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(54) Title: EVOLVED NODE-B (ENB), USER EQUIPMENT (UE) AND METHODS FOR TRANSMISSION OF BEAM-FORMING TRAINING REFERENCES SIGNALS (BTRS)

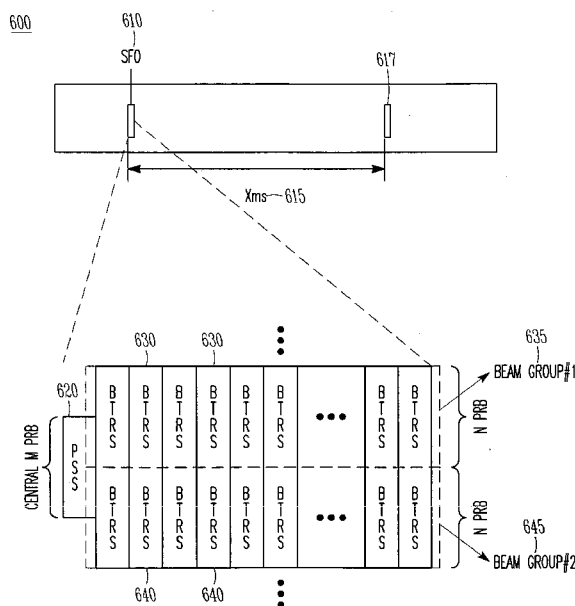


FIG. 6

(57) Abstract: Embodiments of an Evolved Node-B (eNB), User Equipment (UE) and methods for directional communication are generally described herein. The eNB may transmit a beam-forming training reference signal (BTRS) to the UE in accordance with one or more downlink transmission directions. The BTRS may be transmitted in a sub-frame in which a synchronization signal is also transmitted by the eNB. A localized frequency arrangement or a distributed frequency arrangement may be used in accordance with frequency division multiplexing (FDM) for transmission of the BTRS. In some embodiments, the BTRS may be at least partly based on a cell identifier (ID). As an example, the BTRS may be based on a Zadoff-Chu (ZC) sequence. As another example, the BTRS may be based on a maximal length sequence (m-sequence).

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EVOLVED NODE-B (ENB), USER EQUIPMENT (UE) AND METHODS  
FOR TRANSMISSION OF BEAM-FORMING TRAINING REFERENCE  
SIGNALS (BTRS)

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PRIORITY CLAIM

[0001] This application claims the benefit of priority to United States  
10 Provisional Patent Application Serial No. 62/258,899, filed November 23, 2015,  
which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

15 [0002] Embodiments pertain to wireless communications. Some  
embodiments relate to wireless networks including 3GPP (Third Generation  
Partnership Project) networks, 3GPP LTE (Long Term Evolution) networks, and  
3GPP LTE-A (LTE Advanced) networks, although the scope of the  
embodiments is not limited in this respect. Some embodiments relate to beam-  
20 forming and/or directional transmission of signals. Some embodiments relate to  
beam-forming training reference signals (BTRS). Some embodiments relate to  
directional reception of signals. Some embodiments relate to millimeter wave  
(mmWave) communication. Some embodiments relate to antenna diversity.

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BACKGROUND

[0003] A mobile network may support communication with mobile  
devices. In some cases, a mobile device may experience degradation in  
30 performance for any number of reasons. As an example, the mobile device may  
be out of coverage of base stations in the network. As another example, the  
mobile device may experience a reduction in signal quality in a challenging

environment. In such scenarios, a performance of the device and/or a user experience may suffer. Accordingly, there is a general need for methods and systems for improving coverage and/or signal quality in these and other scenarios.

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#### BRIEF DESCRIPTION OF THE DRAWINGS

- 10 [0004] FIG. 1 is a functional diagram of a 3GPP network in accordance with some embodiments;
- [0005] FIG. 2 illustrates a block diagram of an example machine in accordance with some embodiments;
- [0006] FIG. 3 is a block diagram of an Evolved Node-B (eNB) in accordance with some embodiments;
- 15 [0007] FIG. 4 is a block diagram of a User Equipment (UE) in accordance with some embodiments;
- [0008] FIG. 5 illustrates the operation of a method of communication in accordance with some embodiments;
- [0009] FIG. 6 illustrates an example sub-frame format in accordance with some embodiments;
- 20 [0010] FIG. 7 illustrates another example sub-frame format in accordance with some embodiments;
- [0011] FIG. 8 illustrates another example sub-frame format in accordance with some embodiments; and
- 25 [0012] FIG. 9 illustrates the operation of another method of communication in accordance with some embodiments.

## DETAILED DESCRIPTION

[0013] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other  
5 embodiments may incorporate structural, logical, electrical, process, and other changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.

[0014] FIG. 1 is a functional diagram of a 3GPP network in accordance  
10 with some embodiments. It should be noted that embodiments are not limited to the example 3GPP network shown in FIG. 1, as other networks may be used in some embodiments. As an example, a Fifth Generation (5G) network may be used in some cases. As another example, a network that supports millimeter wave (mmWave) communication may be used in some cases. As another  
15 example, a network that supports centimeter wave (cmWave) communication may be used in some cases. In some embodiments, a network may support one or more of mmWave communication, cmWave communication, communication in accordance with 3GPP standards, communication in accordance with 5G standards, communication in accordance with another standard and/or other  
20 types of communication. Such networks may or may not include some or all of the components shown in FIG. 1, and may include additional components and/or alternative components in some cases.

[0015] The network comprises a radio access network (RAN) (e.g., as depicted, the E-UTRAN or evolved universal terrestrial radio access network)  
25 100 and the core network 120 (e.g., shown as an evolved packet core (EPC)) coupled together through an S1 interface 115. For convenience and brevity sake, only a portion of the core network 120, as well as the RAN 100, is shown.

[0016] The core network 120 includes a mobility management entity (MME) 122, a serving gateway (serving GW) 124, and packet data network gateway (PDN GW) 126. The RAN 100 includes Evolved Node-B's (eNBs) 104  
30 (which may operate as base stations) for communicating with User Equipment (UE) 102. The eNBs 104 may include macro eNBs and low power (LP) eNBs.

[0017] In some embodiments, the eNB 104 may transmit beam-forming training reference signals (BTRS) and/or synchronization signals to the UE 102 during a sub-frame. The BTRSs may be transmitted in accordance with one or more transmission directions, in some cases. The UE 102 may send beam-  
5 forming feedback to the eNB 104, and the feedback may be based on reception of the BTRSs at the UE 102 in some cases. These embodiments will be described in more detail below.

[0018] The MME 122 is similar in function to the control plane of legacy Serving GPRS Support Nodes (SGSN). The MME 122 manages mobility  
10 aspects in access such as gateway selection and tracking area list management. The serving GW 124 terminates the interface toward the RAN 100, and routes data packets between the RAN 100 and the core network 120. In addition, it may be a local mobility anchor point for inter-eNB handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful  
15 intercept, charging, and some policy enforcement. The serving GW 124 and the MME 122 may be implemented in one physical node or separate physical nodes. The PDN GW 126 terminates an SGi interface toward the packet data network (PDN). The PDN GW 126 routes data packets between the EPC 120 and the external PDN, and may be a key node for policy enforcement and charging data  
20 collection. It may also provide an anchor point for mobility with non-LTE accesses. The external PDN can be any kind of IP network, as well as an IP Multimedia Subsystem (IMS) domain. The PDN GW 126 and the serving GW 124 may be implemented in one physical node or separated physical nodes.

[0019] The eNBs 104 (macro and micro) terminate the air interface  
25 protocol and may be the first point of contact for a UE 102. In some embodiments, an eNB 104 may fulfill various logical functions for the RAN 100 including but not limited to RNC (radio network controller functions) such as radio bearer management, uplink and downlink dynamic radio resource management and data packet scheduling, and mobility management. In  
30 accordance with embodiments, UEs 102 may be configured to communicate Orthogonal Frequency Division Multiplexing (OFDM) communication signals with an eNB 104 over a multicarrier communication channel in accordance with

an Orthogonal Frequency Division Multiple Access (OFDMA) communication technique. The OFDM signals may comprise a plurality of orthogonal subcarriers.

[0020] The S1 interface 115 is the interface that separates the RAN 100 and the EPC 120. It is split into two parts: the S1-U, which carries traffic data between the eNBs 104 and the serving GW 124, and the S1-MME, which is a signaling interface between the eNBs 104 and the MME 122. The X2 interface is the interface between eNBs 104. The X2 interface comprises two parts, the X2-C and X2-U. The X2-C is the control plane interface between the eNBs 104, while the X2-U is the user plane interface between the eNBs 104.

[0021] With cellular networks, LP cells are typically used to extend coverage to indoor areas where outdoor signals do not reach well, or to add network capacity in areas with very dense phone usage, such as train stations. As used herein, the term low power (LP) eNB refers to any suitable relatively low power eNB for implementing a narrower cell (narrower than a macro cell) such as a femtocell, a picocell, or a micro cell. Femtocell eNBs are typically provided by a mobile network operator to its residential or enterprise customers. A femtocell is typically the size of a residential gateway or smaller and generally connects to the user's broadband line. Once plugged in, the femtocell connects to the mobile operator's mobile network and provides extra coverage in a range of typically 30 to 50 meters for residential femtocells. Thus, a LP eNB might be a femtocell eNB since it is coupled through the PDN GW 126. Similarly, a picocell is a wireless communication system typically covering a small area, such as in-building (offices, shopping malls, train stations, etc.), or more recently in-aircraft. A picocell eNB can generally connect through the X2 link to another eNB such as a macro eNB through its base station controller (BSC) functionality. Thus, LP eNB may be implemented with a picocell eNB since it is coupled to a macro eNB via an X2 interface. Picocell eNBs or other LP eNBs may incorporate some or all functionality of a macro eNB. In some cases, this may be referred to as an access point base station or enterprise femtocell.

[0022] In some embodiments, a downlink resource grid may be used for downlink transmissions from an eNB 104 to a UE 102, while uplink

transmission from the UE 102 to the eNB 104 may utilize similar techniques. The grid may 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 correspond 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. The smallest time-frequency unit in a resource grid is denoted as a resource element (RE). Each resource grid comprises a number of resource blocks (RBs), which describe the mapping of certain physical channels to resource elements. Each resource block comprises a collection of resource elements in the frequency domain and may represent the smallest quanta of resources that currently can be allocated. There are several different physical downlink channels that are conveyed using such resource blocks. With particular relevance to this disclosure, two of these physical downlink channels are the physical downlink shared channel and the physical down link control channel.

