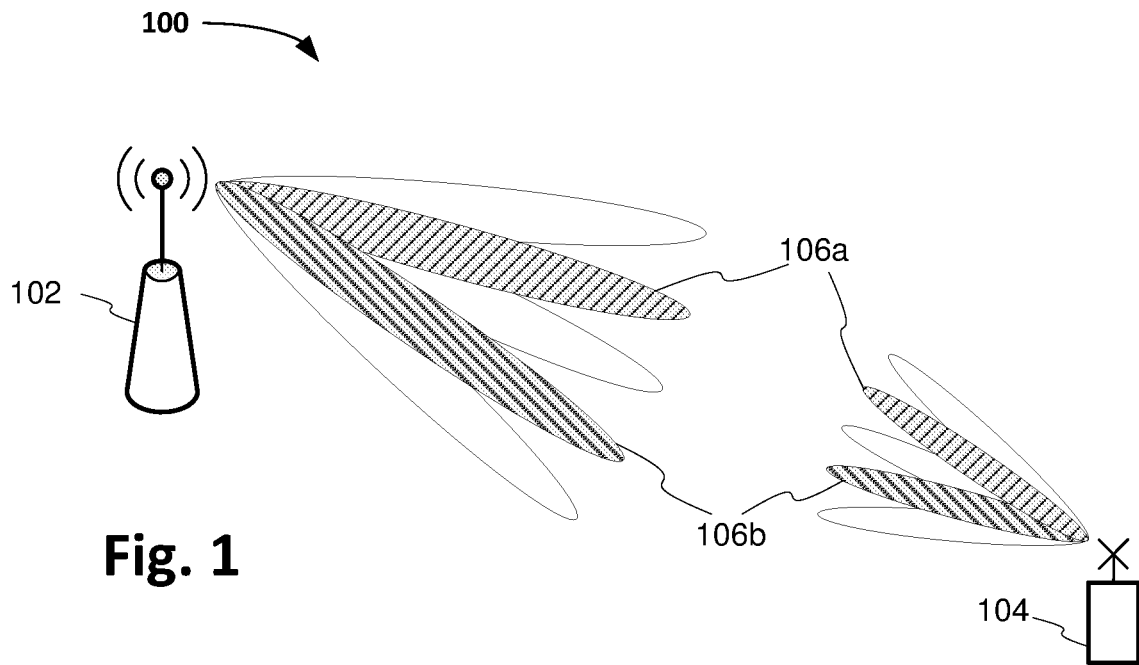


Fig. 1

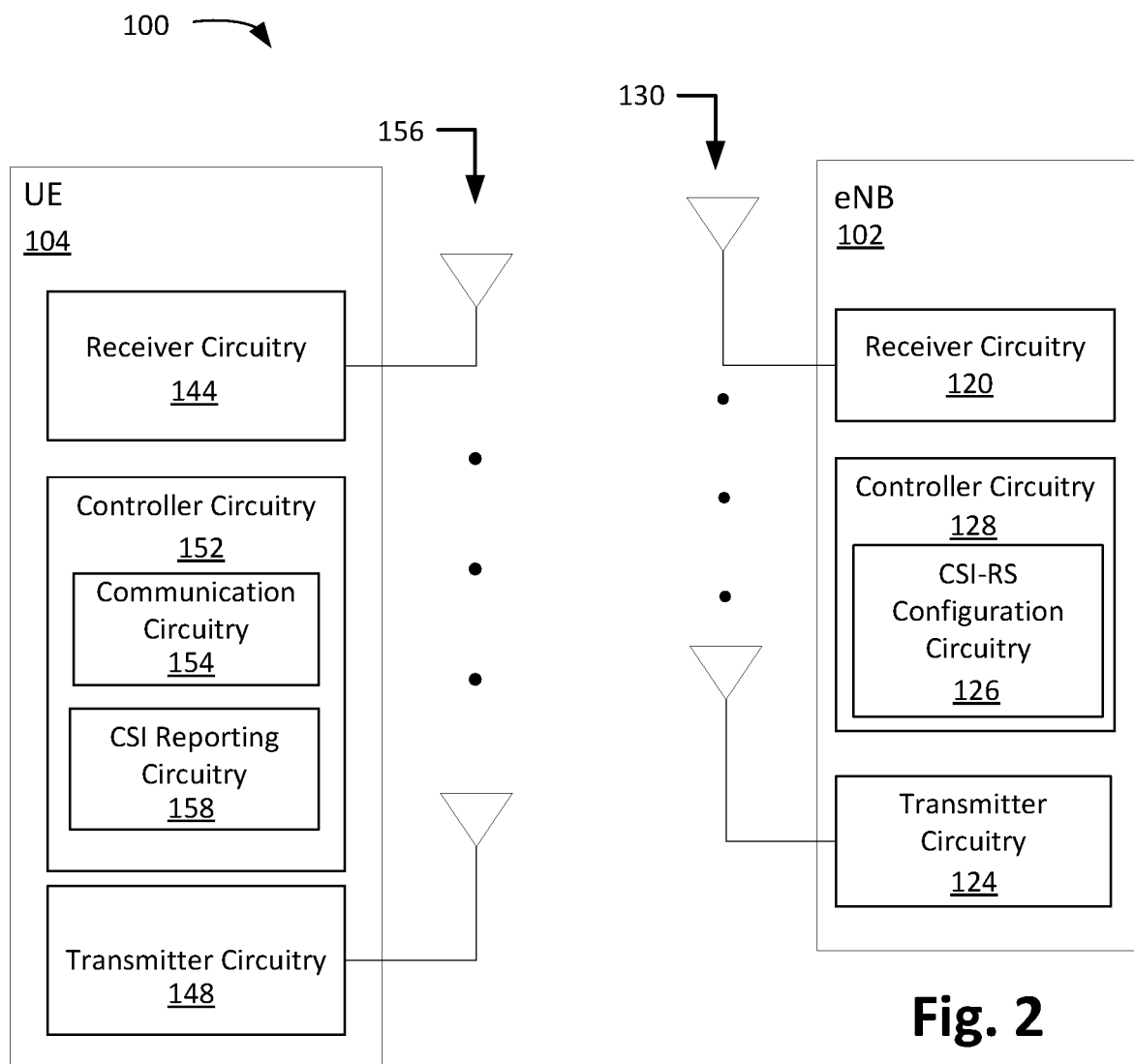
