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(54) Title: CONTROL SIGNALING FOR BEAM MANAGEMENT

(57) Abstract: Embodiments of the present disclosure describe methods and apparatuses for beam management signaling.

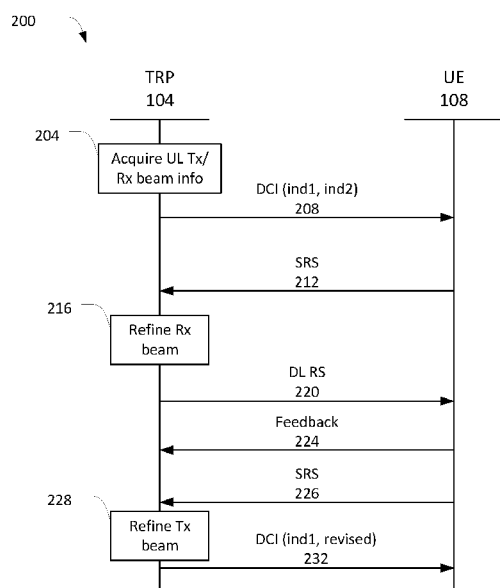


Figure 2

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CONTROL SIGNALING FOR BEAM MANAGEMENT

Related Application

This application claims priority to PCT Application Number PCT/CN2017/072940 filed February 6, 2017. The specification of said application is hereby incorporated by reference
5 in its entirety.

Field

Embodiments of the present disclosure generally relate to the field of networks, and more particularly, to apparatuses, systems, and methods for control signaling for beam management in cellular networks.

10

Background

Beamforming may be used at both the Transmission/Reception Point (“TRP”) side and the user equipment (“UE”) side in fifth generation (“5G”) communication systems. Beam management may be performed in both downlink and uplink to maintain the TRP/UE beams for communication.

15

Brief Description of the Drawings

Embodiments will be readily understood by the following detailed description in conjunction with the accompanying drawings. To facilitate this description, like reference numerals designate like structural elements. Embodiments are illustrated by way of example and not by way of limitation in the figures of the accompanying drawings.

20 Figure 1 illustrates a network in accordance with some embodiments.

Figure 2 illustrates a message flow diagram in accordance with some embodiments.

Figure 3 illustrates an example operation flow/algorithmic structure in accordance with some embodiments.

25 Figure 4 illustrates an example operation flow/algorithmic structure in accordance with some embodiments.

Figure 5 illustrates an electronic device in accordance with some embodiments.

Figure 6 illustrates baseband circuitry in accordance with some embodiments.

Figure 7 illustrates communication circuitry in accordance with some embodiments.

Figure 8 illustrates radio-frequency circuitry in accordance with some embodiments.

Figure 9 illustrates a control-plane protocol stack in accordance with some embodiments.

Figure 10 illustrates a user-plane protocol stack in accordance with some embodiments.

Figure 11 illustrates hardware resources in accordance with some embodiments.

Detailed Description

- 5 In the following detailed description, reference is made to the accompanying drawings, which form a part hereof wherein like numerals designate like parts throughout, and in which is shown by way of illustration embodiments that may be practiced. It is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope of the present disclosure.
- 10 Various operations may be described as multiple discrete actions or operations in turn, in a manner that is most helpful in understanding the claimed subject matter. However, the order of description should not be construed as to imply that these operations are necessarily order dependent. In particular, these operations may not be performed in the order of presentation. Operations described may be performed in a different order than the
- 15 described embodiment. Various additional operations may be performed or described operations may be omitted in additional embodiments.

For the purposes of the present disclosure, the phrases “A or B,” “A and/or B,” and “A/B” mean (A), (B), or (A and B).

- The description may use the phrases “in an embodiment,” or “in embodiments,” which
- 20 may each refer to one or more of the same or different embodiments. Furthermore, the terms “comprising,” “including,” “having,” and the like, as used with respect to embodiments of the present disclosure, are synonymous.

- Figure 1 illustrates wireless communication between a transmission/reception point (“TRP”) 104 and a user equipment (“UE”) 108 in accordance with various embodiments.
- 25 The TRP 104 may be part of, or controlled by, an access node (“AN”) 106 of a radio access network (“RAN”). The access node 106 may be referred to as a base station (“BS”), NodeB, evolved NodeB (“eNB”), next Generation NodeB (“gNB”), RAN node, Road Side Unit (“RSU”), and so forth, and can comprise a ground station (e.g., a terrestrial access point) or a satellite station providing coverage within a geographic area
- 30 (e.g., a cell). An RSU may refer to any transportation infrastructure entity implemented in or by a gNB/eNB/RAN node or a stationary (or relatively stationary) UE, where an RSU

implemented in or by a UE may be referred to as a “UE-type RSU,” and an RSU implemented in or by an eNB may be referred to as an “eNB-type RSU.”

In some embodiments, the RAN may be a next generation (“NG”) radio access network (“RAN”), in which case the TRP 104 may be part of, or controlled by, a gNB that
5 communicates with the UE 108 using a new radio (“NR”) access technology.

The UE 108 may be any mobile or non-mobile computing device that is connectable to one or more cellular networks. For example, the UE 108 may be a smartphone, a laptop computer, a desktop computer, a vehicular computer, a smart sensor, etc. In some
10 embodiments, the UE 108 may be an Internet of Things (“IoT”) UE, which may include a network access layer designed for low-power IoT applications utilizing short-lived UE connections. An IoT UE can utilize technologies such as machine-to-machine (“M2M”) or machine-type communications (“MTC”) for exchanging data with an MTC server or device via a public land mobile network (“PLMN”), Proximity-Based Service (“ProSe”) or device-to-device (“D2D”) communication, sensor networks, or IoT networks. The
15 M2M or MTC exchange of data may be a machine-initiated exchange of data. An IoT network describes interconnecting IoT UEs, which may include uniquely identifiable embedded computing devices (within the Internet infrastructure), with short-lived connections. The IoT UEs may execute background applications (for example, keep-alive messages, status updates, etc.) to facilitate the connections of the IoT network.

20 In accordance with some embodiments, the UE 108 can be configured to communicate using Orthogonal Frequency-Division Multiplexing (“OFDM”) communication signals with the TRP 104 over a multicarrier communication channel in accordance with various communication techniques, such as, but not limited to, an Orthogonal Frequency-Division Multiple Access (“OFDMA”) communication technique (for example, for downlink
25 communications) or a Single Carrier Frequency Division Multiple Access (“SC-FDMA”) communication technique (for example, for uplink or sidelink communications), although the scope of the embodiments is not limited in this respect. The OFDM signals can comprise a plurality of orthogonal subcarriers.

In some embodiments, a downlink resource grid can be used for downlink transmissions
30 from the TRP 104 to the UE 108, while uplink transmissions can utilize similar techniques. The grid can be a time-frequency grid, called a resource grid or time-frequency resource grid, which is the physical resource in the downlink in each slot. Such

a time-frequency plane representation is a common practice for OFDM systems, which makes it intuitive for radio resource allocation. Each column and each row of the resource grid corresponds to one OFDM symbol and one OFDM subcarrier, respectively. The duration of the resource grid in the time domain corresponds to one slot in a radio frame.

- 5 The smallest time-frequency unit in a resource grid is denoted as a resource element. Each resource grid comprises a number of resource blocks, which describe the mapping of certain physical channels to resource elements. Each resource block comprises a collection of resource elements; in the frequency domain, this may represent the smallest quantity of resources that currently can be allocated. There are several different physical channels that
10 are conveyed using such resource blocks.

- A physical downlink shared channel (“PDSCH”) and physical uplink shared channel (“PUSCH”) may carry user data and higher-layer signaling (for example, radio resource control (“RRC”) signaling messages). Physical downlink control channel (“PDCCH”) may carry downlink control information about, for example, the transport format and resource
15 allocations related to the PDSCH/PUSCH channel, among other things. A PDCCH may also inform the UE 108 about the transport format, resource allocation, and HARQ (Hybrid Automatic Repeat Request) information related to the PUSCH. A physical uplink control channel (“PUCCH”) may carry uplink control information about, for example, HARQ acknowledgement/negative acknowledgement (“ACK/NACK”), multiple-input,
20 multiple-output (“MIMO”) feedback such as rank indicator and precoding matrix, channel quality indicators, etc.

- The TRP 104 and the UE 108 may each engage in beamforming for uplink (“UL”) or downlink (“DL”) communications. This may be especially beneficial in 5G systems that use high frequency communications, for example, millimeter wave (“mmWave”) communications. As used herein, mmWave communications may be communications
25 using a wavelength between 1 and 10 millimeters, which corresponds to a range of frequency spectrum between 30 and 300 gigahertz. Antenna elements used in mmWave systems may be small enough for multiple elements to be implemented in the relatively small form factors typically employed by UEs. Furthermore, beamforming may help to
30 mitigate at least some of the mmWave challenges resulting from, for example, pathloss, line-of-sight, and transmission range issues.

For UL communication, beamforming at the UE-side may result in one or more UL transmit (“Tx”) beams and beamforming at the TRP-side may result in one or more UL

receive (“Rx”) beams. Figure 1 schematically illustrates three UL Tx beams: UL Tx beam 112(a); UL Tx beam 112(b); and UL Tx beam 112(c). Figure 1 also schematically illustrates three UL Rx beams: UL Rx beam 116(a), UL Rx beam 116(b), and UL Rx beam 116(c). Various embodiments may include different numbers of UL Tx/Rx beams,
5 which may not be equal to one another.

A beam management procedure may be performed to determine an appropriate UL Tx beam employed by the UE 108 and UL Rx beam employed by the TRP 104. Uplink beam management may be generally broken into three operations. First, an initial UL Tx/Rx beam may be acquired. Second, a UL Rx beam may be refined. And third, the UL Tx
10 beam may be refined. Various signaling concepts described herein may include control signaling used for beam management procedures as well as signaling relating to, resulting from, or resulting in various reference signals that may be used with respect to the beam management procedures.

Figure 2 illustrates a message flow diagram 200 that describes a specific signaling
15 exchange that may be used to perform or facilitate these beam management procedures in accordance with some embodiments.

At 204, the TRP 104 may acquire initial UL Tx/Rx beam pair information. The initial UL Tx/Rx beam pair information may include information to identify a UL Tx beam to be used by the UE 108 and a UL Rx beam to be used by the TRP 104. The information may
20 include, for example, a beam index of the UL Tx beam, a beam index of the UL Rx beam, a beam index of a beam pair link that includes both a UL Tx beam and a UL Rx beam, or other UL Rx/Tx beam parameters.

The acquisition of the initial UL Tx/Rx beam pair information may be accomplished by, for example, an exhaustive search, an iterative search, or a context information (“CI”)-
25 based search. An exhaustive search may be conducted by a device sequentially stepping through all beams of a predefined codebook that cover an entire angular space. An iterative search may include first and second phases. In a first phase, the TRP 104 may transmit relatively wide angle pilots. The UE 108 may transmit feedback, which the TRP 104 may use to identify a sector on which to focus. In the second phase, the TRP 104/UE
30 108 may perform a search for narrow beams within the chosen sector. The context information (“CI”)-based approach may include the TRP 104 or another access node transmitting context information, for example, global positioning satellite (“GPS”)

coordinates, of TRPs. The context information may be transmitted, for example, using Long Term Evolution (“LTE”) frequencies. The UE 108 may use the context information to select the TRP 104 and an appropriate beam. Various combinations of these processes may be used to acquire the initial UL beam pair information.