**[0023]** The physical downlink shared channel (PDSCH) carries user data and higher-layer signaling to a UE 102 (FIG. 1). The physical downlink control channel (PDCCH) carries information about the transport format and resource allocations related to the PDSCH channel, among other things. It also informs the UE 102 about the transport format, resource allocation, and hybrid automatic repeat request (HARQ) information related to the uplink shared channel. Typically, downlink scheduling (e.g., assigning control and shared channel resource blocks to UEs 102 within a cell) may be performed at the eNB 104 based on channel quality information fed back from the UEs 102 to the eNB 104, and then the downlink resource assignment information may be sent to a UE 102 on the control channel (PDCCH) used for (assigned to) the UE 102.

**[0024]** The PDCCH uses CCEs (control channel elements) to convey the control information. Before being mapped to resource elements, the PDCCH complex-valued symbols are first organized into quadruplets, which are then permuted using a sub-block inter-leaver for rate matching. Each PDCCH is

transmitted using one or more of these control channel elements (CCEs), where each CCE corresponds to nine sets of four physical resource elements known as resource element groups (REGs). Four QPSK symbols are mapped to each REG. The PDCCH can be transmitted using one or more CCEs, depending on the size of DCI and the channel condition. There may be four or more different PDCCH formats defined in LTE with different numbers of CCEs (e.g., aggregation level, L=1, 2, 4, or 8).

[0025] 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 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 logic, at least partially operable in hardware. Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software.

[0026] FIG. 2 illustrates a block diagram of an example machine in accordance with some embodiments. The machine 200 is an example machine upon which any one or more of the techniques and/or methodologies discussed herein may be performed. In alternative embodiments, the machine 200 may operate as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine 200 may operate in the capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine 200 may act as a peer machine in peer-to-peer (P2P) (or other distributed) network environment. The machine 200 may be a UE 102, eNB 104, access point (AP), station (STA), mobile device, base station, personal computer (PC), a tablet PC, a set-top box (STB), a personal digital assistant (PDA), a mobile telephone, a smart phone, a web appliance, a network router, switch or bridge, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken

by that machine. Further, while only a single machine is illustrated, the term “machine” shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein, such as cloud computing, software as a service (SaaS), other computer cluster configurations.

[0027] Examples as described herein, may include, or may operate on, logic or a number of components, modules, or mechanisms. Modules are tangible entities (e.g., hardware) capable of performing specified operations and may be configured or arranged in a certain manner. In an example, circuits may be arranged (e.g., internally or with respect to external entities such as other circuits) in a specified manner as a module. In an example, the whole or part of one or more computer systems (e.g., a standalone, client or server computer system) or one or more hardware processors may be configured by firmware or software (e.g., instructions, an application portion, or an application) as a module that operates to perform specified operations. In an example, the software may reside on a machine readable medium. In an example, the software, when executed by the underlying hardware of the module, causes the hardware to perform the specified operations.

[0028] Accordingly, the term “module” is understood to encompass a tangible entity, be that an entity that is physically constructed, specifically configured (e.g., hardwired), or temporarily (e.g., transitorily) configured (e.g., programmed) to operate in a specified manner or to perform part or all of any operation described herein. Considering examples in which modules are temporarily configured, each of the modules need not be instantiated at any one moment in time. For example, where the modules comprise a general-purpose hardware processor configured using software, the general-purpose hardware processor may be configured as respective different modules at different times. Software may accordingly configure a hardware processor, for example, to constitute a particular module at one instance of time and to constitute a different module at a different instance of time.

[0029] The machine (e.g., computer system) 200 may include a hardware processor 202 (e.g., a central processing unit (CPU), a graphics processing unit

(GPU), a hardware processor core, or any combination thereof), a main memory 204 and a static memory 206, some or all of which may communicate with each other via an interlink (e.g., bus) 208. The machine 200 may further include a display unit 210, an alphanumeric input device 212 (e.g., a keyboard), and a user interface (UI) navigation device 214 (e.g., a mouse). In an example, the display unit 210, input device 212 and UI navigation device 214 may be a touch screen display. The machine 200 may additionally include a storage device (e.g., drive unit) 216, a signal generation device 218 (e.g., a speaker), a network interface device 220, and one or more sensors 221, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The machine 200 may include an output controller 228, such as a serial (e.g., universal serial bus (USB), parallel, or other wired or wireless (e.g., infrared (IR), near field communication (NFC), etc.) connection to communicate or control one or more peripheral devices (e.g., a printer, card reader, etc.).

15   **[0030]**       The storage device 216 may include a machine readable medium 222 on which is stored one or more sets of data structures or instructions 224 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 224 may also reside, completely or at least partially, within the main memory 204, within static memory 206, or within the hardware processor 202 during execution thereof by the machine 200. In an example, one or any combination of the hardware processor 202, the main memory 204, the static memory 206, or the storage device 216 may constitute machine readable media. In some embodiments, the machine readable medium may be or may include a non-transitory computer-readable storage medium.

25   **[0031]**       While the machine readable medium 222 is illustrated as a single medium, the term "machine readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) configured to store the one or more instructions 224. The term "machine readable medium" may include any medium that is capable of storing, encoding, or carrying instructions for execution by the machine 200 and that cause the machine 200 to perform any one or more of the techniques of the

present disclosure, or that is capable of storing, encoding or carrying data structures used by or associated with such instructions. Non-limiting machine readable medium examples may include solid-state memories, and optical and magnetic media. Specific examples of machine readable media may include:

- 5 non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; Random Access Memory (RAM); and CD-ROM and DVD-ROM  
10 disks. In some examples, machine readable media may include non-transitory machine readable media. In some examples, machine readable media may include machine readable media that is not a transitory propagating signal.

- [0032]** The instructions 224 may further be transmitted or received over a communications network 226 using a transmission medium via the network  
15 interface device 220 utilizing any one of a number of transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communication networks may include a local area network (LAN), a wide area network (WAN), a packet data network (e.g., the Internet), mobile telephone  
20 networks (e.g., cellular networks), Plain Old Telephone (POTS) networks, and wireless data networks (e.g., Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards known as Wi-Fi®, IEEE 802.16 family of standards known as WiMax®, IEEE 802.15.4 family of standards, a Long Term Evolution (LTE) family of standards, a Universal Mobile Telecommunications  
25 System (UMTS) family of standards, peer-to-peer (P2P) networks, among others. In an example, the network interface device 220 may include one or more physical jacks (e.g., Ethernet, coaxial, or phone jacks) or one or more antennas to connect to the communications network 226. In an example, the network interface device 220 may include a plurality of antennas to wirelessly  
30 communicate using at least one of single-input multiple-output (SIMO), multiple-input multiple-output (MIMO), or multiple-input single-output (MISO) techniques. In some examples, the network interface device 220 may wirelessly

communicate using Multiple User MIMO techniques. The term “transmission medium” shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution by the machine 200, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

[0033] FIG. 3 is a block diagram of an Evolved Node-B (eNB) in accordance with some embodiments. It should be noted that in some embodiments, the eNB 300 may be a stationary non-mobile device. The eNB 300 may be suitable for use as an eNB 104 as depicted in FIG. 1. The eNB 300 may include physical layer circuitry 302 and a transceiver 305, one or both of which may enable transmission and reception of signals to and from the UE 200, other eNBs, other UEs or other devices using one or more antennas 301. As an example, the physical layer circuitry 302 may perform various encoding and decoding functions that may include formation of baseband signals for transmission and decoding of received signals. As another example, the transceiver 305 may perform various transmission and reception functions such as conversion of signals between a baseband range and a Radio Frequency (RF) range. Accordingly, the physical layer circuitry 302 and the transceiver 305 may be separate components or may be part of a combined component. In addition, some of the described functionality related to transmission and reception of signals may be performed by a combination that may include one, any or all of the physical layer circuitry 302, the transceiver 305, and other components or layers. The eNB 300 may also include medium access control layer (MAC) circuitry 304 for controlling access to the wireless medium. The eNB 300 may also include processing circuitry 306 and memory 308 arranged to perform the operations described herein. The eNB 300 may also include one or more interfaces 310, which may enable communication with other components, including other eNBs 104 (FIG. 1), components in the EPC 120 (FIG. 1) or other network components. In addition, the interfaces 310 may enable communication with other components that may not be shown in FIG. 1, including components external to the network. The interfaces 310 may be wired or wireless or a combination thereof. It should be noted that in some embodiments, an eNB or

other base station may include some or all of the components shown in either FIG. 2 or FIG. 3 or both.

[0034] FIG. 4 is a block diagram of a User Equipment (UE) in accordance with some embodiments. The UE 400 may be suitable for use as a UE 102 as depicted in FIG. 1. In some embodiments, the UE 400 may include application circuitry 402, baseband circuitry 404, Radio Frequency (RF) circuitry 406, front-end module (FEM) circuitry 408 and one or more antennas 410, coupled together at least as shown. In some embodiments, other circuitry or arrangements may include one or more elements and/or components of the application circuitry 402, the baseband circuitry 404, the RF circuitry 406 and/or the FEM circuitry 408, and may also include other elements and/or components in some cases. As an example, “processing circuitry” may include one or more elements and/or components, some or all of which may be included in the application circuitry 402 and/or the baseband circuitry 404. As another example, “transceiver circuitry” may include one or more elements and/or components, some or all of which may be included in the RF circuitry 406 and/or the FEM circuitry 408. These examples are not limiting, however, as the processing circuitry and/or the transceiver circuitry may also include other elements and/or components in some cases. It should be noted that in some embodiments, a UE or other mobile device may include some or all of the components shown in either FIG. 2 or FIG. 4 or both.

[0035] The application circuitry 402 may include one or more application processors. For example, the application circuitry 402 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with and/or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications and/or operating systems to run on the system.

[0036] The baseband circuitry 404 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband

circuitry 404 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 406 and to generate baseband signals for a transmit signal path of the RF circuitry 406. Baseband processing circuitry 404 may interface with the application circuitry 402 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 406. For example, in some embodiments, the baseband circuitry 404 may include a second generation (2G) baseband processor 404a, third generation (3G) baseband processor 404b, fourth generation (4G) baseband processor 404c, and/or other baseband processor(s) 404d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 404 (e.g., one or more of baseband processors 404a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 406. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 404 may include Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 404 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.