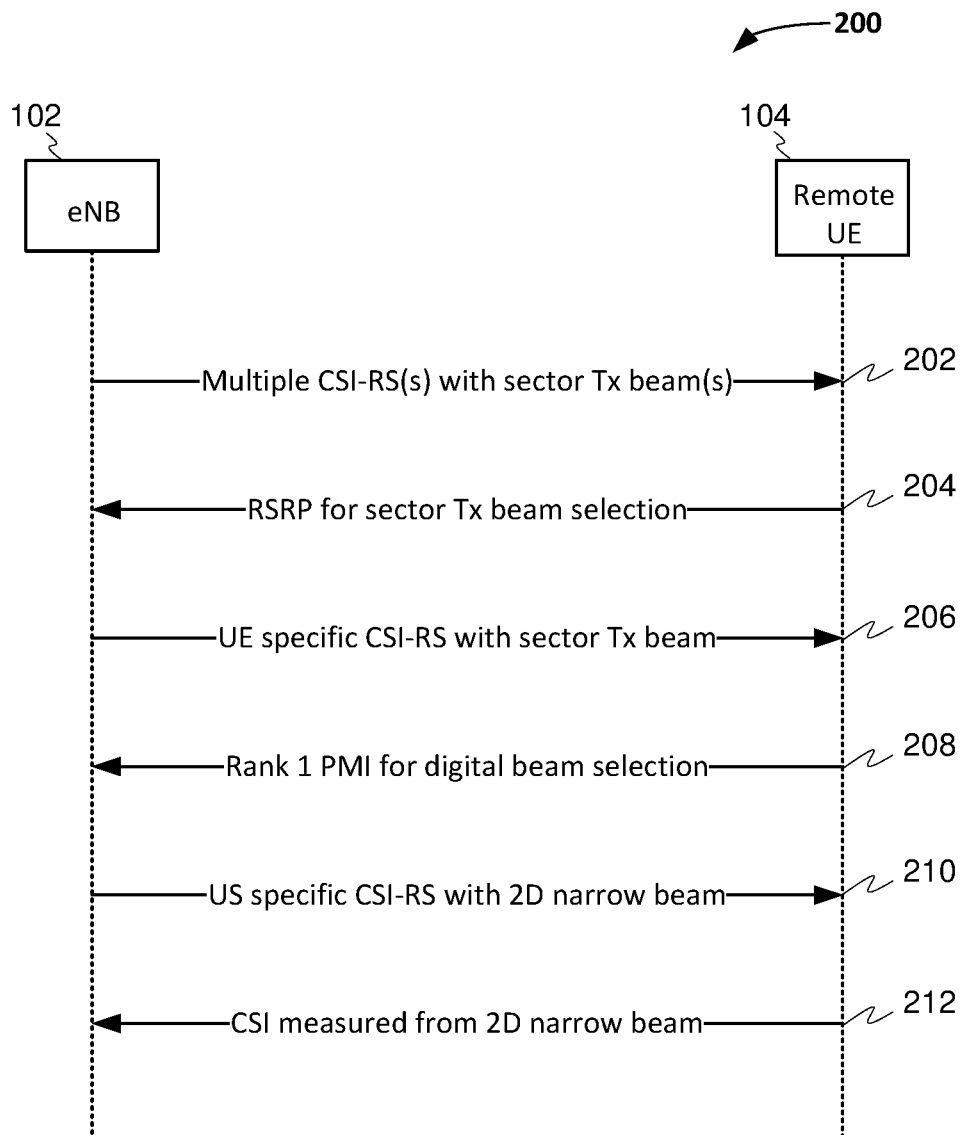