- 5 In some embodiments, an initial UL Tx/Rx beam pair may be identified as a complement to a DL Rx/Tx beam pair that has been previously identified. For example, the TRP 104 may initially identify an Rx beam (“RxBeam2”) that is to be used by the UE 108 for DL communications and a Tx beam (“TxBeam3”) that is to be used by the TRP 104 for DL communications. In some embodiments, the UL Tx/Rx beam pair may be determined
10 based on those beams. For example, the initial UL beam pair may include TxBeam2, which corresponds to RxBeam2, for the UE 108 and RxBeam3, which corresponds to TxBeam3, for the TRP 104.

- At 208, the TRP 104 may transmit, to the UE 108, downlink control information (“DCI”) including a first indication (“ind1”) that indicates a UL beam index and a second
15 indication (“ind2”) that indicates a link type of an uplink transmit beam. The DCI may be used to trigger transmission of a sounding reference signal (“SRS”) from the UE 108.

- The first indication may be, for example, an SRS resource indicator (“SRI”) or any other type of indicator that may serve as a basis for the UE 108 selecting a particular UL beam. In some embodiments, for example, when there are multiple beam pair links (“BPLs”)
20 maintained between the TRP 104 and the UE 108, the first indication may be an indication of a link index. The UE 108 may use the link index to determine the appropriate UL beam. In some embodiments, the first indication may simply be a beam index of the UL beam.

- Different power control processes may be used for different channels or reference signals. Thus, providing the second indication to indicate the link type of the uplink transmit beam
25 (or BPL) may allow a more accurate selection of desired beams. In some embodiments, an uplink transmit beam (or BPL) may have a control link type, which may indicate that the uplink transmit beam is to be used to transmit control information. In some embodiments, the uplink transmit beam (or BPL) may have a data link type, which may indicate that the uplink transmit beam is to be used to transmit data information. In various embodiments,
30 the first indication and the second indication may be transmitted in the same or different messages.

At 212, the UE 108 may generate and send one or more instances of an SRS based on the

UL beam index and link type. In some embodiments, the SRS may be transmitted using the UL beam corresponding to the UL beam index provided at 208 and using an uplink power set based on the link type. While various embodiments describe use of an SRS, other embodiments may use other uplink beam management reference signals.

5 At 216, the TRP 104 may refine the UL Rx beam based on the received SRS. Having refined the UL Rx beam, the TRP 104 may transmit one or more downlink reference signals (“RSs”) at 220. The UE 108 may measure the downlink reference signals and provide feedback at 224. In some embodiments, the feedback may be based on reference signal received power (“RSRP”) measurements; however, other measurements used. In
10 this manner, the UE uplink power control information may be updated.

At 226, the UE 108 may transmit an additional SRS using, for example, transmit-beam sweeping. In some embodiments, multiple instances of the SRS may be transmitted at 226 by different UL Tx beams. The TRP 104 may receive the different instances with one receive beam (for example, the one selected at 216). In some embodiments, the TRP 104
15 may construct and send DCI to the UE that instructs the UE to transmit the plurality of repetitions of the SRS using a corresponding plurality of UL Tx beams.

At 228, the TRP 104 may refine the UL Tx beam and provide DCI, at 232, with a revised first indication, if the refined UL Tx beam is different than the initial UL Tx beam indicated at 208. In some embodiments, the TRP 104 may process, with a first uplink
20 receive beam, the plurality of instances of the SRS at 226 and refine the UL Tx beam based on the processing the instances.

Figure 3 illustrates an operation flow/algorithmic structure 300 in accordance with some embodiments. The operation flow/algorithmic structure 300 may be performed by the TRP 104 or circuitry therein in accordance with various embodiments. While this and other
25 embodiments describe operations performed by the TRP 104, it will be understood that some or all of these operations may additionally/alternatively be performed by components of the AN 106 outside of the TRP 104.

The operation flow/algorithmic structure 300 may include, at 304, acquiring initial UL Tx/Rx beam pair information. Acquisition of the initial UL Tx/Rx beam pair information
30 at 304 may be similar to that described above with respect to 204.

The operation flow/algorithmic structure 300 may further include, at 308, transmitting UL beam index and link-type indications. As described above, the indications may be provided in the DCI transmitted through one or more messages.

5 In some embodiments, the indications transmitted at 308 may refer to previously configured parameters. For example, in some embodiments, the TRP 104 may configure the UE 108 with a number of parameter sets. This may be done using higher layer signaling such as, but not limited to, radio resource control (“RRC”) signaling. The indications transmitted at 308, which may be through DCI, may select from the pre-configured parameter sets.

10 In some embodiments, the indications transmitted at 308 may be part of instructions provided to the UE 108, from the TRP 104, that instruct the UE 108 to transmit a plurality of repetitions of an SRS using an indicated uplink transmit beam.

The operation flow/algorithmic structure 300 may further include, at 312, processing one or more instances of an SRS and refining an uplink receive beam based on the processed
15 SRS. In some embodiments, the TRP 104 may refine an uplink receive beam by performing a receive-beam sweep. For example, consider that the TRP 104 instructs the UE 108 to transmit a plurality of repetitions of an SRS using uplink transmit beam 112(a). The TRP 104 may receive a first instance of the SRS using uplink receive beam 116(a), a second instance of the SRS using uplink receive beam 116(b), and a third instance of the
20 SRS using uplink receive beam 116(c). Upon processing these received SRS instances, the TRP 104 may determine that a particular uplink receive beam, for example, uplink receive beam 116(a), is the most efficient to use with the uplink transmit beam used to transmit the SRS instances.

In the event the TRP 104 selects an uplink receive beam that is different from the initial
25 uplink receive beam, the operation flow/algorithmic structure 300 may further include, at 316, transmitting the downlink reference signal based on the refined uplink receive beam. Power control processes may be beam specific, with different beams having different power control parameters. Thus, if the uplink receive beam is changed, the original power control parameters that the UE 108 has may no longer be applicable. Transmitting the
30 downlink reference signal may allow the UE 108 to perform a coupling loss measurement that may be used to determine an uplink transmit power.

Prior to transmitting the downlink reference signal for measurement, the TRP 104 may transmit reference signal indicators, in DCI or higher-layer signaling, that the UE 108 may use to identify the downlink reference signal.

5 The operation flow/algorithmic structure 300 may further include, at 320, processing feedback corresponding to the downlink reference signal and performing uplink power control. The UL power control may be based on the measurements of the DL RSRP, for example.

The operation flow/algorithmic structure 300 may further include, at 324, refining UL Tx beam and transmitting indications of the refined uplink transmit beam and a type of link.
10 The refining of the uplink transmit beam may be based on multiple instances of a SRS transmitted using transmit beam sweeping.

Figure 4 illustrates an operation flow/algorithmic structure 400 in accordance with some embodiments. The operation flow/algorithmic structure 400 may be performed by the UE
15 108 or circuitry therein in accordance with various embodiments.

The operation flow/algorithmic structure 400 may include, at 404, processing first DCI to identify uplink beam index and link-type indications. In some embodiments, the indications of the DCI may reference preconfigured parameter sets. The indications in the DCI may include, directly or indirectly, an indication of an uplink transmit beam by, for
20 example, inclusion of a UL transmit beam index, a link index, or some other indication. In some embodiments, the indications may include an SRI that may be used by the UE 108 to determine an uplink transmit beam. The indications in the DCI may also include, directly or indirectly, an indication of the link type of the uplink transmit beam (or BPL).

The operation flow/algorithmic structure 400 may include, at 408, configuring a
25 transmission beam based on the indications in the DCI. For example, upon receiving the indications, the UE 108 may determine that it is to use a first uplink transmit beam, for example, uplink transmit beam 112(a), and may select an uplink transmit beam power based on the link type. The configuration of the transmission beam may be based on additional beam configuration parameters stored in memory of the UE. The beam
30 configuration parameters may be stored in a beamforming codebook in some embodiments.

The operation flow/algorithmic structure 400 may include, at 412, transmitting an SRS using the configured transmission beam. In some embodiments, the UE 108 may transmit multiple instances of the SRS using the same or different uplink transmit beams. In some embodiments, in order to determine a desired UL Tx/Rx beam, the TRP 104 may use
5 receive-beam sweeping or the UE 108 may use transmit-beam sweeping while the UE 108 is transmitting the multiple instances of the SRS.

The operation flow/algorithmic structure 400 may include, at 416, receiving a downlink reference signal and providing feedback. The UE 108 may receive various indications that provide reference signal configuration information. The UE 108 may then measure a
10 reference signal based on the reference signal configuration information to determine a channel quality/state. Any of a number of measurements may be performed on the reference signal to determine the channel quality/state, including, for example, reference signal receive power (“RSRP”), reference signal receive quality (“RSRQ”), etc. Upon performing the measurements, the UE 108 may feed back an indication of the
15 measurement to the TRP 104.

The operation flow/algorithmic structure 400 may include, at 420, the processing second DCI to identify a refined UL beam index. As discussed above, in some instances the TRP 104 may refine an uplink beam based on received feedback. In these cases, the UE 108, upon processing the second DCI, may reconfigure the transmit circuitry in order to utilize
20 the refined uplink transmit beam for subsequent transmission.

Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. Figure 5 illustrates, for one embodiment, example components of an electronic device 500. In embodiments, the electronic device 500 may be, implement, be incorporated into, or otherwise be a part of UE 108, AN 106, TRP 104,
25 or a computer device that may perform, implement, or incorporate one or more of the features of the UE 108, AN 106, or TRP 104.

In some embodiments, the electronic device 500 may include application circuitry 502, baseband circuitry 504, radio frequency (“RF”) circuitry 506, front-end module (“FEM”) circuitry 508 and one or more antennas 510, coupled together at least as shown. In
30 embodiments where the electronic device 500 is implemented in or by an AN, the electronic device 500 may also include network interface circuitry (not shown) for

communicating over a wired interface (for example, an X2 interface, an S1 interface, and the like).

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,
5 or 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 include
10 logic, at least partially operable in hardware.

The application circuitry 502 may include one or more application processors. For example, the application circuitry 502 may include circuitry such as, but not limited to, one or more single-core or multi-core processors 502a. The processor(s) 502a may include any combination of general-purpose processors and dedicated processors (for example,
15 graphics processors, application processors, etc.). The processors 502a may be coupled with and/or may include computer-readable media 502b (also referred to as “CRM 502b,” “memory 502b,” “storage 502b,” or “memory/storage 502b”) and may be configured to execute instructions stored in the CRM 502b to enable various applications and/or operating systems to run on the system.

20 The baseband circuitry 504 may include circuitry such as, but not limited to, one or more single-core or multi-core processors to perform any of the beam management procedures described herein. In some embodiments, the baseband circuitry 504 may be configured to perform one or more processes, techniques, and/or methods as described herein, or portions thereof. For example, the baseband circuitry 504 may construct, process, or cause
25 signaling of the various messages described and discussed in the message flow diagram 200 of Figure 2. Furthermore, the baseband circuitry 504 may implement the operation flow/algorithmic structure 300 of Figure 3 or the operation flow/algorithmic structure 400 of Figure 4 according to some embodiments.

The baseband circuitry 504 may include one or more baseband processors and/or control
30 logic to process baseband signals received from a receive signal path of the RF circuitry 506 and to generate baseband signals for a transmit signal path of the RF circuitry 506. Baseband circuitry 504 may interface with the application circuitry 502 for generation and

processing of the baseband signals and for controlling operations of the RF circuitry 506. For example, in some embodiments, the baseband circuitry 504 may include a second generation (“2G”) baseband processor 504a, third generation (“3G”) baseband processor 504b, fourth generation (“4G”) baseband processor 504c, fifth generation (“5G”) baseband processor 504h, and/or other baseband processor(s) 504d for other existing generations, generations in development or to be developed in the future (for example, 6G, etc.).