[0037] In some embodiments, the baseband circuitry 404 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) 404e of the baseband circuitry 404 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) 404f. The audio DSP(s) 404f may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments. Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the baseband circuitry 404 and the application circuitry 402 may be implemented together such as, for example, on a system on a chip (SOC).

10 **[0038]** In some embodiments, the baseband circuitry 404 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 404 may support communication with an evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN),  
15 a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 404 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

**[0039]** RF circuitry 406 may enable communication with wireless  
20 networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 406 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 406 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 408 and provide  
25 baseband signals to the baseband circuitry 404. RF circuitry 406 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 404 and provide RF output signals to the FEM circuitry 408 for transmission.

**[0040]** In some embodiments, the RF circuitry 406 may include a receive  
30 signal path and a transmit signal path. The receive signal path of the RF circuitry 406 may include mixer circuitry 406a, amplifier circuitry 406b and filter circuitry 406c. The transmit signal path of the RF circuitry 406 may include

filter circuitry 406c and mixer circuitry 406a. RF circuitry 406 may also include synthesizer circuitry 406d for synthesizing a frequency for use by the mixer circuitry 406a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 406a of the receive signal path may be  
5 configured to down-convert RF signals received from the FEM circuitry 408 based on the synthesized frequency provided by synthesizer circuitry 406d. The amplifier circuitry 406b may be configured to amplify the down-converted signals and the filter circuitry 406c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted  
10 signals to generate output baseband signals. Output baseband signals may be provided to the baseband circuitry 404 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 406a of the receive signal path may comprise passive mixers, although the scope  
15 of the embodiments is not limited in this respect. In some embodiments, the mixer circuitry 406a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 406d to generate RF output signals for the FEM circuitry 408. The baseband signals may be provided by the baseband circuitry 404 and  
20 may be filtered by filter circuitry 406c. The filter circuitry 406c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

**[0041]** In some embodiments, the mixer circuitry 406a of the receive signal path and the mixer circuitry 406a of the transmit signal path may include  
25 two or more mixers and may be arranged for quadrature downconversion and/or upconversion respectively. In some embodiments, the mixer circuitry 406a of the receive signal path and the mixer circuitry 406a 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 406a of the  
30 receive signal path and the mixer circuitry 406a may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments,

the mixer circuitry 406a of the receive signal path and the mixer circuitry 406a of the transmit signal path may be configured for super-heterodyne operation.

[0042] 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 406 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 404 may include a digital baseband interface to communicate with the RF circuitry 406. 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.

[0043] In some embodiments, the synthesizer circuitry 406d 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 406d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider. The synthesizer circuitry 406d may be configured to synthesize an output frequency for use by the mixer circuitry 406a of the RF circuitry 406 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 406d 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 404 or the applications processor 402 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 402.

[0044] Synthesizer circuitry 406d of the RF circuitry 406 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N

or  $N+1$  (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up  
5 into  $N_d$  equal packets of phase, where  $N_d$  is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

[0045] In some embodiments, synthesizer circuitry 406d may be configured to generate a carrier frequency as the output frequency, while in other  
10 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  
15 ( $f_{LO}$ ). In some embodiments, the RF circuitry 406 may include an IQ/polar converter.

[0046] FEM circuitry 408 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 410, amplify the received signals and provide the amplified versions of  
20 the received signals to the RF circuitry 406 for further processing. FEM circuitry 408 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 406 for transmission by one or more of the one or more antennas 410.

[0047] In some embodiments, the FEM circuitry 408 may include a  
25 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 406). The transmit signal path of  
30 the FEM circuitry 408 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 406), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more

antennas 410. In some embodiments, the UE 400 may include additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface.

[0048] The antennas 230, 301, 410 may comprise one or more  
5 directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, patch antennas, loop antennas, microstrip antennas or other types of antennas suitable for transmission of RF signals. In some multiple-input multiple-output (MIMO) embodiments, the antennas 230, 301, 410 may be effectively separated to take advantage of spatial diversity and the different  
10 channel characteristics that may result.

[0049] In some embodiments, the UE 400 and/or the eNB 300 may be a mobile device and may be a portable wireless communication device, such as a personal digital assistant (PDA), a laptop or portable computer with wireless communication capability, a web tablet, a wireless telephone, a smartphone, a  
15 wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, a wearable device such as a medical device (e.g., a heart rate monitor, a blood pressure monitor, etc.), or other device that may receive and/or transmit information wirelessly. In some embodiments, the UE 400 or eNB 300 may be configured to operate in accordance with 3GPP  
20 standards, although the scope of the embodiments is not limited in this respect. Mobile devices or other devices in some embodiments may be configured to operate according to other protocols or standards, including IEEE 802.11 or other IEEE standards. In some embodiments, the UE 400, eNB 300 or other device may include one or more of a keyboard, a display, a non-volatile memory  
25 port, multiple antennas, a graphics processor, an application processor, speakers, and other mobile device elements. The display may be an LCD screen including a touch screen.

[0050] Although the UE 400 and the eNB 300 are each illustrated as having several separate functional elements, one or more of the functional  
30 elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For example, some

elements may comprise one or more microprocessors, DSPs, field-programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), radio-frequency integrated circuits (RFICs) and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements may refer to one or more processes operating on one or more processing elements.

[0051] Embodiments may be implemented in one or a combination of hardware, firmware and software. Embodiments may also be implemented as instructions stored on a computer-readable storage device, which may be read and executed by at least one processor to perform the operations described herein. A computer-readable storage device may include any non-transitory mechanism for storing information in a form readable by a machine (e.g., a computer). For example, a computer-readable storage device may include read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and other storage devices and media. Some embodiments may include one or more processors and may be configured with instructions stored on a computer-readable storage device.

[0052] It should be noted that in some embodiments, an apparatus used by the UE 400 and/or eNB 300 and/or machine 200 may include various components of the UE 200 and/or the eNB 300 and/or the machine 200 as shown in FIGs. 2-4. Accordingly, techniques and operations described herein that refer to the UE 400 (or 102) may be applicable to an apparatus for a UE. In addition, techniques and operations described herein that refer to the eNB 300 (or 104) may be applicable to an apparatus for an eNB.

[0053] In accordance with some embodiments, the eNB 104 may transmit a beam-forming training reference signal (BTRS) to the UE 102 in accordance with one or more downlink transmission directions. The BTRS may be transmitted in a sub-frame in which a synchronization signal is also transmitted by the eNB 104. In some embodiments, time resources and/or frequency resources used for transmission of the BTRS may be exclusive to resources used for the transmission of the synchronization signal. As an example, the BTRS may be based on a Zadoff-Chu (ZC) sequence. As another

example, the BTRS may be based on a maximal length sequence (m-sequence). These embodiments are described in more detail below.

[0054] FIG. 5 illustrates the operation of a method of communication in accordance with some embodiments. It is important to note that embodiments of the method 500 may include additional or even fewer operations or processes in comparison to what is illustrated in FIG. 5. In addition, embodiments of the method 500 are not necessarily limited to the chronological order that is shown in FIG. 5. In describing the method 500, reference may be made to FIGs. 1-4 and 6-9, although it is understood that the method 500 may be practiced with any other suitable systems, interfaces and components.

[0055] In addition, while the method 500 and other methods described herein may refer to eNBs 104 or UEs 102 operating in accordance with 3GPP standards, 5G standards and/or other standards, embodiments of those methods are not limited to just those eNBs 104 or UEs 102 and may also be practiced on other devices, such as a Wi-Fi access point (AP) or user station (STA). In addition, the method 500 and other methods described herein may be practiced by wireless devices configured to operate in other suitable types of wireless communication systems, including systems configured to operate according to various IEEE standards such as IEEE 802.11. The method 500 may also refer to an apparatus for a UE 102 and/or eNB 104 and/or other device described above.

[0056] In some embodiments, the method 500 and other methods described herein may be practiced by wireless devices configured to communicate in millimeter wave (mmWave) frequency bands and/or in networks that support mmWave communication. Accordingly, signals may be transmitted and/or received as part of the method 500 at millimeter wave (mmWave) frequencies, in some cases. As an example, frequencies in the range of 6 GHz or higher may be used. It should be noted, however, that embodiments are not limited to usage of mmWave frequency bands, as other frequency bands may be used in some cases. In some embodiments, the devices may be configured to operate at one or more centimeter wave (cmWave) frequency ranges and may transmit and/or receive signals at the cmWave frequencies.

[0057] As part of operation in the mmWave frequency bands, various techniques may be used to provide antenna gains that may be higher than those used by devices and systems operating in lower frequency bands. As an example, directional antennas, directional transmission and/or directional reception may be used. It should be noted, however, that usage of directional antennas, directional transmission and/or directional reception is not limited to mmWave operation, and may also be performed at frequencies other than mmWave frequencies in some embodiments. For instance, directional techniques may be performed at centimeter wave (cmWave) frequencies in some cases.

[0058] At operation 505 of the method 500, the eNB 104 may transmit a synchronization signal during a sub-frame. Embodiments are not limited to transmission of one synchronization signal, however, as multiple synchronization signals may be transmitted in some cases. In some embodiments, the synchronization signal may be transmitted to enable operations at one or more UEs 102, such as time synchronization, frequency synchronization, frame synchronization, time tracking, frequency tracking, frequency correction and/or others. Accordingly, such synchronization signals may not necessarily be dedicated synchronization signals transmitted to a particular UE 102 in some cases, although the scope of embodiments is not limited in this respect. In some embodiments, the synchronization signal may be transmitted in time resources and/or frequency resources allocated for synchronization signals. For instance, when orthogonal frequency division multiplexing (OFDM) transmission is used, a synchronization signal may be transmitted during one or more OFDM symbol periods dedicated for synchronization signals and in one or more portions of channel resources (such as RBs, REs and/or other) that may be dedicated for synchronization signals. It should be noted that embodiments are not limited to transmission of synchronization signals in dedicated time resources and/or frequency resources, however.

[0059] As an example, one or more primary synchronization signals (PSS) and/or secondary synchronization signals (SSS), which may be part of a

3GPP standard and/or other standard, may be used. Embodiments are not limited to usage of the PSS, SSS and/or other signals that are part of standards, however, as any suitable synchronization signal may be used in some embodiments. As another example, when orthogonal frequency division multiplexing (OFDM) transmission is used, a PSS and/or SSS may be transmitted during a single OFDM symbol period. In some cases, a PSS and an SSS may be transmitted in adjacent OFDM symbol periods. In some cases, multiple PSS and/or SSS may be transmitted.