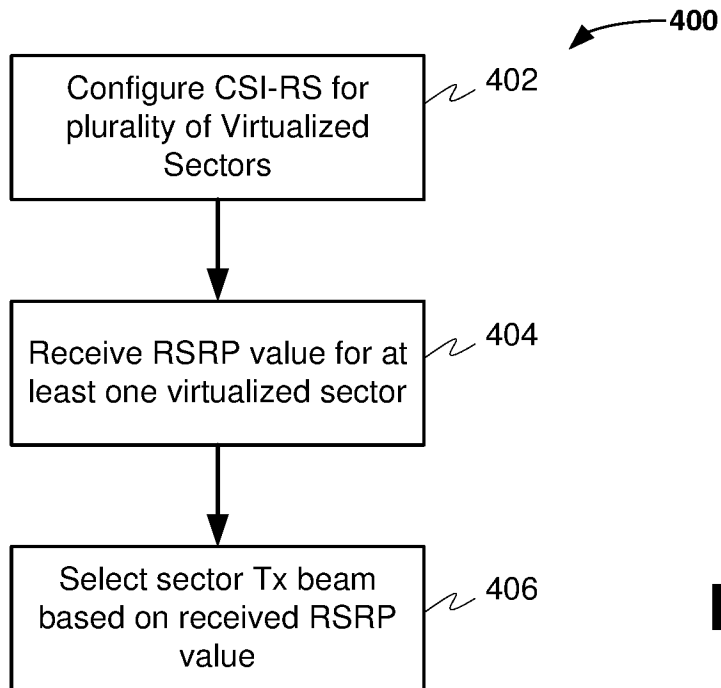
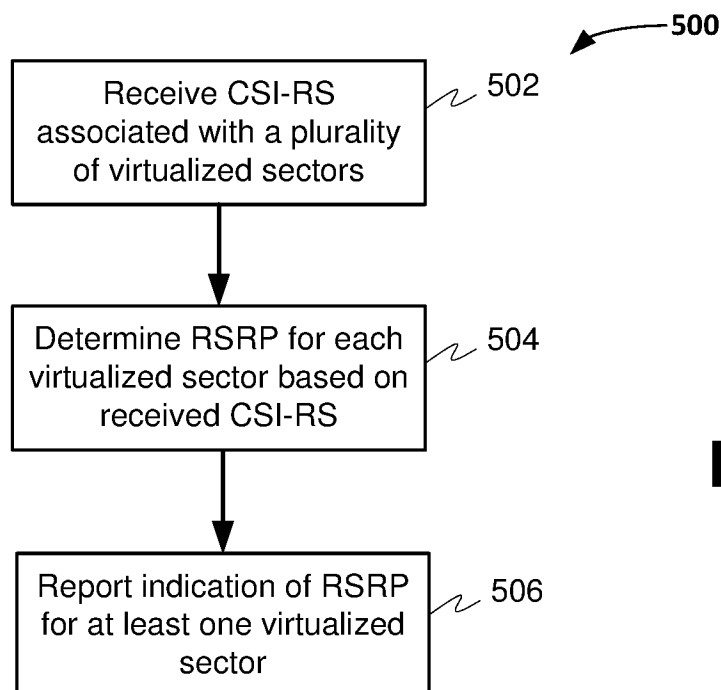