The baseband circuitry 504 (for example, one or more of baseband processors 504a-d, h) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 506. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, and the like. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 504 may include Fast-Fourier Transform (“FFT”), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 504 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.

In some embodiments, the baseband circuitry 504 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (“E-UTRAN”) 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”) 504e of the baseband circuitry 504 may be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP and/or RRC layers.

In various embodiments, the 5G baseband processor 504h may perform the PHY and possibly some or all of the MAC layer operations described above with respect to Figures 2, 3, and 4; while the CPU 504e may perform some or all of the MAC layer operations and the RLC, PDCP, and RRC layer operations. In some embodiments, the CPU 504e may configure, at the RRC layer, for example, the various parameter sets that may be used for beam management procedures, while the 5G baseband circuitry 504h may be used to process, construct, or signal DCI including the indications of the uplink transmit beam and

link type; configure the uplink transmit beam; and measure the DL RS and provide feedback.

In some embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (“DSP(s)”) 504f. The audio DSP(s) 504f may include elements for
5 compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments.

The baseband circuitry 504 may further include computer-readable media 504g (also referred to as “CRM 504g,” “memory 504g,” “storage 504g,” or “CRM 504g”). The CRM 504g may be used to load and store data and/or instructions for operations performed by
10 the processors of the baseband circuitry 504. For example, the CRM 504g may include instructions that, when executed by one or more processors, cause a device (for example, an AN 106, TRP 104, or UE 108) to perform any of the operations described herein. The CRM 504g may also include data stored to facilitate the operations. For example, the CRM 504g may store beam configuration parameters, e.g., a beamforming codebook, that
15 is access by baseband circuitry to configure transmit/receive beams. CRM 504g for one embodiment may include any combination of suitable volatile memory and/or non-volatile memory. The CRM 504g may include any combination of various levels of memory/storage, including, but not limited to, read-only memory (“ROM”) having embedded software instructions (for example, firmware), random access memory (for
20 example, dynamic random access memory (“DRAM”)), cache, buffers, etc. The CRM 504g may be shared among the various processors or dedicated to particular processors.

Components of the baseband circuitry 504 may be suitably combined in a single chip or a single chipset, or disposed on a same circuit board in some embodiments. In some
25 embodiments, some or all of the constituent components of the baseband circuitry 504 and the application circuitry 502 may be implemented together, such as, for example, on a system on a chip (“SOC”).

In some embodiments, the baseband circuitry 504 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 504 may support communication with an E-UTRAN and/or other
30 wireless metropolitan area networks (“WMAN”), a wireless local area network (“WLAN”), a wireless personal area network (“WPAN”). Embodiments in which the

baseband circuitry 504 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

RF circuitry 506 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 506 may include switches, filters, amplifiers, etc., to facilitate the communication with the wireless network. RF circuitry 506 may include a receive signal path that may include circuitry to down-convert RF signals received from the FEM circuitry 508 and provide baseband signals to the baseband circuitry 504. RF circuitry 506 may also include a transmit signal path that may include circuitry to up-convert baseband signals provided by the baseband circuitry 504 and provide RF output signals to the FEM circuitry 508 for transmission.

In some embodiments, the RF circuitry 506 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 506 may include mixer circuitry 506a, amplifier circuitry 506b, and filter circuitry 506c. The transmit signal path of the RF circuitry 506 may include filter circuitry 506c and mixer circuitry 506a. RF circuitry 506 may also include synthesizer circuitry 506d for synthesizing a frequency for use by the mixer circuitry 506a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 506a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 508 based on the synthesized frequency provided by synthesizer circuitry 506d. The amplifier circuitry 506b may be configured to amplify the down-converted signals and the filter circuitry 506c 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 504 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 506a 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 506a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 506d to generate RF output signals for the FEM circuitry 508. The baseband signals may be provided by the baseband circuitry 504 and

may be filtered by filter circuitry 506c. The filter circuitry 506c may include an LPF, although the scope of the embodiments is not limited in this respect.

In some embodiments, the mixer circuitry 506a of the receive signal path and the mixer circuitry 506a of the transmit signal path may include two or more mixers and may be
5 arranged for quadrature downconversion and/or upconversion, respectively. In some embodiments, the mixer circuitry 506a of the receive signal path and the mixer circuitry 506a of the transmit signal path may include two or more mixers and may be arranged for image rejection (for example, Hartley image rejection). In some embodiments, the mixer circuitry 506a of the receive signal path and the mixer circuitry 506a of the transmit signal
10 path may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 506a of the receive signal path and the mixer circuitry 506a 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
15 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 506 may include analog-to-digital converter (“ADC”) and digital-to-analog converter (“DAC”) circuitry and the baseband circuitry 504 may include a digital
20 baseband interface to communicate with the RF circuitry 506.

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.

In some embodiments, the synthesizer circuitry 506d may be a fractional-N synthesizer or
25 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 506d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider. The synthesizer circuitry 506d may be configured to synthesize an output frequency for use by the mixer
30 circuitry 506a of the RF circuitry 506 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 506d may be a fractional N/N+1 synthesizer.

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 504 or the application circuitry 502 depending on the desired output frequency. In some embodiments, a divider control input (for example, N) may be
5 determined from a look-up table based on a channel indicated by the application circuitry 502.

Synthesizer circuitry 506d of the RF circuitry 506 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
10 phase accumulator (“DPA”). In some embodiments, the DMD may be configured to divide the input signal by either N or N+1 (for example, 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
15 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.

In some embodiments, synthesizer circuitry 506d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may
20 be a multiple of the carrier frequency (for example, 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 506 may include an
25 IQ/polar converter.

FEM circuitry 508 may include a receive signal path that may include circuitry configured to operate on RF signals received from one or more antennas 510, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 506 for further processing. FEM circuitry 508 may also include a transmit signal path that may
30 include circuitry configured to amplify signals for transmission provided by the RF circuitry 506 for transmission by one or more of the one or more antennas 510. In some embodiments, the FEM circuitry 508 may include a Tx/Rx switch to switch between transmit mode and receive mode operation. The FEM circuitry 508 may include a receive

signal path and a transmit signal path. The receive signal path of the FEM circuitry 508 may include a low-noise amplifier (“LNA”) to amplify received RF signals and provide the amplified received RF signals as an output (for example, to the RF circuitry 506). The transmit signal path of the FEM circuitry 508 may include a power amplifier (“PA”) to
5 amplify input RF signals (for example, provided by RF circuitry 506), and one or more filters to generate RF signals for subsequent transmission (for example, by one or more of the one or more antennas 510).

In some embodiments, the electronic device 500 may include additional elements such as, for example, a display, a camera, one or more sensors, and/or interface circuitry (for
10 example, input/output (“I/O”) interfaces or buses) (not shown). In embodiments where the electronic device 500 is implemented in or by an eNB, the electronic device 500 may include network interface circuitry. The network interface circuitry may be one or more computer hardware components that connect electronic device 500 to one or more network elements, such as one or more servers within a core network or one or more other eNBs
15 via a wired connection. To this end, the network interface circuitry may include one or more dedicated processors and/or field programmable gate arrays (“FPGAs”) to communicate using one or more network communications protocols such as X2 application protocol (“AP”), S1 AP, Stream Control Transmission Protocol (“SCTP”), Ethernet, Point-to-Point, Fiber Distributed Data Interface (“FDDI”), and/or any other
20 suitable network communications protocols.

Figure 6 illustrates example interfaces of baseband circuitry 504 in accordance with some embodiments. As discussed above, the baseband circuitry 504 of Figure 6 may comprise processors and CRM 504g utilized by said processors. Each of the processors 504b, 504c, 504h, and 504d may include a memory interface, 604b, 604c, 604h, and 604d,
25 respectively, to send/receive data to/from the CRM 504g.

The baseband circuitry 504 may further include one or more interfaces to communicatively couple to other circuitries/devices, such as a memory interface 612 (for example, an interface to send/receive data to/from memory external to the baseband circuitry 504), an application circuitry interface 614 (for example, an interface to
30 send/receive data to/from the application circuitry 502 of Figure 5), an RF circuitry interface 616 (for example, an interface to send/receive data to/from RF circuitry 506 of Figure 6), a wireless hardware connectivity interface 618 (for example, an interface to send/receive data to/from Near Field Communication (“NFC”) components, Bluetooth®

components (for example, Bluetooth® Low Energy), Wi-Fi® components, and other communication components), and a power management interface 620 (for example, an interface to send/receive power or control signals to/from a power management controller. Figure 7 illustrates communication circuitry 700 according to some aspects.

5 Communication circuitry 700 may be similar to, and substantially interchangeable with, components of electronic device 500. Components as shown in communication circuitry 700 are shown here for illustrative purposes and may include other components not shown here in Figure 7.

Communication circuitry 700 may include protocol processing circuitry 705 may
10 correspond to CPU 504e, processor 502a, etc. The protocol processing circuitry may implement one or more of MAC, RLC, PDCP, RRC and non-access stratum (“NAS”) functions. Protocol processing circuitry 705 may include one or more processing cores (not shown, but similar to those described elsewhere herein) to execute instructions and one or more memory structures (not shown, but similar to those described elsewhere
15 herein) to store program and data information.

Communication circuitry 700 may further include digital baseband circuitry 710, which may be similar to baseband processors of the baseband circuitry 504. The digital baseband circuitry 710 may implement PHY layer functions including one or more of hybrid
20 automatic repeat request (“HARQ”) functions; scrambling and/or descrambling; coding and/or decoding; layer mapping and/or demapping; modulation symbol mapping; received symbol and/or bit metric determination; multi-antenna port precoding and/or decoding, which may include one or more of space-time, space-frequency or spatial coding; reference signal generation and/or detection; preamble sequence generation and/or decoding; synchronization sequence generation and/or detection; control channel signal
25 blind decoding; and other related functions.

Communication circuitry 700 may further include transmit circuitry 715, receive circuitry 720 and/or antenna array 730.

Communication circuitry 700 may further include RF circuitry 725, which may correspond to RF circuitry 506 or FEM circuitry 508. In an aspect of the invention, RF
30 circuitry 725 may include multiple parallel RF chains for one or more of transmit or receive functions, each connected to one or more antennas of the antenna array 730.

In an aspect of the disclosure, protocol processing circuitry 705 may include one or more instances of control circuitry (not shown) to provide control functions for one or more of digital baseband circuitry 710, transmit circuitry 715, receive circuitry 720, and/or radio frequency circuitry 725.

- 5 In some embodiments, communication circuitry 700 may be specifically configured for mmWave communications. For example, the communication circuitry 700 may have a hybrid beamforming architecture in which precoding and combining are done in both baseband and RF sections. For example, the digital baseband circuitry 710 may implement a baseband precoder (in transmitter) and combiner (in receiver) using digital signal
10 processing, while RF circuitry 725 may implement RF precoding (in transmitter) and combiner (in receiver) using phase shifters.

Figure 8 illustrates an exemplary radio-frequency circuitry 725 in Figure 7 according to some aspects.

- RF circuitry 725 may include one or more instances of radio chain circuitry 872, which in
15 some aspects may include one or more filters, power amplifiers, low-noise amplifiers, programmable phase shifters and power supplies (not shown).