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[0060] At operation 510, the eNB 104 may divide frequency resources (such as RBs, REs and/or others) and/or transmission directions for beam-forming training reference signal (BTRS) groups. At operation 515, the eNB 104 may determine one or more BTRSs and/or BTRS sequences to be transmitted. Examples of such will be presented below. At operation 520, the eNB 104 may transmit one or more BTRSs to a UE 102 during the sub-frame. That is, the BTRSs may be transmitted during the same sub-frame used for the transmission of the synchronization signal at operation 505. It should be noted, however, that embodiments are not limited to transmission of the BTRSs and the synchronization signal in the same sub-frame. At operation 525, one or more control messages may be transmitted, to the UE 102 and/or other component, which may indicate information related to the BTRSs, such as frequency resources, time resources, BTRS parameters and/or other information. For instance, one or more dedicated radio resource control (RRC) messages from a primary cell, 5G master information blocks (xMIB), 5G system information blocks (xSIB) and/or UE specific RRC signaling messages from a serving cell may be used. Such messages/blocks may be included in a 3GPP standard, 5G standard and/or other standards, in some embodiments, although embodiments are not limited to usage of control messages that are included in a standard.

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[0061] In some embodiments, the BTRSs may be transmitted in accordance with one or more downlink transmission directions from the eNB 104 to the UE 102. Accordingly, the BTRSs may be transmitted to enable beam tracking, at the UE 102, of the downlink transmission directions, in some cases.

[0062] In some embodiments, one or more BTRSs may be transmitted by different transmit beams (and/or according to different transmission directions) using time division multiplexing (TDM) and/or frequency division multiplexing (FDM) techniques. Accordingly, some or all transmission beam candidates may be traversed to enable beam sweeping at the UE 102, in some cases. It should be noted that different sequences or a same sequence may be used for BTRS generation for different BTRS groups (and/or transmit beams to be used by those BTRS groups for beam transmission).

[0063] In some embodiments, the frequency resources used for BTRS transmission may include any number of resource blocks (RBs), resource elements (REs), sub-channels, sub-carriers and/or other frequency unit. As a non-limiting example, an RB may comprise multiple REs. Time resources used for BTRS transmission may include any number of OFDM symbol periods, symbol periods and/or other time unit, in some embodiments. The frequency resources and/or time resources may be allocated for and/or reserved for BTRS transmission in some embodiments.

[0064] In some embodiments, the BTRSs may be transmitted separately from and/or independently of synchronization signals during the sub-frame. For instance, the BTRS and the synchronization signals may be transmitted in non-overlapping (and/or exclusive) time resources. Such a separation may enable decoupling of synchronization and initial beam acquisition operations performed at the UE 102. Such a decoupling may enable some implementation aspects at the UE 102 to be simplified, in some cases. It should be noted, however, that embodiments are not limited to transmission of the BTRS and the synchronization signals in time resources that are non-overlapping and/or exclusive. For instance, the same time resources and/or overlapping time resources may be used, in some embodiments.

[0065] In some embodiments, a BTRS may be transmitted by the eNB 104 in a periodic manner, which may be in accordance with a periodicity parameter. As an example, a number of sub-frames between sub-frames in which BTRS transmissions are performed may be related to the periodicity parameter. Such a periodicity parameter may be configurable, in some cases,

and may be communicated as part of one or more control messages. In some cases, such a periodicity parameter may be part of a standard, such as a 3GPP standard and/or other standard, although embodiments are not limited to periodicity parameters included in standards.

5    **[0066]**       As an example, a first BTRS may be transmitted to the UE 102 in accordance with a first group of downlink transmission directions and a second BTRS may be transmitted to the UE 102 in accordance with a second group of downlink transmission directions. Although this example of two groups may illustrate some or all concepts described herein, it is understood that this example  
10 and related concepts may be extended to a number of groups larger than two, in some cases. A TDM technique may be used, in some cases, in which the first BTRS may be transmitted during a first group of one or more orthogonal frequency division multiplexing (OFDM) symbol periods of a sub-frame and the second BTRS may be transmitted during a second group of one or more OFDM  
15 symbol periods of the sub-frame.

**[0067]**       It should be noted that in some embodiments, one or more BTRSs may be transmitted by the eNB 104 in accordance with a group of downlink transmission directions from the eNB 104 to the UE 102. As an example, a single BTRS may be used, in which case the BTRS may be transmitted in  
20 accordance with the group of downlink transmission directions. As another example, multiple BTRSs may be used, in which case one or more of the BTRSs may be transmitted in accordance with a portion of the downlink transmission directions in the group. As another example, the group of downlink transmission directions may be divided into multiple groups (such as BTRS groups), and the  
25 BTRS for each BTRS group may be transmitted in accordance with the downlink transmission directions in the BTRS group. These examples are not limiting, however, as any suitable arrangement for transmission of multiple BTRSs in accordance with multiple downlink transmission directions may be used.

30   **[0068]**       As another example, when  $K$  BTRS groups are used, a group of downlink transmission directions may be divided into  $K$  non-overlapping portions and frequency resources used for BTRS transmissions may be divided

into  $K$  non-overlapping portions. Accordingly, each of the  $K$  BTRS groups may transmit in accordance with a portion of the transmission directions in a portion of the frequency resources allocated for BTRS transmission. The eNB 104 may transmit (to the UE 102 and/or other component) one or more control messages that indicate that  $K$  BTRS groups and/or portions are to be used, in some cases. In another example, a value of  $K$  may be fixed in a specification, such as a 3GPP LTE specification, 5G specification and/or other specification.

[0069] In some cases, an FDM technique may be used, in which the first and second BTRS may be transmitted as part of an OFDM signal during a same OFDM symbol period of a sub-frame. In an example localized frequency arrangement of FDM, a first group of contiguous resource blocks (RBs) may be used for the transmission of the first BTRS and a second group of contiguous RBs may be used for the transmission of the second BTRS. In another example localized frequency arrangement of FDM, a first group of adjacent resource blocks (RBs) may be used for the transmission of the first BTRS and a second group of adjacent RBs may be used for the transmission of the second BTRS. As a non-limiting example of the localized frequency arrangement, a starting frequency position may be a central physical RB (PRB), and one or more blocks of RBs may be allocated in the lower and/or upper frequency ranges. For instance, the frequency resources of the system may include  $N_{bw}$  RBs. When two BTRS groups are used, for instance, and a central PRB is indexed by  $N_{bw}/2$ , a first group of  $N$  RBs may range from  $N_{bw}/2$  to  $(N_{bw}/2 + N - 1)$  and a second group of  $N$  RBs may range from  $(N_{bw}/2 - 1)$  to  $(N_{bw}/2 - N)$ . When  $K$  BTRS groups are used, blocks of RBs that include  $\text{floor}(N_{bw}/K)$  may be used for each BTRS group.

[0070] In an example distributed frequency arrangement of FDM, a first group of REs used for the transmission of the first BTRS may be interleaved, in frequency, with a second group of REs used for the transmission of the second BTRS. This may be extended to a number of BTRS groups  $K$ , which may be larger than two in some cases. As a non-limiting example of the distributed frequency arrangement, when  $K$  BTRS groups are used, the REs used for a particular BTRS group may be spaced apart in frequency by  $K$  REs. For

instance, BTRS groups indexed by 1, 2, ...,  $K$ , may be allocated to REs (in increasing frequency order) according to an interleaved arrangement of [ ... 1, 2, ...  $K$ , 1, 2, ...  $K$ , 1, 2 ... ].

**[0071]** In another example distributed frequency arrangement of FDM, a first group of RBs used for the transmission of the first BTRS may be interleaved, in frequency, with a second group of RBs used for the transmission of the second BTRS. This may be extended to a number of BTRS groups  $K$ , which may be larger than two in some cases. As a non-limiting example of the distributed frequency arrangement, when  $K$  BTRS groups are used, the RBs used for a particular BTRS group may be spaced apart in frequency by  $K$  RBs. For instance, BTRS groups indexed by 1, 2, ...,  $K$ , may be allocated to RBs (in increasing frequency order) according to an interleaved arrangement of [ ... 1, 2, ...  $K$ , 1, 2, ...  $K$ , 1, 2 ... ].

**[0072]** It should be noted that embodiments are not limited to the FDM examples described above. In some embodiments, the REs and/or RBs used for the BTRS groups may not necessarily be distributed according to any particular pattern and/or formula. That is, the REs and/or RBs available for the BTRS groups may be distributed to the BTRS groups in any suitable manner.

**[0073]** FIG. 6 illustrates an example sub-frame format in accordance with some embodiments. FIG. 7 illustrates another example sub-frame format in accordance with some embodiments. Although the example sub-frame formats 610 and 710 may illustrate some or all techniques, operations and/or concepts described herein, it is understood that embodiments are not limited by the examples 610 and 710 in terms of number, type, size, arrangement and/or other aspects of elements shown in FIGs. 6-7. Such elements include, but are not limited to sub-frames, frames, signals, synchronization signals, BTRSs, OFDM symbol periods, RBs, REs and/or others.

**[0074]** Referring to FIG. 6, BTRSs 630 and a PSS 620 may be transmitted during the example sub-frame 610 (labeled SF0 in this case), which may comprise multiple OFDM symbols. In the arrangement 600, another sub-frame 617 may be transmitted after a duration of  $X$  milliseconds (denoted by 615), which may be in accordance with a periodic transmission arrangement, in

some cases. Accordingly, BTRSs may be transmitted in sub-frames such as 610 and 617 (and/or others at integer multiples of  $X$  milliseconds) and may be excluded from sub-frames transmitted in between sub-frames that include BTRS transmission (like those in between 610 and 617). As an example, a starting  
5 OFDM symbol may be defined to occur right after the PSS 620 (and/or SSS in some cases) is transmitted.

[0075] In the example sub-frame 610, BTRSs 630 may be transmitted in accordance with transmission directions in a first beam group (as indicated by 635) in a top set of  $N$  PRBs. In addition, BTRSs 640 may be transmitted in  
10 accordance with transmission directions in a second beam group (as indicated by 645) in a bottom set of  $N$  PRBs. Accordingly, the example sub-frame 610 may operate in accordance with a localized frequency arrangement.