Fig. 2

**Fig. 3**

**Fig. 4****Fig. 5**

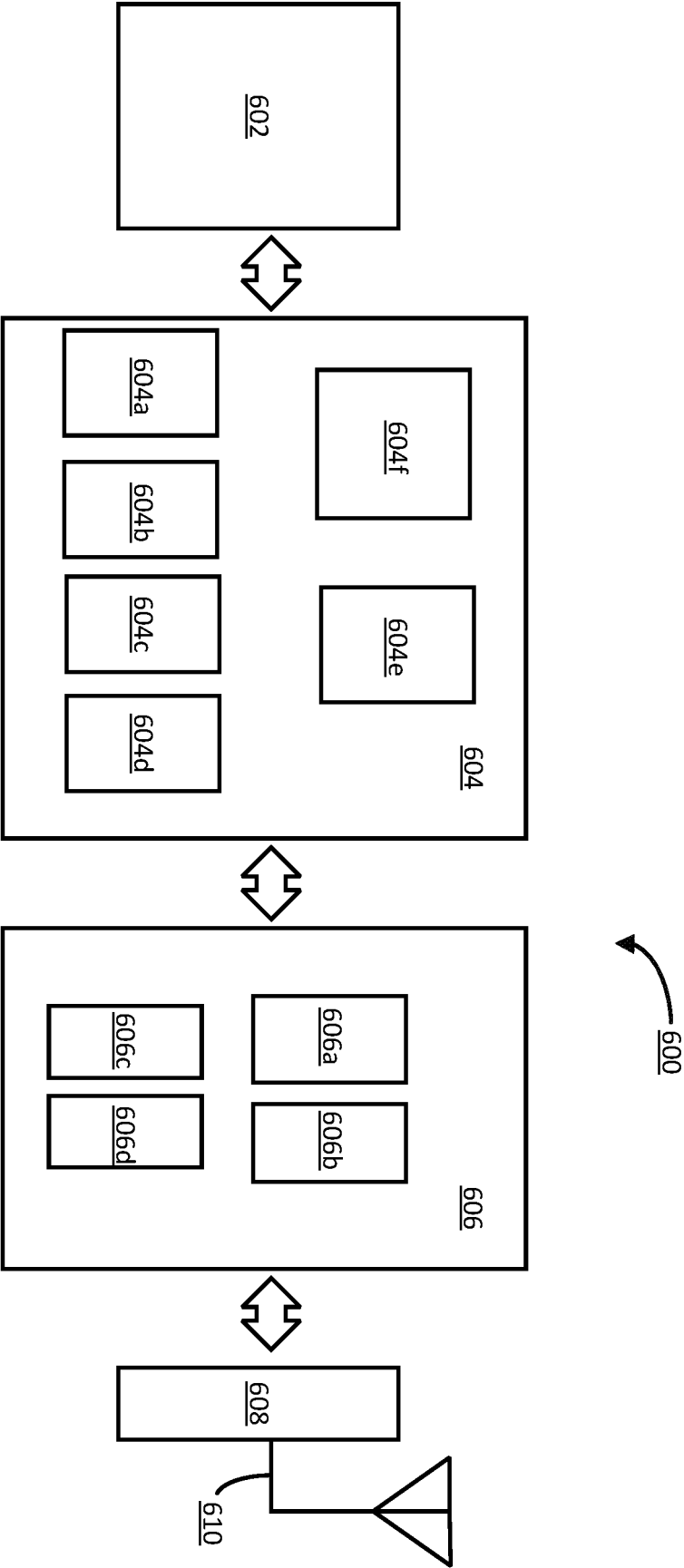


Fig. 6

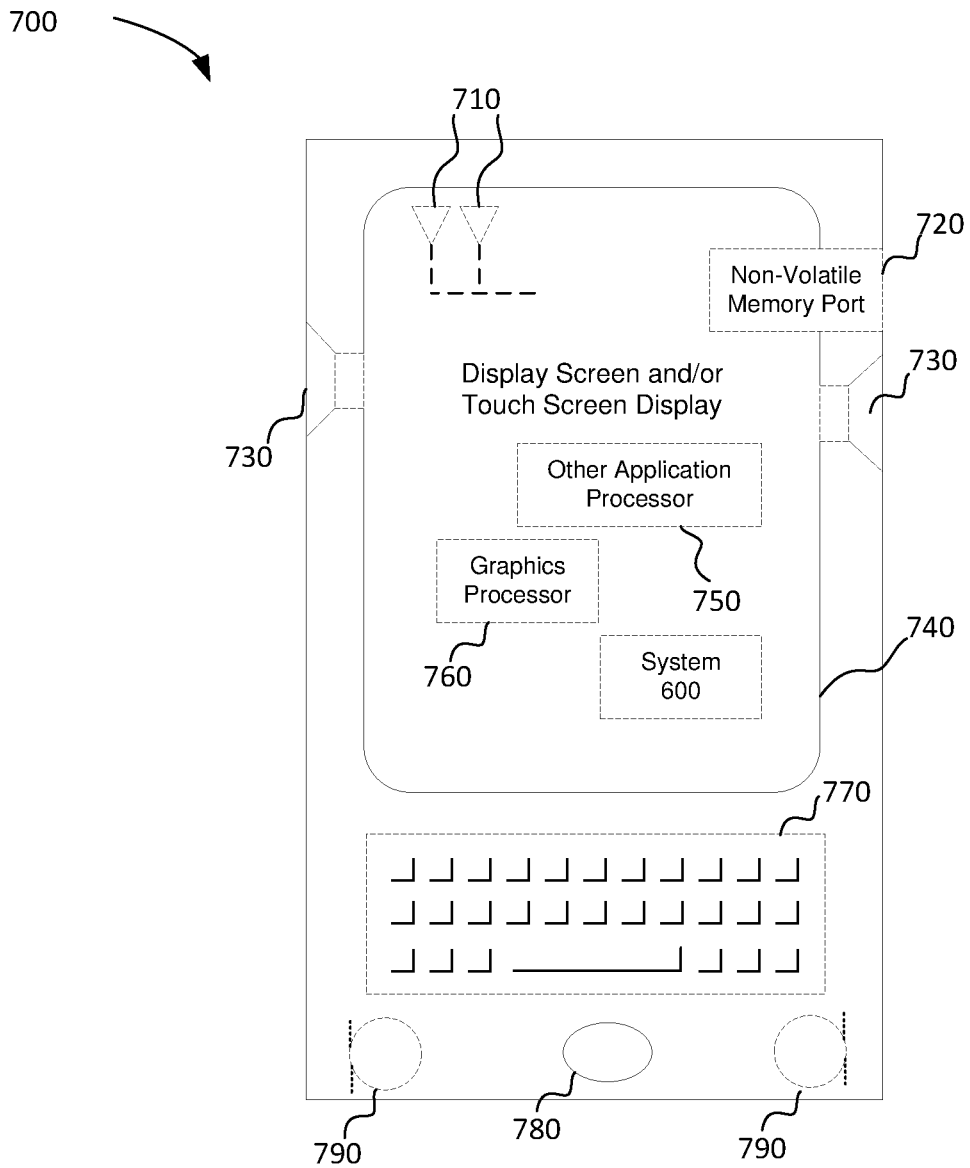


Fig. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2016/078453**A. CLASSIFICATION OF SUBJECT MATTER**

H04B 7/02(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04B; H04W; H04Q; H04L

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)

CNKI,CNPAT,WPI,EPODOC,IEEE,GOOGLE,3GPP: RS, CSI-RS, eNB, CSI, sectors, RSRP, angle, vertical+, horizontal+, downtilt, tilt, measure, report

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2014182383 A1 (INTEL IP CORPORATION) 13 November 2014 (2014-11-13) description, pages 5-6, 14, figures 4A-4B	1-25
X	WO 2014052806 A1 (INTERDIGITAL PATENT HOLDINGS, INC.) 03 April 2014 (2014-04-03) description, paragraphs [0209]-[0219]	1-25
A	WO 2014099343 A1 (MOTOROLA MOBILITY LLC) 26 June 2014 (2014-06-26) the whole document	1-25
A	US 2011103504 A1 (FUTUREWEI TECHNOLOGIES, INC.) 05 May 2011 (2011-05-05) the whole document	1-25

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

* Special categories of cited documents:

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

Date of the actual completion of the international search

18 July 2016

Date of mailing of the international search report

26 July 2016

Name and mailing address of the ISA/CN

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2016/078453

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