- Radio-frequency circuitry 725 may include power combining and dividing circuitry 874 in some aspects. In some aspects, power combining and dividing circuitry 874 may operate bidirectionally, such that the same physical circuitry may be configured to operate as a
20 power divider when the device is transmitting, and as a power combiner when the device is receiving. In some aspects, power combining and dividing circuitry 874 may include one or more wholly or partially separate circuitries to perform power dividing when the device is transmitting and power combining when the device is receiving. In some aspects, power combining and dividing circuitry 874 may include passive circuitry comprising one
25 or more two-way power divider/combiners arranged in a tree. In some aspects, power combining and dividing circuitry 874 may include active circuitry comprising amplifier circuits.

- In some aspects, radio-frequency circuitry 725 may connect to transmit circuitry 715 and receive circuitry 720 in Figure 7 via one or more radio chain interfaces 876 or a combined
30 radio chain interface 878.

In some aspects, one or more radio chain interfaces 876 may provide one or more interfaces to one or more receive or transmit signals, each associated with a single antenna structure which may comprise one or more antennas.

5 In some aspects, the combined radio chain interface 878 may provide a single interface to one or more receive or transmit signals, each associated with a group of antenna structures comprising one or more antennas.

In some embodiments, the combined radio chain interface 878 may be used for mmWave communications, while the radio chain interfaces 876 may be used for lower-frequency communications.

10 Figure 9 is an illustration of a protocol stack of a control plane 900 in accordance with some embodiments. In this embodiment, the control plane 900 is shown as a communications protocol stack between the UE 108 and the AN 106.

The PHY layer 901 may transmit or receive information used by the MAC layer 902 over one or more air interfaces. The PHY layer 901 may further perform link adaptation or
15 adaptive modulation and coding (“AMC”), power control, cell search (for example, for initial synchronization and handover purposes), and other measurements used by higher layers, such as the RRC layer 905. The PHY layer 901 may still further perform error detection on the transport channels, forward error correction (“FEC”) coding/decoding of the transport channels, modulation/demodulation of physical channels, interleaving, rate
20 matching, mapping onto physical channels, and Multiple Input Multiple Output (“MIMO”) antenna processing. As described above, the PHY layer 901 may process, construct, or signal DCI including the indications of the uplink transmit beam and link type; configure the uplink transmit beam; and measure the DL RS and provide feedback.

The MAC layer 902 may perform mapping between logical channels and transport
25 channels, multiplexing of MAC service data units (“SDUs”) from one or more logical channels onto transport blocks (“TB”) to be delivered to PHY via transport channels, de-multiplexing MAC SDUs to one or more logical channels from transport blocks (“TB”) delivered from the PHY via transport channels, multiplexing MAC SDUs onto TBs, scheduling information reporting, error correction through hybrid automatic repeat request
30 (“HARQ”), and logical channel prioritization.

The RLC layer 903 may operate in a plurality of modes of operation, including: Transparent Mode (“TM”), Unacknowledged Mode (“UM”), and Acknowledged Mode

(“AM”). The RLC layer 903 may execute transfer of upper layer protocol data units (“PDUs”), error correction through automatic repeat request (“ARQ”) for AM data transfers, and concatenation, segmentation and reassembly of RLC SDUs for UM and AM data transfers. The RLC layer 903 may also execute re-segmentation of RLC data PDUs
 5 for AM data transfers, reorder RLC data PDUs for UM and AM data transfers, detect duplicate data for UM and AM data transfers, discard RLC SDUs for UM and AM data transfers, detect protocol errors for AM data transfers, and perform RLC re-establishment.

The PDCP layer 904 may execute header compression and decompression of IP data, maintain PDCP Sequence Numbers (“SNs”), perform in-sequence delivery of upper layer
 10 PDUs at re-establishment of lower layers, eliminate duplicates of lower layer SDUs at re-establishment of lower layers for radio bearers mapped on RLC AM, cipher and decipher control plane data, perform integrity protection and integrity verification of control plane data, control timer-based discard of data, and perform security operations (for example, ciphering, deciphering, integrity protection, integrity verification, etc.).

15 The main services and functions of the RRC layer 905 may include broadcast of system information (for example, included in Master Information Blocks (“MIBs”) or System Information Blocks (“SIBs”) related to the non-access stratum (“NAS”)), broadcast of system information related to the access stratum (“AS”), paging, establishment, maintenance and release of an RRC connection between the UE and E-UTRAN (for
 20 example, RRC connection paging, RRC connection establishment, RRC connection modification, and RRC connection release), establishment, configuration, maintenance and release of point to point radio bearers, security functions including key management, inter radio access technology (“RAT”) mobility, and measurement configuration for UE measurement reporting. As described above, the RRC layer 905 may configure the
 25 parameter sets for beam management signaling. Said MIBs and SIBs may comprise one or more information elements (“IEs”), which may each comprise individual data fields or data structures.

The UE 108 and the AN node 106 may utilize a Uu interface (for example, an LTE-Uu interface) to exchange control plane data via a protocol stack comprising the PHY layer
 30 901, the MAC layer 902, the RLC layer 903, the PDCP layer 904, and the RRC layer 905.

The non-access stratum (“NAS”) protocols 906 form the highest stratum of the control plane between the UE 108 and a mobility management entity. The NAS protocols 906

support the mobility of the UE 108 and the session management procedures to establish and maintain IP connectivity between the UE and a package gateway.

Figure 10 is an illustration of a protocol stack of a user plane in accordance with some embodiments. In this embodiment, the user plane 1000 is shown as a communications
5 protocol stack between the UE 108 and the AN 106. The user plane 1000 may utilize at least some of the same protocol layers as the control plane 900. For example, the UE 108 and the AN 106 may utilize a Uu interface (for example, an LTE-Uu interface) to exchange user plane data via a protocol stack comprising a PHY layer 1001, a MAC layer 1002, an RLC layer 1003, and a PDCP layer 1004.

10 Figure 11 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (for example, a non-transitory machine-readable storage medium) and perform any one or more of the beam management signaling methodologies discussed herein. Specifically, Figure 11 shows a diagrammatic representation of hardware resources 1100
15 including one or more processors (or processor cores) 1110, one or more memory/storage devices 1120, and one or more communication resources 1130, each of which may be communicatively coupled via a bus 1140. For embodiments where node virtualization (for example, network function virtualization (“NFV”)) is utilized, a hypervisor 1102 may be executed to provide an execution environment for one or more network slices/sub-slices to
20 utilize the hardware resources 1100.

The processors 1110 (for example, a CPU, a reduced instruction set computing (“RISC”) processor, a complex instruction set computing (“CISC”) processor, a graphics processing unit (“GPU”), a digital signal processor (“DSP”) such as a baseband processor, an application specific integrated circuit (“ASIC”), a radio-frequency integrated circuit
25 (“RFIC”), another processor, or any suitable combination thereof) may include, for example, a processor 1112 and a processor 1114. The processors may correspond to any processors of the AN 106 or the UE 108 described herein.

The memory/storage devices 1120 may include main memory, disk storage, or any suitable combination thereof. The memory/storage devices 1120 may include, but are not
30 limited to, any type of volatile or non-volatile memory such as dynamic random access memory (“DRAM”), static random-access memory (“SRAM”), erasable programmable read-only memory (“EPROM”), electrically erasable programmable read-only memory

(“EEPROM”), Flash memory, solid-state storage, etc. The memory/storage devices 1120 may correspond to CRM 502b or 504g of Figure 5.

The communication resources 1130 may include interconnection or network interface components or other suitable devices to communicate with one or more peripheral devices 1104 or one or more databases 1106 via a network 1108. For example, the communication resources 1130 may include wired communication components (for example, for coupling via a Universal Serial Bus (“USB”)), cellular communication components, near-field communication (“NFC”) components, Bluetooth® components (for example, Bluetooth® Low Energy), Wi-Fi® components, and other communication components.

Instructions 1150 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 1110 to perform any one or more of the methodologies discussed herein.

The instructions 1150 may cause the processors 1110 to perform the operation flow/algorithmic structure 300, 400 or other operations of an AN, UE, or TRP described herein.

The instructions 1150 may reside, completely or partially, within at least one of the processors 1110 (for example, within the processor’s cache memory), the memory/storage devices 1120, or any suitable combination thereof. Furthermore, any portion of the instructions 1150 may be transferred to the hardware resources 1100 from any combination of the peripheral devices 1104 or the databases 1106. Accordingly, the memory of processors 1110, the memory/storage devices 1120, the peripheral devices 1104, and the databases 1106 are examples of computer-readable and machine-readable media.

The resources described in Figure 11 may also be referred to as circuitry. For example, communication resources 1130 may also be referred to as communication circuitry 1130.

Some non-limiting examples are provided below.

Example 1 includes one or more computer-readable media having instructions that, when executed by one or more processors, cause a UE to: process downlink control information (“DCI”) to determine an uplink beam index and a link type of an uplink transmit beam; and cause a sounding reference signal (“SRS”) to be transmitted based on the uplink beam index and the link type of the uplink transmit beam.

Example 2 includes the one or more computer-readable media of example 1 or some other example herein, wherein the instructions, when executed, further cause the UE to: set a power for the SRS based on the link type of the uplink transmit beam.

5 Example 3 includes the one or more computer-readable media of example 1 or 2 or some other example herein, wherein the DCI includes an indication of a beam pair link index and the instructions, when executed, further cause the UE to process the DCI to determine the uplink beam index based on the beam pair link index.

10 Example 4 includes the one or more computer-readable media of example 1 or 2 or some other example herein, wherein the DCI includes an indication of a transmit beam index and the instructions, when executed, further cause the UE to process the DCI to determine the uplink beam index based on the transmit beam index.

Example 5 includes the one or more computer-readable media of example 1 or 2 or some other example herein, wherein the link type is to indicate the uplink transmit beam is to transmit data or control information.

15 Example 6 includes the one or more computer-readable media of example 1 or 2 or some other example herein, wherein the instructions, when executed, further cause the UE to: identify, after the SRS is transmitted, a downlink reference signal; and perform a coupling loss measurement based on the downlink reference signal.

20 Example 7 includes the one or more computer-readable media of example 6 or some other example herein, wherein the instructions, when executed, further cause the UE to: determine, based on the coupling loss measurement, an uplink transmit power; and cause the uplink transmit beam to be transmitted based on the uplink transmit power.

25 Example 8 includes one or more computer-readable media having instructions that, when executed, cause an TRP to: construct downlink control information (“DCI”) to include a first indication of an uplink beam index and a second indication of a link type of a transmit beam; cause the DCI to be transmitted to a user equipment (“UE”); and process a sounding reference signal (“SRS”) transmitted by the UE.

30 Example 9 includes the one or more computer-readable media of example 8 or some other example herein, wherein the instructions, when executed, further cause the TRP to: process a plurality of repetitions of the SRS using a corresponding plurality of uplink receive beams.

Example 10 includes the one or more computer-readable media of example 8 or some other example herein, wherein the instructions, when executed, further cause the TRP to: refine an uplink receive beam based on the SRS; and cause a downlink reference signal to be transmitted to the UE based on said refinement of the uplink receive beam.

- 5 Example 11 includes the one or more computer-readable media of example 8 or some other example herein, wherein the instructions, when executed, further cause the TRP to: construct the DCI to instruct the UE to transmit a plurality of repetitions of the SRS using a corresponding plurality of uplink transmit beams; process, with a first uplink receive beam, the plurality of repetitions of the SRS transmitted by the UE; and refine an uplink
10 transmit beam based on processing of the plurality of repetitions of the SRS.

Example 12 includes the one or more computer-readable media of any one of examples 8-11 or some other example herein, wherein the uplink beam index is a beam pair link index.

Example 13 includes the one or more computer-readable media of any one of examples 8-11 or some other example herein, wherein the uplink beam index is a transmit beam index.