[0076] As shown in the example sub-frame 610, multiple OFDM symbol periods are used for transmission of the BTRSs 630 and for the transmission of  
15 the BTRSs 640. A number of OFDM symbol periods in which BTRSs are to be transmitted may be pre-defined and/or configured by higher layers, in some cases. Embodiments are not limited to transmission in multiple OFDM symbols, however, as a single OFDM symbol may be used in some cases. In addition, other signals may be transmitted in the sub-frame 610, such as CSI-RS (which  
20 may be transmitted right after the BTRSs 630, 640, for instance).

[0077] It should also be noted that embodiments are not limited to transmission of the BTRS in a single sub-frame, as multiple sub-frames may be used in some cases. That is, a number of OFDM symbol periods used for BTRS transmission may be larger than a number of OFDM symbol periods available in  
25 a sub-frame.

[0078] Referring to FIG. 7, BTRSs 730 and a PSS 720 may be transmitted during a sub-frame 710 (labeled SF0 in this case), which may comprise multiple OFDM symbols. In the arrangement 700, another sub-frame 717 may be transmitted after a duration of  $X$  milliseconds (denoted by 715),  
30 which may be in accordance with a periodic transmission arrangement, in some cases. In the example sub-frame 710, BTRSs 730 may be transmitted in accordance with a distributed frequency arrangement in which a first beam group

may be transmitted in REs 740 (indicated by a striped configuration) and a second beam group may be transmitted in REs 745 (indicated by a white box). It should be noted that this arrangement of interleaved REs 740, 745 may be extended to more than two BTRS groups, in some cases. In addition, embodiments are not limited to the number of REs 740, 745 shown in FIG. 7.

[0079] Examples of techniques that may be used for BTRS generation will be presented below, but it is understood that embodiments are not limited by these examples. Accordingly, the BTRSs may be generated using any suitable techniques. In some embodiments, the BTRS may be based on any number of factors such as a cell identifier (ID), virtual cell ID, BTRS ID, BTRS group ID, frame index, sub-frame index, symbol index and/or other factors, although embodiments are not limited as such.

[0080] As an example, the BTRSs may be based on one or more Zadoff-Chu (ZC) sequence. The ZC sequences may be based on one or more base sequences which may be based on factors such as those given above, in some cases. As an example, when a same base sequence is used for generation of multiple ZC sequences, a single cyclic shift value may be applied for the BTRSs. As another example, when same or different base sequences are used for generation of the multiple ZC sequences, different cyclic shift values may be applied for the BTRSs.

[0081] An example technique for generation of a ZC sequence is presented below, although it is understood that embodiments are not limited to usage of this generation technique, and other suitable techniques may be used to generate a ZC sequence and/or other sequence. The ZC sequence may be

$$r(n) = \exp(j\alpha n) r_{us}(n)$$

[0083] In this formula,  $r_{us}(n)$  may be a base sequence,  $u$  may be a sequence group number,  $v$  may be a sequence number, and  $\alpha$  may be a cyclic shift. As an example,  $r_{us}(n)$ ,  $u$ , and  $v$  may be included in and/or generated according to a 3GPP LTE standard and/or other standard. As another example, the base sequence may be defined as a function of a physical cell ID and/or sub-frame index, which may be included in a 3GPP standard and/or other standard in

some cases, although embodiments are not limited as such. Accordingly, inter-cell interference may be randomized, in some cases. These examples are not limiting, however, as these and other parameters used for ZC sequence generation may be selected and/or generated using other suitable techniques, in  
5 some cases.

[0084] As another example, the BTRSs may be or may be based on one or more maximal length sequences (m-sequences). In some embodiments, an initialization for the m-sequence (and/or generation of the m-sequence) may be based on one or more factors such as those given above. As an example, a  
10 pseudo-random sequence  $c(i)$  may be initialized as a function of cell ID and/or sub-frame index, in some cases. The sequence  $c(i)$  may be mapped to a sequence of complex numbers using a formula such as  $r(i) = (1/\sqrt{2}) * (1 - 2*c(2i)) + (j/\sqrt{2}) * (1 - 2c(2i + 1))$ , as an example, although any suitable formula or technique may be used. The complex sequence may be mapped to  
15 REs used for BTRS transmission, in some cases. It should be noted that the sequence  $c(i)$ , the relationship between  $r(i)$  and  $c(i)$ , the cell ID, sub-frame index and/or other parameters may be included in a 3GPP standard and/or other standard, although embodiments are not limited as such. These examples are not limiting, however, as the sequence and/or parameters used for m-sequence  
20 generation may be selected and/or generated using other suitable techniques, in some cases.

[0085] As a non-limiting example, the BTRS may be transmitted according to a downlink transmit direction from the eNB 104 to the first UE 102. The BTRS may enable the UE 102 to perform beam tracking, beam refinement  
25 and/or tracking of one or more downlink transmission directions from the eNB 104 to the UE 102. As a non-limiting example, the UE 102 may use the BTRSs to modify one or more receive directions for reception of signals from the eNB 104 and previously determined receive antenna directions may be used by the UE 102 for reception of the BTRSs.

30 [0086] As an example, when OFDM transmission is used by the eNB 104 for the downlink sub-frame, a first group of one or more OFDM symbol

periods may be allocated for transmission of BTRSs to the UE 102. A second group of one or more OFDM symbol periods may be allocated for transmission of BTRSs to another UE 102. Embodiments are not limited to usage of the first and second UEs 102, however, as additional OFDM symbol periods may be allocated for transmission of one or more BTRSs to other UEs 102 in some cases. The groups of OFDM symbol periods may be adjacent in time, in some cases, although embodiments are not limited as such. In addition, the groups may be non-overlapping in time, in some cases, although embodiments are not limited to non-overlapping arrangements.

10 [0087] At operation 530, the eNB 104 may transmit one or more channel state information reference symbols (CSI-RS) during the sub-frame. In some embodiments, the CSI-RS may be transmitted during an initial sub-frame and in accordance with one or more initial downlink transmission directions from the eNB 104 to the UE 102. In some cases, the CSI-RS may be transmitted to enable an acquisition, at the UE 102, of the initial downlink transmission directions from the eNB 104 to the UE 102. In some embodiments, the CSI-RS may be transmitted during sub-frames for which BTRS are not transmitted, although the scope of embodiments is not limited in this respect. In some cases, the transmission of the CSI-RS may enable the UE 102 to perform receive beam-forming acquisition and/or training in a manner that may be faster than when other signals are used.

[0088] FIG. 8 illustrates another example sub-frame format in accordance with some embodiments. Although the example sub-frame format 810 may illustrate some or all techniques, operations and/or concepts described herein, it is understood that embodiments are not limited by the example 810 and in terms of number, type, size, arrangement and/or other aspects of elements shown in FIG. 8. Such elements include, but are not limited to sub-frames, frames, signals, synchronization signals, BTRSs, OFDM symbol periods, RBs, REs and/or others.

30 [0089] Referring to FIG. 8, CSI-RS 830 and a PSS 820 may be transmitted during a sub-frame 810 (labeled SF0 in this case), which may comprise multiple OFDM symbols. In the arrangement 800, another sub-frame

817 may be transmitted after a duration of X milliseconds (denoted by 815), which may be in accordance with a periodic transmission arrangement, in some cases. In the example sub-frame 810, multiple OFDM symbol periods may be used for transmission of the CSI-RS 830.

5 [0090] At operation 535, the eNB 104 may receive beam-forming feedback from one or more UEs 102. The eNB 104 may determine updated transmission directions for one or more UEs 102 at operation 540. The determination may be based at least partly on the received beam-forming feedback, in some cases. At operation 545, the eNB 104 may transmit one or  
10 more signals in accordance with the updated transmission directions. The signals may include data signals, control signals and/or other signals.

[0091] In some embodiments, the eNB 104 and/or UEs 102 may use previously determined downlink transmission directions for transmission and/or reception of signals. As an example, downlink transmission directions from the  
15 eNB 104 to the UE 102 may be based on previously determined beam-forming weights for one or more directional links from the eNB 104 to the UE 102.

[0092] FIG. 9 illustrates the operation of another method of communication in accordance with some embodiments. As mentioned previously regarding the method 500, embodiments of the method 900 may  
20 include additional or even fewer operations or processes in comparison to what is illustrated in FIG. 9 and embodiments of the method 900 are not necessarily limited to the chronological order that is shown in FIG. 9. In describing the method 900, reference may be made to FIGs. 1-8, although it is understood that the method 900 may be practiced with any other suitable systems, interfaces and  
25 components. In addition, embodiments of the method 900 may refer to UEs 102, eNBs 104, APs, STAs or other wireless or mobile devices. The method 900 may also refer to an apparatus for an eNB 104 and/or UE 102 or other device described above.

[0093] It should be noted that the method 900 may be practiced at a UE  
30 102 and may include exchanging of signals or messages with an eNB 104. Similarly, the method 500 may be practiced at an eNB 104 and may include exchanging of signals or messages with a UE 102. In some cases, operations

and techniques described as part of the method 500 may be relevant to the method 900. In addition, embodiments may include operations performed at the UE 102 that may be reciprocal or similar to other operations described herein performed at the eNB 104. For instance, an operation of the method 900 may include reception of a signal by the UE 102 while an operation of the method 500 may include transmission of the same signal or similar signal by the eNB 104.

[0094] In addition, previous discussion of various techniques and concepts may be applicable to the method 900 in some cases, including BTRS, CSI-RS, training symbols, PSS, SSS, synchronization signals, directional transmission, directional reception, transmission directions, receive directions, sub-frames, TDM, FDM, BTRS sequences, ZC sequences, m-sequences, techniques for generation of sequences, frames, sub-frames, and others. In addition, some or all aspects of the example sub-frames shown in FIGs. 6-8 may be applicable in some cases.

[0095] At operation 905, the UE 102 may receive a synchronization signal from an eNB 104 during a sub-frame. At operation 910, the UE may receive one or more BTRSs from the eNB 104 during the sub-frame (which may or may not be the same sub-frame in which the synchronization signal is received). At operation 915, the UE 102 may receive one or more CSI-RS during a sub-frame (which may or may not be the same sub-frame in which the BTRS and/or synchronization signal are received).

[0096] At operation 920, the UE 102 may receive one or more control messages that indicate information about the BTRSs and/or BTRS groups. For instance, a number of BTRS groups and/or parameters used for BTRS generation may be indicated. At operation 925, the UE 102 may divide frequency resources, such as RBs allocated for transmission of the BTRSs, into groups related to BTRS groups. At operation 930, the UE 102 may determine one or more BTRSs and/or BTRS sequences, which may be based on factors such as those described previously and/or others.

[0097] At operation 935, the UE 102 may transmit beam-forming feedback to the eNB 104. At operation 940, the UE 102 may determine updated

receive antenna directions based at least partly on the reception of the BTRSs. In some cases, the updating may be performed in an attempt to improve receive signal quality, receiver performance and/or other receive metric. As an example, the beam-forming feedback may be related to the reception of the BTRSs, the updated receive antenna directions and/or other information related to directional links between the eNB 104 and the UE 102. At operation 945, the UE 102 may receive a signal (such as a control signal, data signal and/or other signal) from the eNB 104 in accordance with the updated receive directions.

[0098] In Example 1, an apparatus for an Evolved Node-B (eNB) may comprise transceiver circuitry and hardware processing circuitry. The hardware processing circuitry may configure the transceiver circuitry to transmit a synchronization signal during a sub-frame. The hardware processing circuitry may further configure the transceiver circuitry to transmit a beam-forming training reference signal (BTRS) to a User Equipment (UE) in dedicated BTRS time resources of the sub-frame. The BTRS may be transmitted in accordance with one or more downlink transmission directions from the eNB to the UE.

[0099] In Example 2, the subject matter of Example 1, wherein the BTRS may be a first BTRS. The one or more downlink transmission directions may be included in a first group of downlink transmission directions. The hardware processing circuitry may further configure the transceiver circuitry to transmit a second BTRS to the UE in the BTRS time resources and in accordance with a second group of one or more downlink transmission directions.

[00100] In Example 3, the subject matter of one or any combination of Examples 1-2, wherein the first BTRS may be transmitted during a first orthogonal frequency division multiplexing (OFDM) symbol period of the BTRS time resources and the second BTRS may be transmitted during a second OFDM symbol period of the BTRS time resources.

[00101] In Example 4, the subject matter of one or any combination of Examples 1-3, wherein the first and second BTRS may be transmitted as part of an orthogonal frequency division multiplexing (OFDM) signal during a same OFDM symbol period of the BTRS time resources. The first and second BTRS

may be further transmitted in accordance with a localized frequency arrangement, in which a first group of contiguous resource blocks (RBs) may be used for the transmission of the first BTRS and a second group of contiguous RBs may be used for the transmission of the second BTRS.

- 5   **[00102]**        In Example 5, the subject matter of one or any combination of Examples 1-4, wherein the first and second BTRS may be transmitted as part of an orthogonal frequency division multiplexing (OFDM) signal during a same OFDM symbol period of the BTRS time resources. The first and second BTRS may be transmitted in accordance with a distributed frequency arrangement, in  
10   which a first group of resource elements (REs) used for the transmission of the first BTRS may be interleaved in frequency with a second group of REs used for the transmission of the second BTRS.

- [00103]**        In Example 6, the subject matter of one or any combination of Examples 1-5, wherein the BTRS may be based on a BTRS sequence that is  
15   based on a cell identifier (ID) of the eNB.

**[00104]**        In Example 7, the subject matter of one or any combination of Examples 1-6, wherein the BTRS may be further based on at least one of a virtual cell ID, a BTRS ID or a BTRS group ID.

- [00105]**        In Example 8, the subject matter of one or any combination of  
20   Examples 1-7, wherein the BTRS may be further based on at least one of a frame index, a sub-frame index or a symbol index.

**[00106]**        In Example 9, the subject matter of one or any combination of Examples 1-8, wherein the BTRS sequence may be based on a Zadoff-Chu (ZC) sequence for which a base sequence is based at least partly on the cell ID.

- 25   **[00107]**        In Example 10, the subject matter of one or any combination of Examples 1-9, wherein the BTRS sequence may be based on a maximum length sequence (m-sequence) generated in accordance with one or more initialization values that are at least based on the cell ID and an index of the sub-frame.

- [00108]**        In Example 11, the subject matter of one or any combination of  
30   Examples 1-10, wherein the hardware processing circuitry may include baseband circuitry configured to determine the BTRS sequence.

**[00109]** In Example 12, the subject matter of one or any combination of Examples 1-11, wherein the transmission of the BTRS may be to enable beam tracking, at the UE, of the downlink transmission directions from the eNB to the UE.

- 5 **[00110]** In Example 13, the subject matter of one or any combination of Examples 1-12, wherein the hardware processing circuitry may further configure the transceiver circuitry to transmit, during an initial sub-frame and in accordance with one or more initial downlink transmission directions from the eNB to the UE, one or more channel state information reference symbols (CSI-  
10 RS). The CSI-RS may be transmitted to enable an acquisition, at the UE, of the initial downlink transmission directions from the eNB to the UE.

- [00111]** In Example 14, the subject matter of one or any combination of Examples 1-13, wherein the synchronization signal may include a primary synchronization signal (PSS) and/or a secondary synchronization signal (SSS).  
15 The synchronization signal may be transmitted to enable time synchronization and/or frequency synchronization of the UE and/or other UEs.

**[00112]** In Example 15, the subject matter of one or any combination of Examples 1-14, wherein the synchronization signal and the BTRS may be transmitted at a millimeter wave (mmWave) frequency.

- 20 **[00113]** In Example 16, the subject matter of one or any combination of Examples 1-15, wherein the synchronization signal and the BTRS may be transmitted at a centimeter wave (cmWave) frequency.

- [00114]** In Example 17, a non-transitory computer-readable storage medium may store instructions for execution by one or more processors to  
25 perform operations for communication by an Evolved Node-B (eNB). The operations may configure the one or more processors to configure the eNB to transmit an orthogonal frequency division multiplexing (OFDM) signal during an OFDM symbol period of a sub-frame. The OFDM signal may be based at least partly on multiple beam-forming training reference signals (BTRSs). The  
30 operations may further configure the one or more processors to configure the eNB to receive, from a User Equipment (UE), beam-forming feedback based on reception of the BTRSs at the UE. The BTRSs may be transmitted in

accordance with multiple transmission directions from the eNB to the UE and further in accordance with a frequency division multiplexing (FDM) technique.

[00115] In Example 18, the subject matter of Example 17, wherein frequency resources used for the transmission of the BTRSs may include  
5 multiple non-overlapping portions of multiple resource blocks (RBs). The multiple transmission directions may include multiple non-overlapping portions of one or more transmission directions. Each BTRS may be transmitted in one of the portions of RBs and according to transmission directions of one of the portions of transmission directions.

10 [00116] In Example 19, the subject matter of one or any combination of Examples 17-18, wherein the operations may further configure the one or more processors to configure the eNB to transmit a control message that indicates a number of portions of RBs and/or transmission directions to be used for the BTRS transmission.

15 [00117] In Example 20, the subject matter of one or any combination of Examples 17-19, wherein the BTRSs may be based on one or more BTRS sequences that are based on at least a cell identifier (ID) of the eNB.

[00118] In Example 21, the subject matter of one or any combination of Examples 17-20, wherein the BTRS sequences may be based on one or more  
20 Zadoff-Chu (ZC) sequences. When a same base sequence is used for generation of the ZC sequences, a single cyclic shift value may be applied for the BTRSs. When same or different base sequences are used for generation of the ZC sequences, different cyclic shift values may be applied for the BTRSs.

[00119] In Example 22, the subject matter of one or any combination of  
25 Examples 17-21, wherein the operations may further configure the one or more processors to configure the eNB to transmit, during the sub-frame, a primary synchronization signal (PSS) and/or a secondary synchronization signal (SSS) to enable time synchronization and/or frequency synchronization of the UE.

[00120] In Example 23, an apparatus for a User Equipment (UE) may  
30 comprise transceiver circuitry and hardware processing circuitry. The hardware processing circuitry may configure the transceiver circuitry to receive a synchronization signal from an Evolved Node-B (eNB) during a sub-frame. The

hardware processing circuitry may further configure the transceiver circuitry to receive, in accordance with a set of receive directions, one or more beam-forming training reference signals (BTRSs) from the eNB during the sub-frame. The hardware processing circuitry may be configured to determine, based at least partly on the reception of the BTRSs, an updated set of received directions. The BTRSs may be received during BTRS time resources.

[00121] In Example 24, the subject matter of Example 23, wherein the BTRSs may be received as part of an orthogonal frequency division multiplexing (OFDM) signal that comprises multiple resource blocks (RBs). Each BTRS may be received in an exclusive portion of the RBs.

[00122] In Example 25, the subject matter of one or any combination of Examples 23-24, wherein the RBs comprise multiple REs. When the BTRSs are received in accordance with a localized frequency arrangement, the BTRSs may be received in adjacent, non-overlapping portions of the RBs. When the BTRSs are received in accordance with a distributed frequency arrangement, the BTRSs may be received in interleaved portions of the REs.

[00123] In Example 26, the subject matter of one or any combination of Examples 23-25, wherein the hardware processing circuitry may further configure the transceiver circuitry to receive, from the eNB, a control message that indicates a number of BTRSs to be received.

[00124] In Example 27, the subject matter of one or any combination of Examples 23-26, wherein the BTRSs may be based on one or more BTRS sequences that are based at least partly on a cell identifier (ID) of the eNB.

[00125] In Example 28, the subject matter of one or any combination of Examples 23-27, wherein the BTRS sequences may be based on one or more Zadoff-Chu (ZC) sequences.

[00126] In Example 29, the subject matter of one or any combination of Examples 23-28, wherein the hardware processing circuitry may include baseband circuitry configured to determine the updated set of receive directions.

[00127] In Example 30, the subject matter of one or any combination of Examples 23-29, wherein the synchronization signal and the BTRSs may be

received at a centimeter wave (cmWave) or a millimeter wave (mmWave) frequency.

[00128] The Abstract is provided to comply with 37 C.F.R. Section 1.72(b) requiring an abstract that will allow the reader to ascertain the nature and  
5 gist of the technical disclosure. It is submitted with the understanding that it will not be used to limit or interpret the scope or meaning of the claims. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate embodiment.