- 15 Example 14 includes the one or more computer-readable media of any one of examples 8-11 or some other example herein, wherein the link type is to indicate the uplink transmit beam is to transmit data or control information.

- Example 15 includes a method comprising: memory to store beam configuration parameters; and baseband circuitry, to interface with the memory, the baseband circuitry
20 to: identify, based on a message received from a transmission/reception point ("TRP"), a first indication of an uplink ("UL") beam index and a second indication of an intended use of an uplink transmit beam; and configure a transmission beam based on the beam configuration parameters and the first and second indications.

- Example 16 includes the method of example 15 or some other example herein, wherein the
25 second indication indicates whether the uplink transmit beam is to be used for control messages or data messages.

Example 17 includes the method of example 15 or 16 or some other example herein, wherein the message is received via downlink control information ("DCI").

- Example 18 includes the method of example 15 or 16 or some other example herein,
30 wherein the baseband circuitry is further to: identify, after a sounding reference signal

("SRS") is transmitted, a downlink reference signal; and perform a coupling loss measurement based on the downlink reference signal.

Example 19 includes the method of example 18 or some other example herein, wherein the message is a first message and the baseband circuitry is further to identify a third
5 indication of the downlink reference signal in a second message that is received via downlink control information ("DCI") or higher layer signaling.

Example 20 includes the method of example 18 or some other example herein, wherein the baseband circuitry is further to reconfigure the transmission beam based on a result of the coupling loss measurement.

10 Example 21 includes the method of example 18 or some other example herein, further comprising: radio-frequency circuitry having: power combining and dividing circuitry having an interface with the baseband circuitry to receive or transmit signals corresponding to millimeterwave ("mmWave") transmissions; and a radio chain circuitry having a first interface with the baseband circuitry and a second interface with the power
15 combining and dividing circuitry, wherein the first interface is to receive or transmit signals corresponding to non-mmWave transmissions.

Example 22 includes a method comprising: means for acquiring an initial uplink transmit/receive beam pair; means for transmitting, to a user equipment, a first indication of an uplink transmit beam index and a second indication of a link type of a transmit
20 beam; and means for refining a receive beam based on an uplink reference signal from the user equipment.

Example 23 includes the method of example 22 or some other example herein, wherein the first and second indication are transmitted via downlink control information ("DCI").

Example 24 includes the method of example 22 or some other example herein, wherein
25 refining the receive beam comprises performing receive beam sweeping to process a plurality of repetitions of the uplink reference signal.

Example 25 includes the method of any one of examples 22-24 or some other example herein, further comprising: transmitting a downlink reference signal based on refinement of the receive beam.

30 Example 26 includes a method comprising: processing downlink control information ("DCI") to determine an uplink beam index and a link type of an uplink transmit beam;

and causing a sounding reference signal (“SRS”) to be transmitted based on the uplink beam index and the link type of the uplink transmit beam.

Example 27 includes the method of example 26 or some other example herein, further comprising: setting a power for the SRS based on the link type of the uplink transmit
5 beam.

Example 28 includes the method of example 26 or 27 or some other example herein, wherein the DCI includes an indication of a beam pair link index and the method further comprises processing the DCI to determine the uplink beam index based on the beam pair link index.

10 Example 29 includes the method of example 26 or 27 or some other example herein, wherein the DCI includes an indication of a transmit beam index and the method further comprises processing the DCI to determine the uplink beam index based on the transmit beam index.

Example 30 includes the method of example 26 or 27 or some other example herein,
15 wherein the link type is to indicate the uplink transmit beam is to transmit data or control information.

Example 31 includes the method of example 26 or 27 or some other example herein, further comprising: identifying, after the SRS is transmitted, a downlink reference signal; and performing a coupling loss measurement based on the downlink reference signal.

20 Example 32 includes the method of example 26 or 27 or some other example herein, further comprising: determining, based on a coupling loss measurement, an uplink transmit power; and causing the uplink transmit beam to be transmitted based on the uplink transmit power.

Example 33 includes a method comprising: constructing downlink control information
25 (“DCI”) to include a first indication of an uplink beam index and a second indication of a link type of a transmit beam; causing the DCI to be transmitted to a user equipment (“UE”); and processing a sounding reference signal (“SRS”) transmitted by the UE.

Example 34 includes the method of example 33 or some other example herein, further comprising: processing a plurality of repetitions of the SRS using a corresponding
30 plurality of uplink receive beams.

Example 35 includes the method of example 33 or some other example herein, further comprising: refining an uplink receive beam based on the SRS; and causing a downlink reference signal to be transmitted to the UE based on said refinement of the uplink receive beam.

- 5 Example 36 includes the method of example 33 or some other example herein, further comprising: constructing the DCI to instruct the UE to transmit a plurality of repetitions of the SRS using a corresponding plurality of uplink transmit beams; processing, with a first uplink receive beam, the plurality of repetitions of the SRS transmitted by the UE; and updating a reference signal receive power (“RSRP”) measurement corresponding to
10 individual uplink transmit beams based on processing of the plurality of repetitions of the SRS.

Example 37 includes the method of any one of examples 33-36 or some other example herein, wherein the uplink beam index is a beam pair link index.

- 15 Example 38 includes the method of any one of examples 33-36 or some other example herein, wherein the uplink beam index is a transmit beam index.

Example 39 includes the method of any one of examples 33-36 or some other example herein, wherein the to transmit data or control information.

- 20 Example 40 includes a method comprising: identifying, based on a message received from a transmission/reception point (“TRP”), a first indication of an uplink (“UL”) beam index and a second indication of an intended use of an uplink transmit beam; and configuring a transmission beam based, at least in part, on the first and second indications.

Example 41 includes the method of example 40 or some other example herein, wherein the second indication indicates whether the uplink transmit beam is to be used for control messages or data messages.

- 25 Example 42 includes the method of example 40 or 41 or some other example herein, wherein the message is received via downlink control information (“DCI”).

Example 43 includes the method of example 40 or 41 or some other example herein, further comprising: identifying, after an SRS is transmitted, a downlink reference signal; and performing a coupling loss measurement based on the downlink reference signal.

- 30 Example 44 includes the method of example 43 or some other example herein, wherein the message is a first message and the method further comprises identifying a third indication

of the downlink reference signal in a second message that is received via downlink control information (“DCI”) or higher layer signaling.

Example 45 includes the method of example 43 or some other example herein, further comprising reconfiguring the transmission beam based on a result of the coupling loss
5 measurement.

Example 46 includes a method comprising: acquiring an initial uplink transmit/receive beam pair; transmitting, to a user equipment, a first indication of an uplink transmit beam index and a second indication of a link type of a transmit beam; and
refining a receive beam based on an uplink reference signal from the user equipment.

10 Example 47 includes the method of example 46 or some other example herein, wherein the first and second indication are transmitted via downlink control information (“DCI”).

Example 48 includes the method of example 46 or some other example herein, wherein refining the receive beam comprises performing receive beam sweeping to process a plurality of repetitions of the uplink reference signal.

15 Example 49 includes the method of any one of examples 46-48 or some other example herein, further comprising: transmitting a downlink reference signal based on refinement of the receive beam.

Example 50 may include the method of any of the examples 26-49 or some other example herein, wherein the method is performed and/or implemented by a transmission reception
20 point.

Example 51 may include the method of any of the examples 26-49 or some other example herein, wherein the method is performed and/or implemented by a next generation NodeB (“gNB”).

Example 52 may include an apparatus comprising means to perform one or more elements
25 of a method described in or related to any of examples 26-49, or any other method or process described herein.

Example 53 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
30 described in or related to any of examples 26-49, or any other method or process described herein.

Example 54 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 26-49, or any other method or process described herein.

5 Example 55 may include a method, technique, or process as described in or related to any of examples 26-49, or portions or parts thereof.

Example 56 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 26-49, or portions thereof.

10 Example 57 may include a method of communicating in a wireless network as shown and described herein.

Example 58 may include a system for providing wireless communication as shown and described herein.

15 Example 59 may include a device for providing wireless communication as shown and described herein.

The description herein of illustrated implementations, including what is described in the Abstract, is not intended to be exhaustive or to limit the present disclosure to the precise forms disclosed. While specific implementations and examples are described herein for illustrative purposes, a variety of alternate or equivalent embodiments or implementations
20 calculated to achieve the same purposes may be made in light of the above detailed description, without departing from the scope of the present disclosure, as those skilled in the relevant art will recognize.

CLAIMS

What is claimed is:

1. One or more computer-readable media having instructions that, when executed by one or more processors, cause a user equipment ("UE") to:
 - 5 process downlink control information ("DCI") to determine an uplink beam index and a link type of an uplink transmit beam; and
 - cause a sounding reference signal ("SRS") to be transmitted based on the uplink beam index and the link type of the uplink transmit beam.
- 10 2. The one or more computer-readable media of claim 1, wherein the instructions, when executed, further cause the UE to:
 - set a power for the SRS based on the link type of the uplink transmit beam.
- 15 3. The one or more computer-readable media of claim 1 or 2, wherein the DCI includes an indication of a beam pair link index and the instructions, when executed, further cause the UE to process the DCI to determine the uplink beam index based on the beam pair link index.
- 20 4. The one or more computer-readable media of claim 1 or 2, wherein the DCI includes an indication of a transmit beam index and the instructions, when executed, further cause the UE to process the DCI to determine the uplink beam index based on the transmit beam index.
- 25 5. The one or more computer-readable media of claim 1 or 2, wherein the link type is to indicate the uplink transmit beam is to transmit data or control information.
6. The one or more computer-readable media of claim 1 or 2, wherein the instructions, when executed, further cause the UE to:
 - identify, after the SRS is transmitted, a downlink reference signal; and

perform a coupling loss measurement based on the downlink reference signal.

7. The one or more computer-readable media of claim 6, wherein the instructions, when executed, further cause the UE to:

- 5 determine, based on the coupling loss measurement, an uplink transmit power; and
cause the uplink transmit beam to be transmitted based on the uplink transmit power.

8. One or more computer-readable media having instructions that, when executed, cause a transmission/reception point ("TRP") to:

- 10 construct downlink control information ("DCI") to include a first indication of an uplink
beam index and a second indication of a link type of a transmit beam;
cause the DCI to be transmitted to a user equipment ("UE"); and
process a sounding reference signal ("SRS") transmitted by the UE.

- 15 9. The one or more computer-readable media of claim 8, wherein the instructions, when
executed, further cause the TRP to:

process a plurality of repetitions of the SRS using a corresponding plurality of uplink
receive beams.

- 20 10. The one or more computer-readable media of claim 8, wherein the instructions, when
executed, further cause the TRP to:

refine an uplink receive beam based on the SRS; and

cause a downlink reference signal to be transmitted to the UE based on said refinement of
the uplink receive beam.

25

11. The one or more computer-readable media of claim 8, wherein the instructions, when
executed, further cause the TRP to:

construct the DCI to instruct the UE to transmit a plurality of repetitions of the SRS using a corresponding plurality of uplink transmit beams;

process, with a first uplink receive beam, the plurality of repetitions of the SRS transmitted by the UE; and

- 5 refine an uplink transmit beam based on processing of the plurality of repetitions of the SRS.

12. The one or more computer-readable media of any one of claims 8-11, wherein the uplink beam index is a beam pair link index.

10

13. The one or more computer-readable media of any one of claims 8-11, wherein the uplink beam index is a transmit beam index.

14. The one or more computer-readable media of any one of claims 8-11, wherein the link
15 type is to indicate the uplink transmit beam is to transmit data or control information.

15. A user equipment ("UE") comprising:

memory to store beam configuration parameters; and

baseband circuitry, to interface with the memory, the baseband circuitry to:

- 20 identify, based on a message received from a transmission/reception point ("TRP"), a first indication of an uplink ("UL") beam index and a second indication of an intended use of an uplink transmit beam; and
- configure a transmission beam based on the beam configuration parameters and the first and second indications.

25

16. The apparatus of claim 15, wherein the second indication indicates whether the uplink transmit beam is to be used for control messages or data messages.

17. The apparatus of claim 15 or 16, wherein the message is received via downlink control information (“DCI”).

18. The apparatus of claim 15 or 16, wherein the baseband circuitry is further to:

5 identify, after an SRS is transmitted, a downlink reference signal; and
perform a coupling loss measurement based on the downlink reference signal.

19. The apparatus of claim 18, wherein the message is a first message and the baseband circuitry is further to identify a third indication of the downlink reference signal in a
10 second message that is received via downlink control information (“DCI”) or higher layer signaling.

20. The apparatus of claim 18, wherein the baseband circuitry is further to reconfigure the transmission beam based on a result of the coupling loss measurement.

15

21. The apparatus of claim 18, further comprising:

radio-frequency circuitry having:

power combining and dividing circuitry having an interface with the baseband circuitry to receive or transmit signals corresponding to millimeterwave (“mmWave”) transmissions; and
20

a radio chain circuitry having a first interface with the baseband circuitry and a second interface with the power combining and dividing circuitry, wherein the first interface is to receive or transmit signals corresponding to non-mmWave transmissions.

25 22. An apparatus comprising:

means for acquiring an initial uplink transmit/receive beam pair;

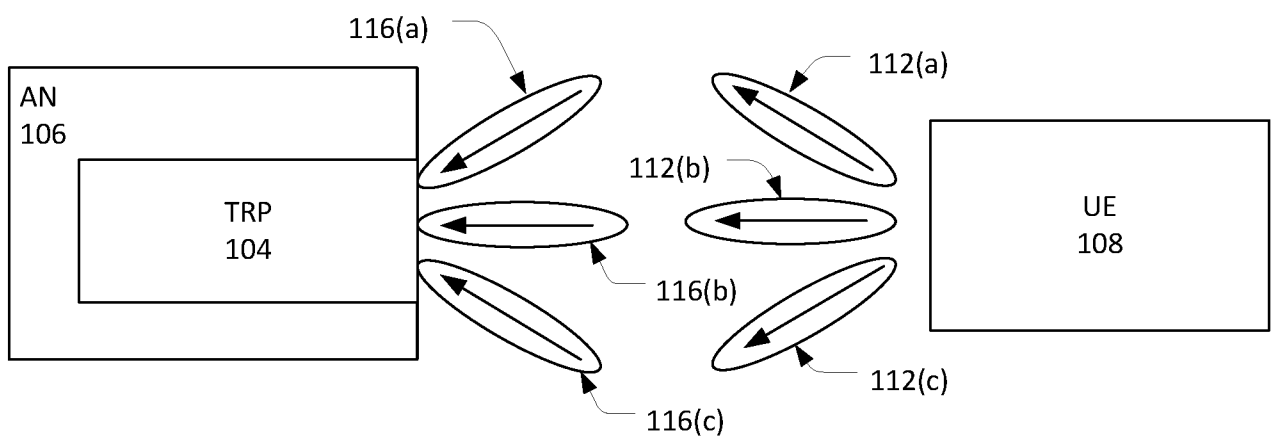
means for transmitting, to a user equipment, a first indication of an uplink transmit beam index and a second indication of a link type of a transmit beam; and

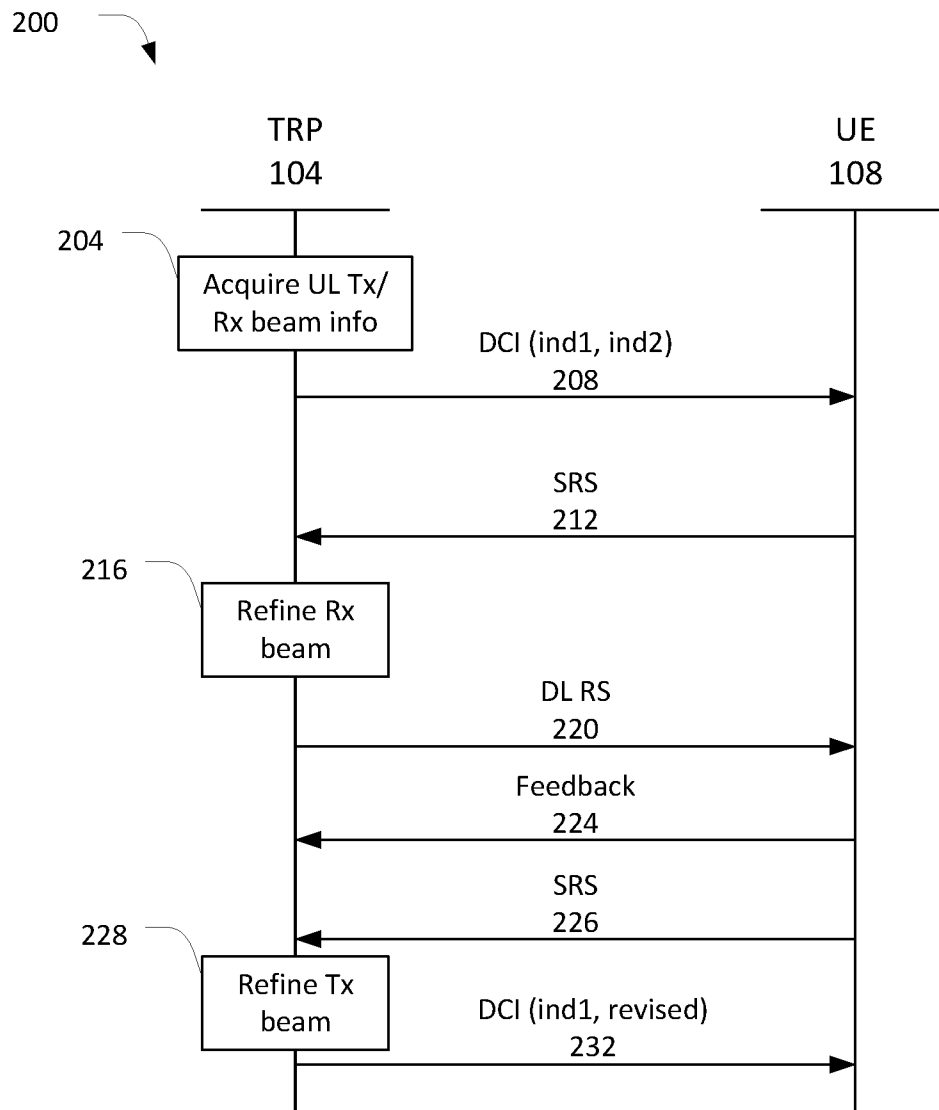
means for refining a receive beam based on an uplink reference signal from the user equipment.

23. The apparatus of claim 22, wherein the first and second indication are transmitted via
5 downlink control information (“DCI”).

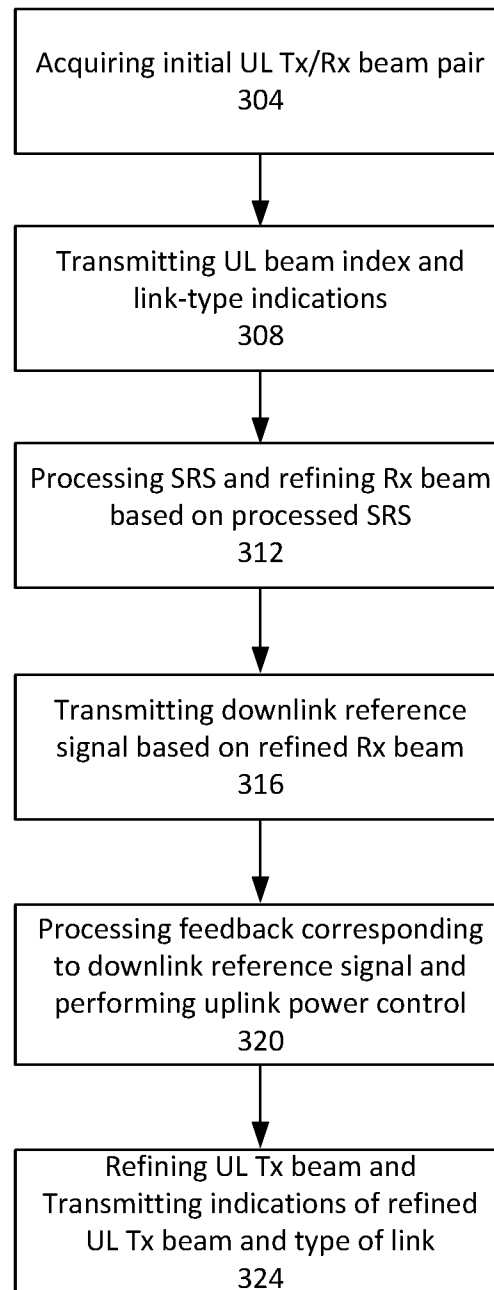
24. The apparatus of claim 22, wherein means for refining the receive beam is to perform receive beam sweeping to process a plurality of repetitions of the uplink reference signal.

10 25. The apparatus of any one of claims 22-24, further comprising:
means for transmitting a downlink reference signal based on refinement of the receive beam.