## CLAIMS

What is claimed is:

- 5           1. An apparatus for an Evolved Node-B (eNB), the apparatus comprising transceiver circuitry and hardware processing circuitry, the hardware processing circuitry to configure the transceiver circuitry to:
- transmit a synchronization signal during a sub-frame; and
- transmit a beam-forming training reference signal (BTRS) to a User
- 10   Equipment (UE) in dedicated BTRS time resources of the sub-frame,
- wherein the BTRS is transmitted in accordance with one or more downlink transmission directions from the eNB to the UE.
2. The apparatus according to claim 1, wherein:
- 15   the BTRS is a first BTRS,
- the one or more downlink transmission directions are included in a first group of downlink transmission directions,
- the hardware processing circuitry is to further configure the transceiver circuitry to transmit a second BTRS to the UE in the BTRS time resources and
- 20   in accordance with a second group of one or more downlink transmission directions.
3. The apparatus according to claim 2, wherein the first BTRS is transmitted during a first orthogonal frequency division multiplexing (OFDM)
- 25   symbol period of the BTRS time resources and the second BTRS is transmitted during a second OFDM symbol period of the BTRS time resources.
4. The apparatus according to claim 2, wherein:
- the first and second BTRS are transmitted as part of an orthogonal
- 30   frequency division multiplexing (OFDM) signal during a same OFDM symbol period of the BTRS time resources, and

the first and second BTRS are further transmitted in accordance with a localized frequency arrangement, wherein a first group of contiguous resource blocks (RBs) is used for the transmission of the first BTRS and a second group of contiguous RBs is used for the transmission of the second BTRS.

5

5. The apparatus according to claim 2, wherein:

the first and second BTRS are transmitted as part of an orthogonal frequency division multiplexing (OFDM) signal during a same OFDM symbol period of the BTRS time resources, and

10

the first and second BTRS are transmitted in accordance with a distributed frequency arrangement, wherein a first group of resource elements (REs) used for the transmission of the first BTRS is interleaved in frequency with a second group of REs used for the transmission of the second BTRS.

15

6. The apparatus according to claim 1, wherein the BTRS is based on a BTRS sequence that is based on a cell identifier (ID) of the eNB.

7. The apparatus according to claim 6, wherein the BTRS is further based on at least one of a virtual cell ID, a BTRS ID or a BTRS group ID.

20

8. The apparatus according to claim 6, wherein the BTRS is further based on at least one of a frame index, a sub-frame index or a symbol index.

9. The apparatus according to claim 6, wherein the BTRS sequence is based on a Zadoff-Chu (ZC) sequence for which a base sequence is based at least partly on the cell ID.

25

10. The apparatus according to claim 6, wherein the BTRS sequence is based on a maximum length sequence (m-sequence) generated in accordance with one or more initialization values that are at least based on the cell ID and an index of the sub-frame.

30

11. The apparatus according to claim 6, wherein the hardware processing circuitry includes baseband circuitry configured to determine the BTRS sequence.

5           12. The apparatus according to claim 1, wherein the transmission of the BTRS is to enable beam tracking, at the UE, of the downlink transmission directions from the eNB to the UE.

10           13. The apparatus according to claim 12, wherein:  
the hardware processing circuitry is to further configure the transceiver circuitry to transmit, during an initial sub-frame and in accordance with one or more initial downlink transmission directions from the eNB to the UE, one or more channel state information reference symbols (CSI-RS), and  
the CSI-RS are transmitted to enable an acquisition, at the UE, of the  
15 initial downlink transmission directions from the eNB to the UE.

14. The apparatus according to claim 1, wherein:  
the synchronization signal includes a primary synchronization signal (PSS) and/or a secondary synchronization signal (SSS), and  
20 the synchronization signal is transmitted to enable time synchronization and/or frequency synchronization of the UE and/or other UEs.

15. The apparatus according to claim 1, wherein the synchronization signal and the BTRS are transmitted at a millimeter wave (mmWave) frequency.  
25

16. The apparatus according to claim 1, wherein the synchronization signal and the BTRS are transmitted at a centimeter wave (cmWave) frequency.

17. A non-transitory computer-readable storage medium that stores  
30 instructions for execution by one or more processors to perform operations for communication by an Evolved Node-B (eNB), the operations to configure the one or more processors to configure the eNB to:

transmit an orthogonal frequency division multiplexing (OFDM) signal during an OFDM symbol period of a sub-frame, the OFDM signal based at least partly on multiple beam-forming training reference signals (BTRSs);

receive, from a User Equipment (UE), beam-forming feedback based on  
5 reception of the BTRSs at the UE,

wherein the BTRSs are transmitted in accordance with multiple transmission directions from the eNB to the UE and further in accordance with a frequency division multiplexing (FDM) technique.

10 18. The non-transitory computer-readable storage medium according to claim 17, wherein:

frequency resources used for the transmission of the BTRSs include multiple non-overlapping portions of multiple resource blocks (RBs),

the multiple transmission directions include multiple non-overlapping  
15 portions of one or more transmission directions,

each BTRS is transmitted in one of the portions of RBs and according to transmission directions of one of the portions of transmission directions.

19. The non-transitory computer-readable storage medium according to  
20 claim 18, the operations to further configure the one or more processors to configure the eNB to transmit a control message that indicates a number of portions of RBs and/or transmission directions to be used for the BTRS transmission.

25 20. The non-transitory computer-readable storage medium according to claim 17, wherein the BTRSs are based on one or more BTRS sequences that are based on at least a cell identifier (ID) of the eNB.

21. The non-transitory computer-readable storage medium according to  
30 claim 20, wherein:

the BTRS sequences are based on one or more Zadoff-Chu (ZC) sequences,

when a same base sequence is used for generation of the ZC sequences, a single cyclic shift value is applied for the BTRSs, and

when same or different base sequences are used for generation of the ZC sequences, different cyclic shift values are applied for the BTRSs.

5

22. The non-transitory computer-readable storage medium according to claim 17, the operations to further configure the one or more processors to configure the eNB to transmit, during the sub-frame, a primary synchronization signal (PSS) and/or a secondary synchronization signal (SSS) to enable time  
10 synchronization and/or frequency synchronization of the UE.

23. An apparatus for a User Equipment (UE), the apparatus comprising transceiver circuitry and hardware processing circuitry, the hardware processing circuitry configured to:

15 configure the transceiver circuitry to receive a synchronization signal from an Evolved Node-B (eNB) during a sub-frame;

configure the transceiver circuitry to receive, in accordance with a set of receive directions, one or more beam-forming training reference signals (BTRSs) from the eNB during the sub-frame; and

20 determine, based at least partly on the reception of the BTRSs, an updated set of received directions,

wherein the BTRSs are received during BTRS time resources.

24. The apparatus according to claim 23, wherein:

25 the BTRSs are received as part of an orthogonal frequency division multiplexing (OFDM) signal that comprises multiple resource blocks (RBs), and each BTRS is received in an exclusive portion of the RBs.

25. The apparatus according to claim 24, wherein:

30 the RBs comprise multiple REs,

when the BTRSs are received in accordance with a localized frequency arrangement, the BTRSs are received in adjacent, non-overlapping portions of the RBs, and

5 when the BTRSs are received in accordance with a distributed frequency arrangement, the BTRSs are received in interleaved portions of the REs.

26. The apparatus according to claim 23, the hardware processing circuitry to further configure the transceiver circuitry to receive, from the eNB, a control message that indicates a number of BTRSs to be received.  
10

27. The apparatus according to claim 23, wherein the BTRSs are based on one or more BTRS sequences that are based at least partly on a cell identifier (ID) of the eNB.

15 28. The apparatus according to claim 27, wherein the BTRS sequences are based on one or more Zadoff-Chu (ZC) sequences.

29. The apparatus according to claim 23, wherein the hardware processing circuitry includes baseband circuitry configured to determine the updated set of receive directions.  
20

30. The apparatus according to claim 23, wherein the synchronization signal and the BTRSs are received at a centimeter wave (cmWave) or a millimeter wave (mmWave) frequency.  
25