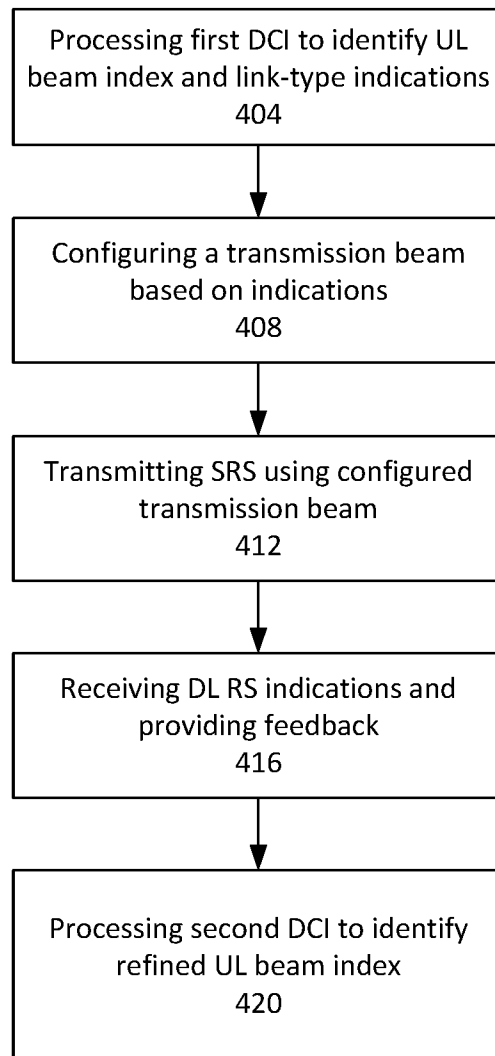
**Figure 1**

**Figure 2**

300

**Figure 3**

400

**Figure 4**

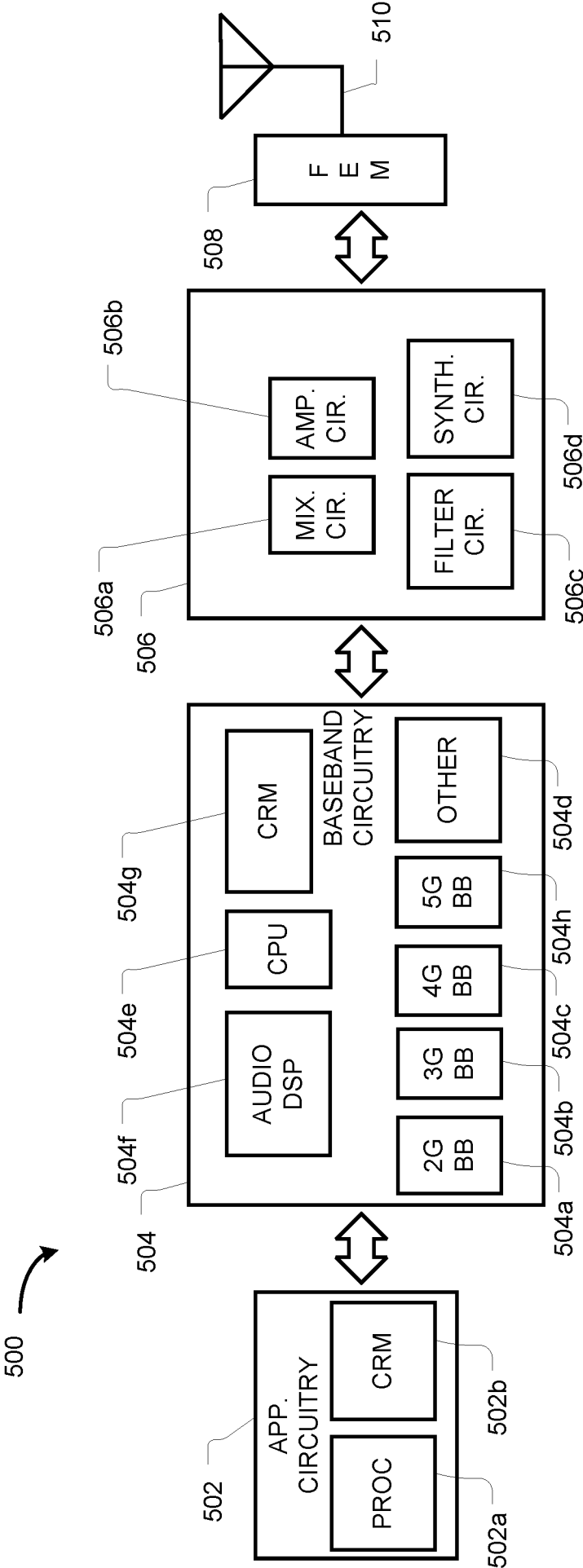


Figure 5

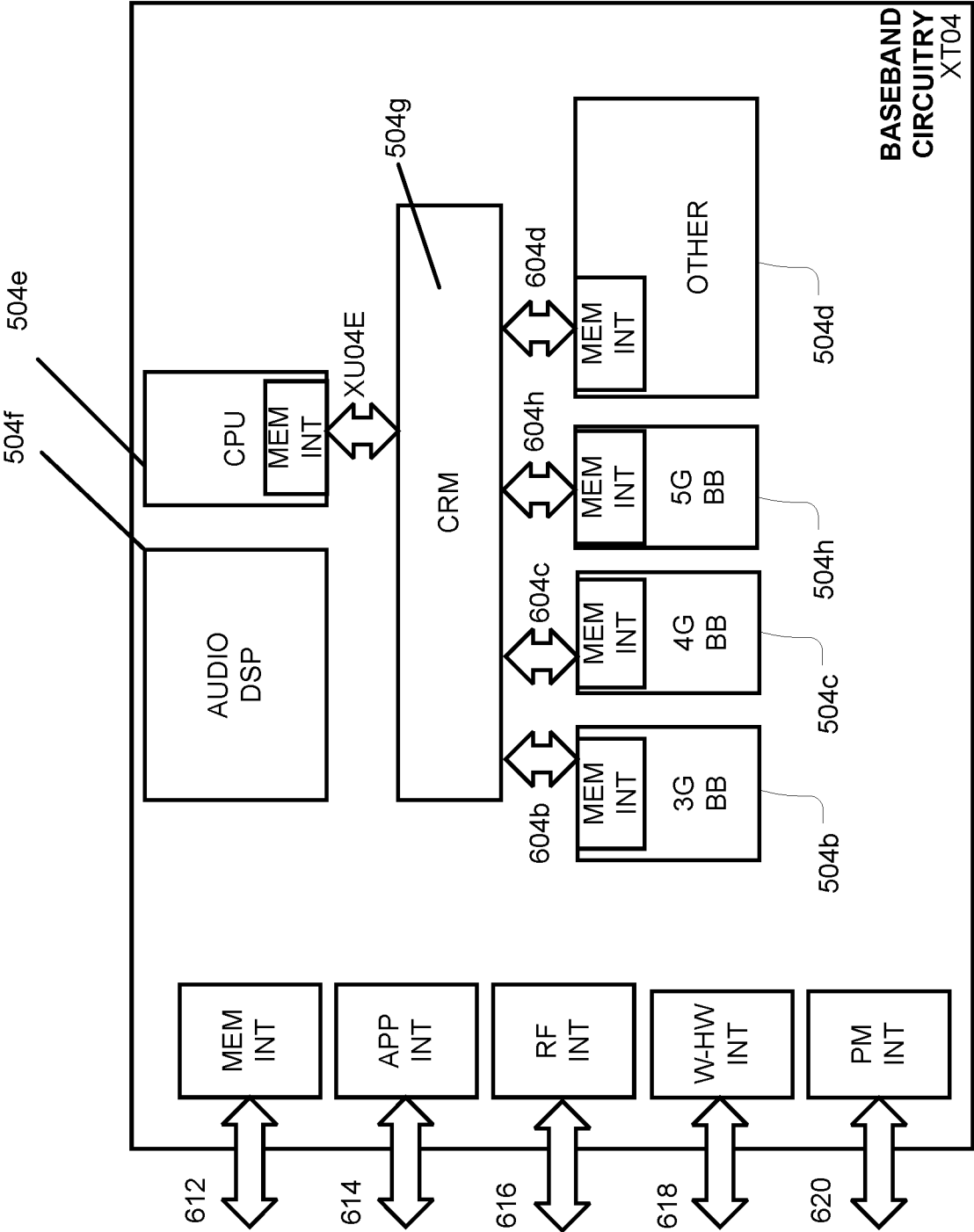


Figure 6

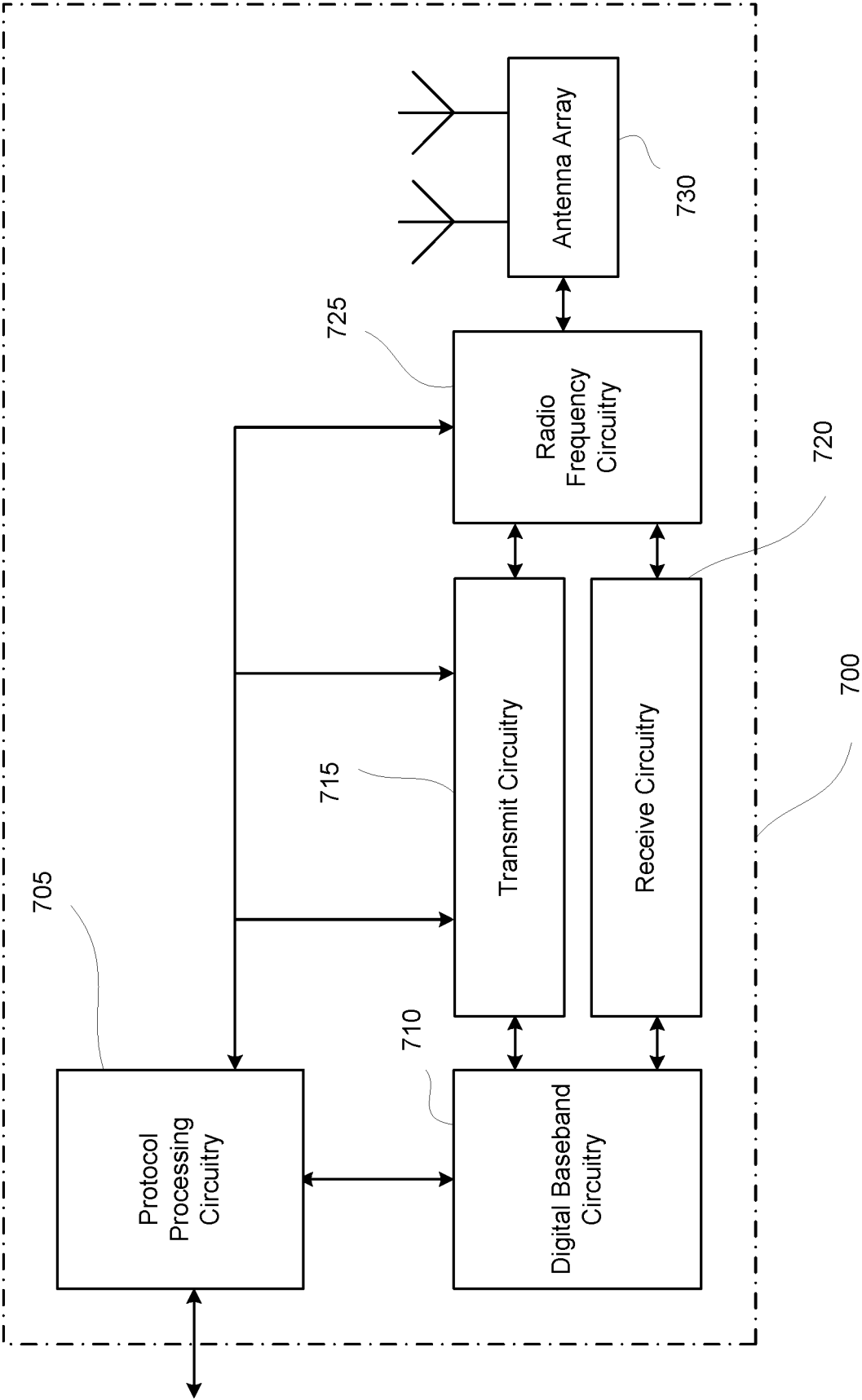


Figure 7

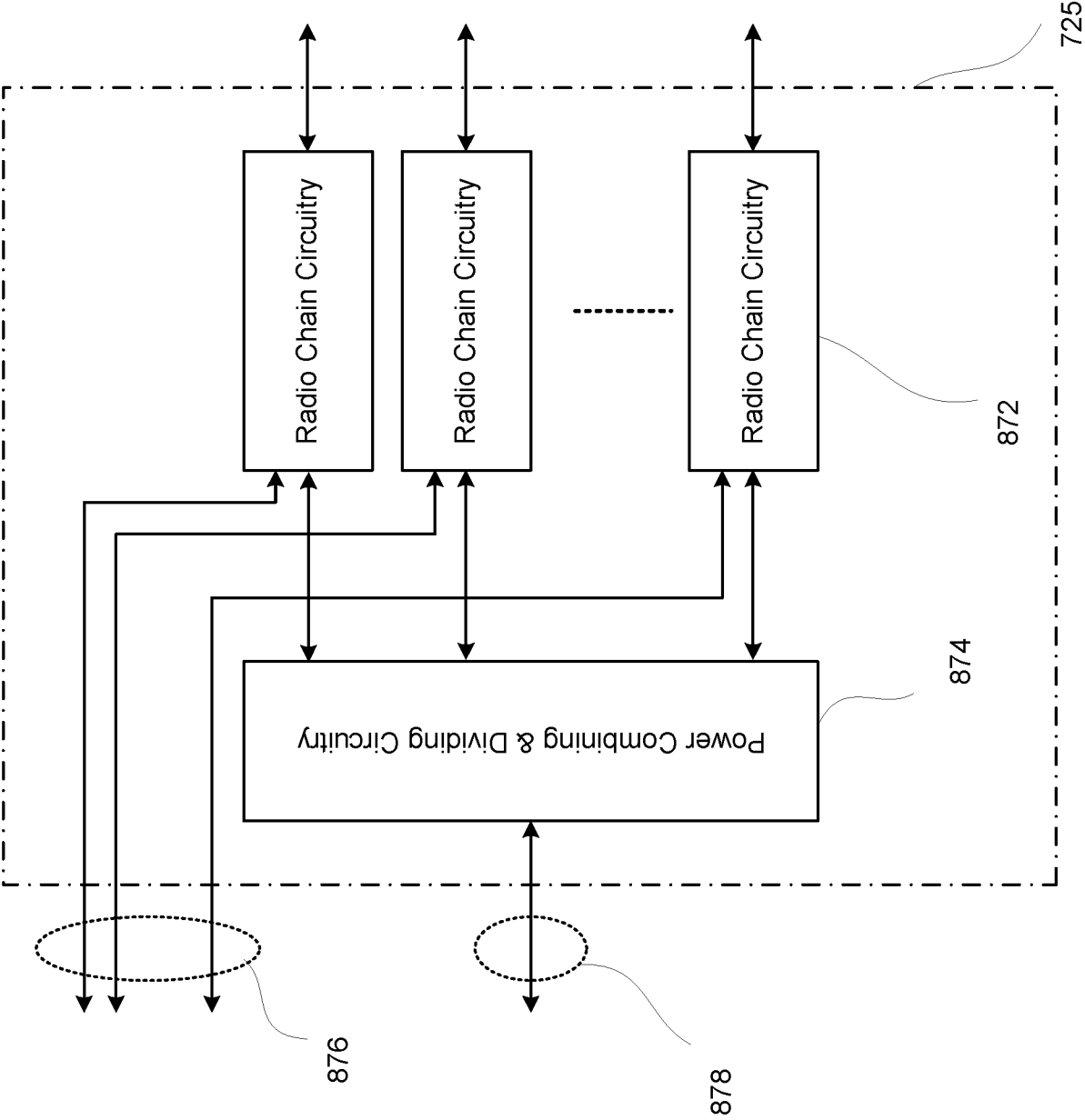


Figure 8

900

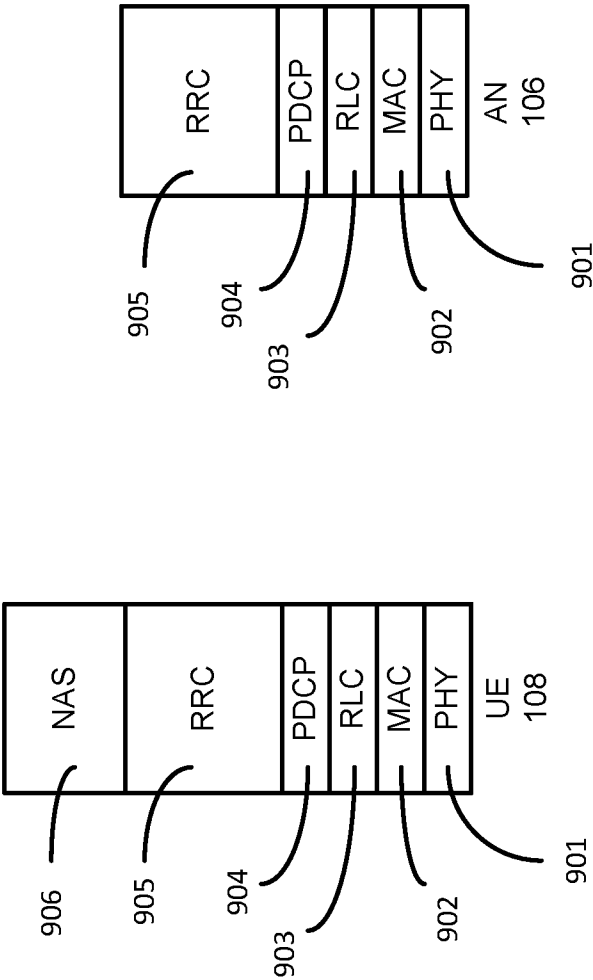


Figure 9

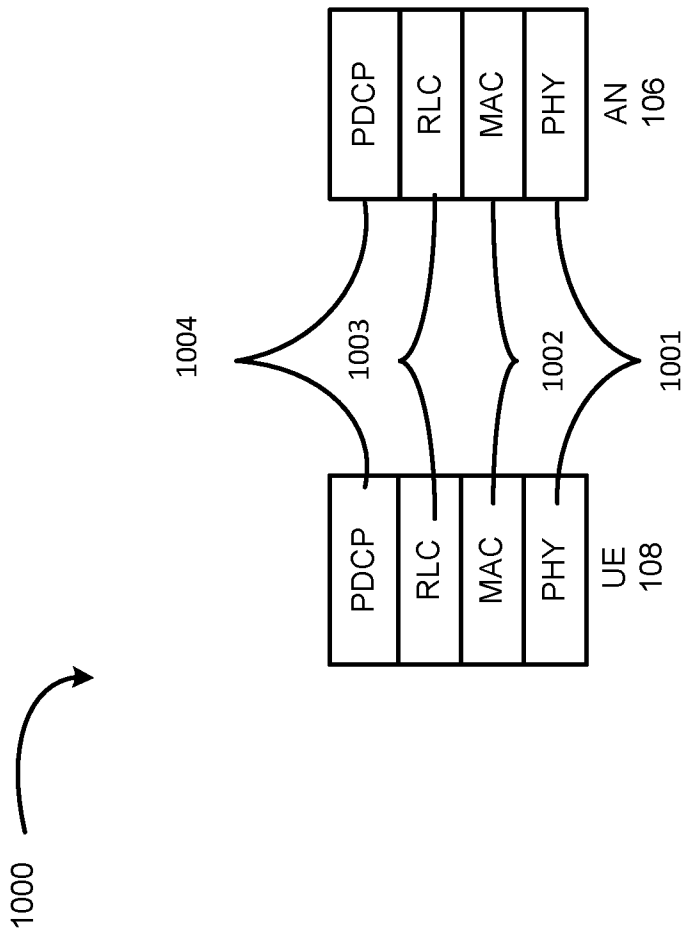


Figure 10

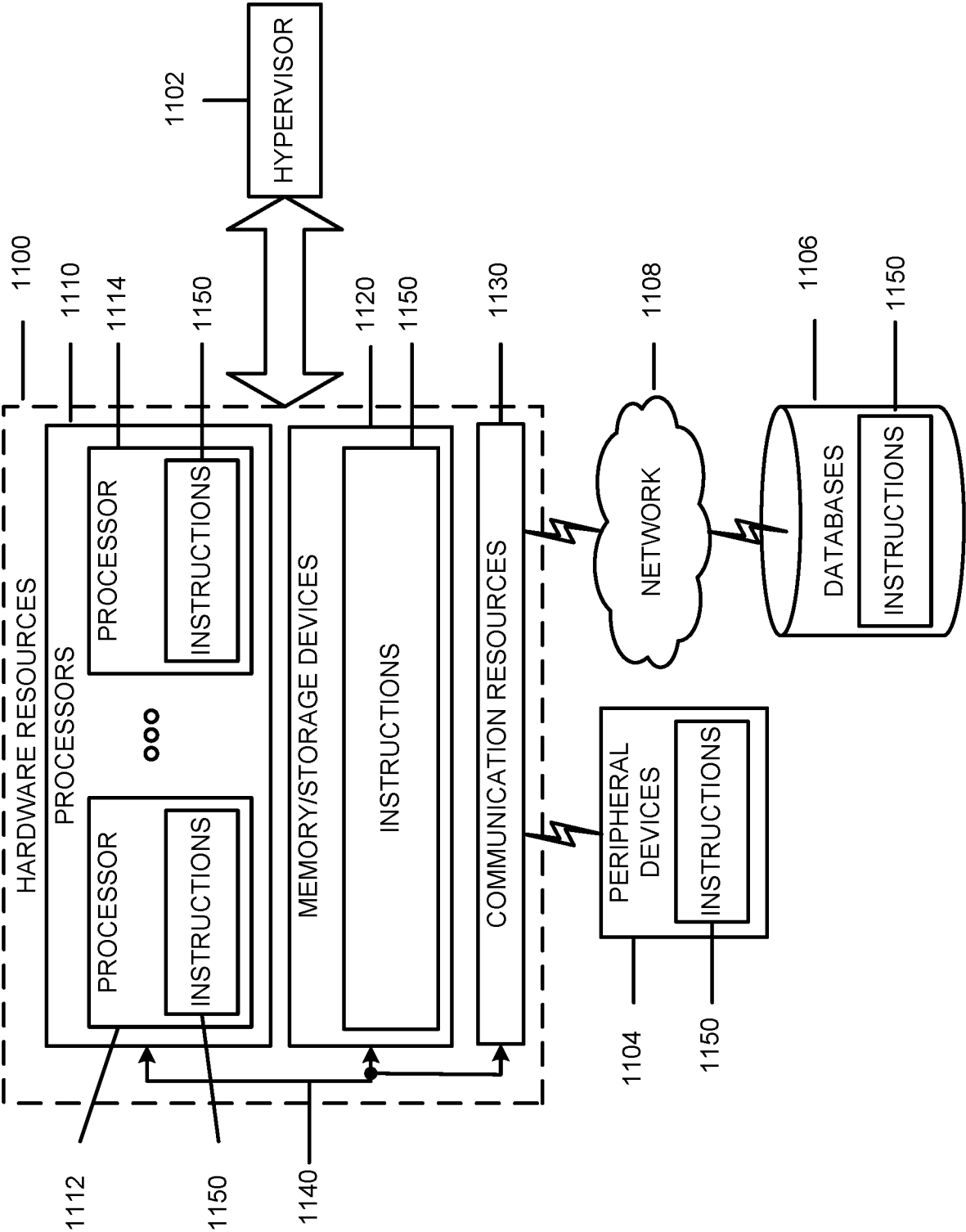


Figure 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/015726

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B7/06 H04B7/08
ADD.

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

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)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2016/165128 A1 (HUAWEI TECHNOLOGIES CO LTD) 20 October 2016 (2016-10-20) page 29 - page 37 page 39 - page 40 page 42 figures 2-4, 7, 9, 13, 16, 17 & EP 3 280 068 A1 (HUAWEI TECH CO LTD [CN]) 7 February 2018 (2018-02-07) paragraph [0170] - paragraph [0214] paragraph [0225] - paragraph [0236] paragraph [0278] paragraph [0299] - paragraph [0301] figures 2-4, 7, 9, 13, 16, 17	1-25
A	US 2015/230263 A1 (ROY ARNAB [US] ET AL) 13 August 2015 (2015-08-13) paragraph [0141] - paragraph [0146]; figure 16 ----- -/--	1-25



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

23 April 2018

Date of mailing of the international search report

08/05/2018

Name and mailing address of the ISA/

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Authorized officer

Spinnler, Florian

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/015726

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2016/150490 A1 (OUCHI WATARU [JP] ET AL) 26 May 2016 (2016-05-26) paragraph [0156] - paragraph [0160] paragraph [0189] - paragraph [0191] paragraph [0240] - paragraph [0242] paragraph [0359] - paragraph [0360] -----	1-25

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2018/015726

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