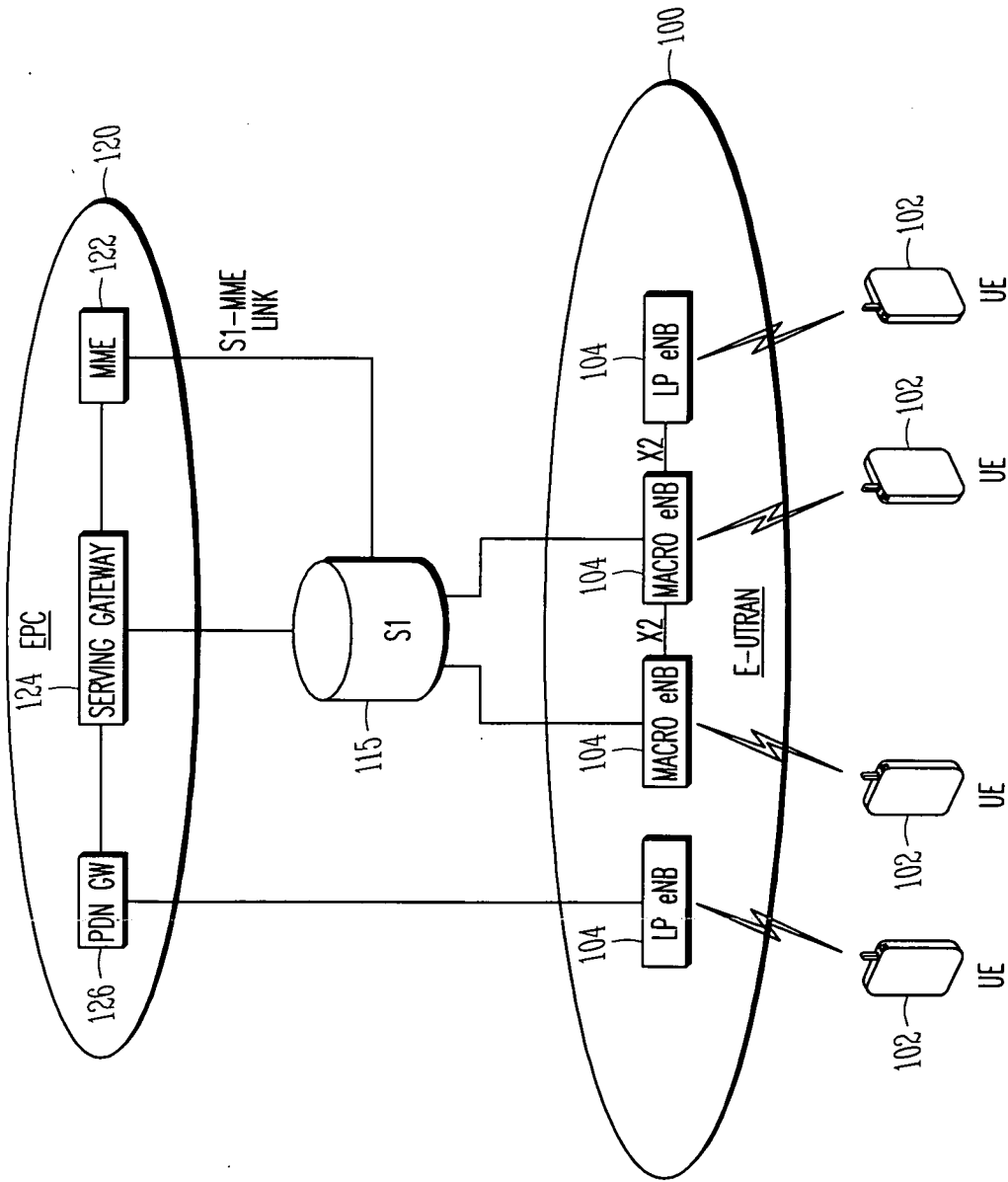
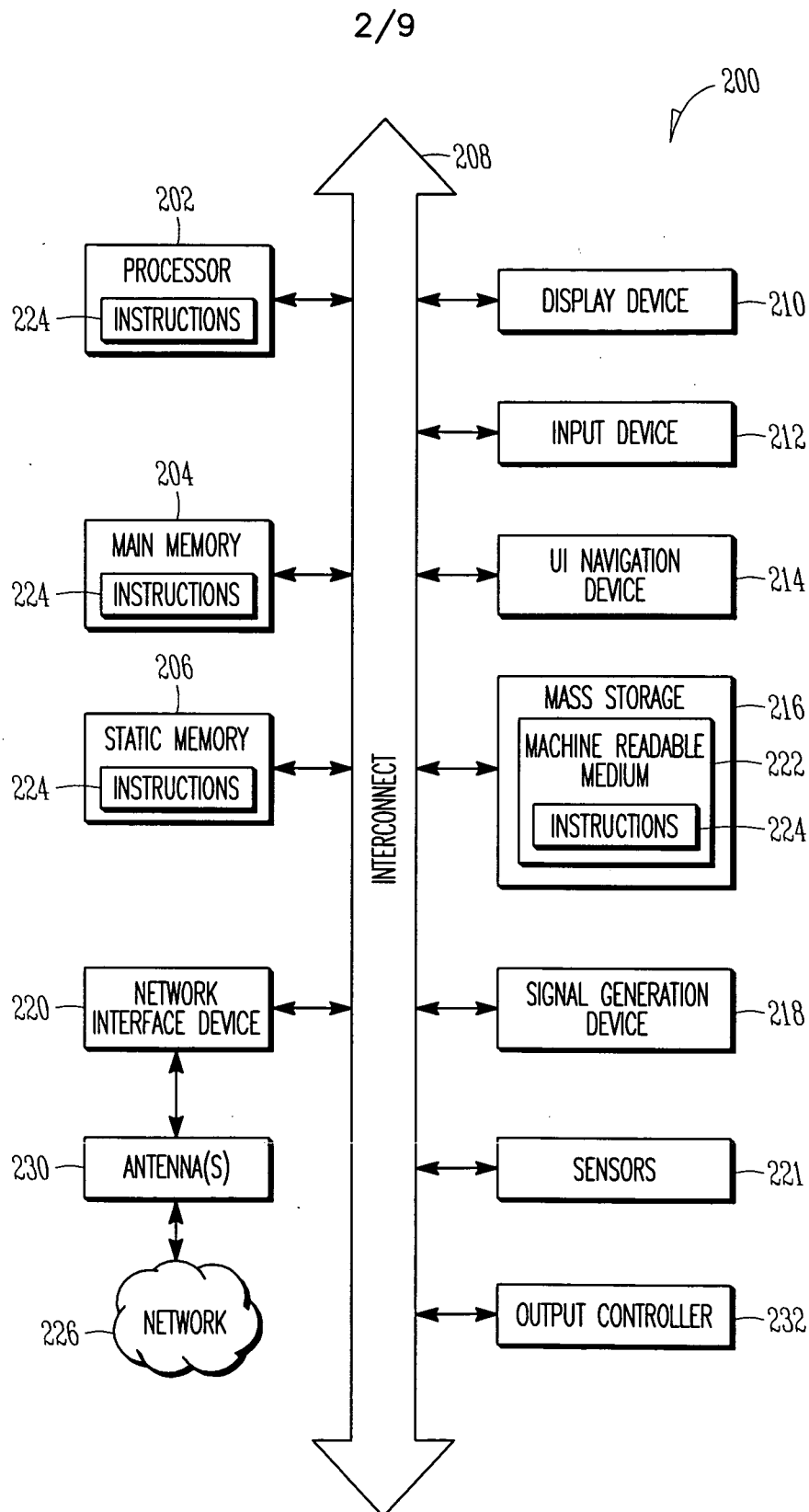
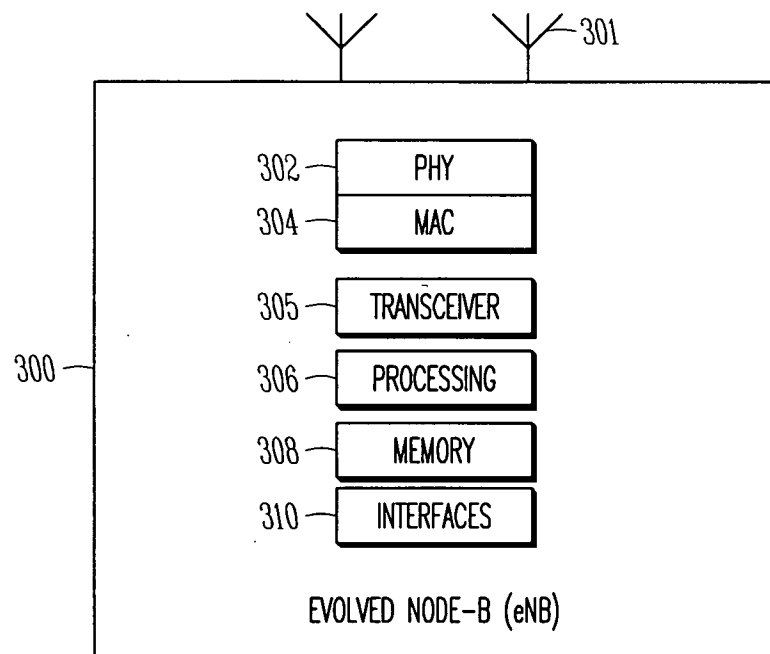


FIG. 1



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*FIG. 3*

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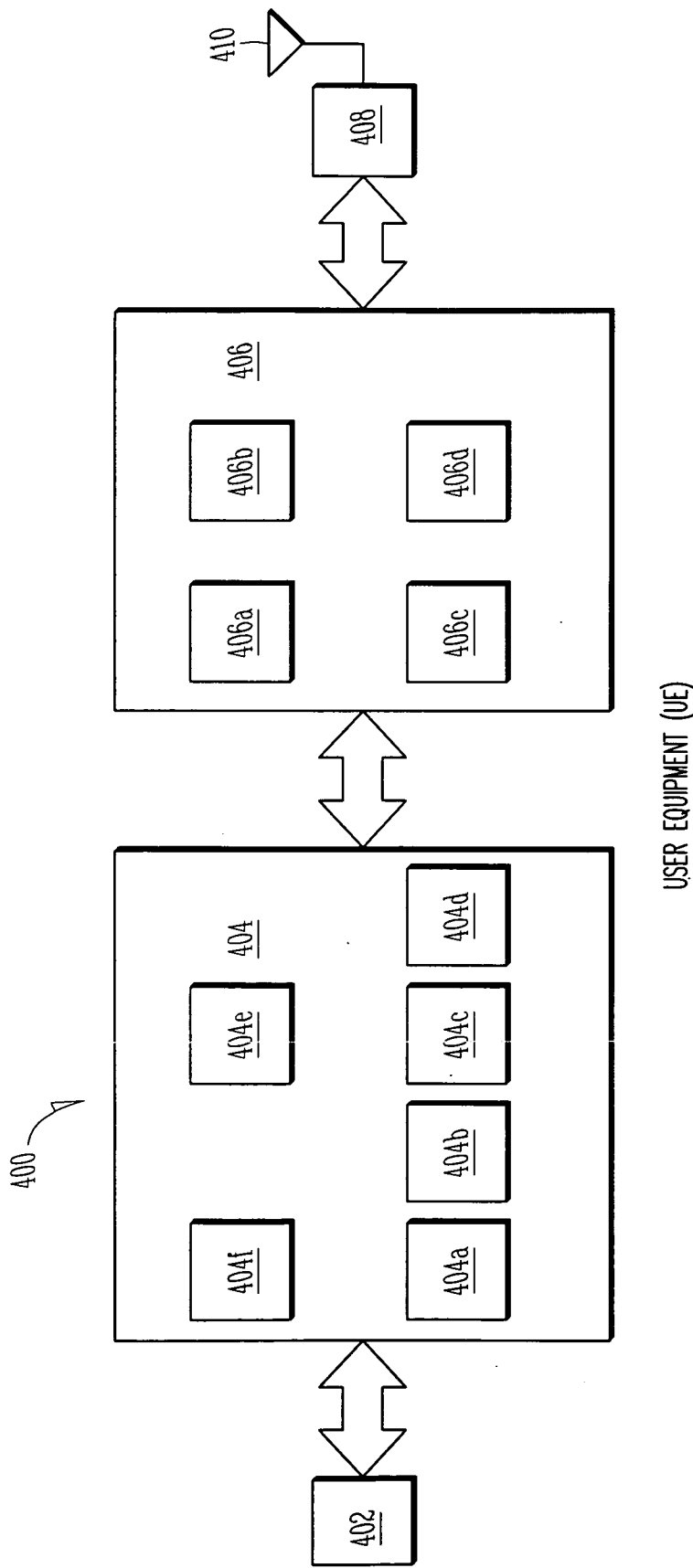
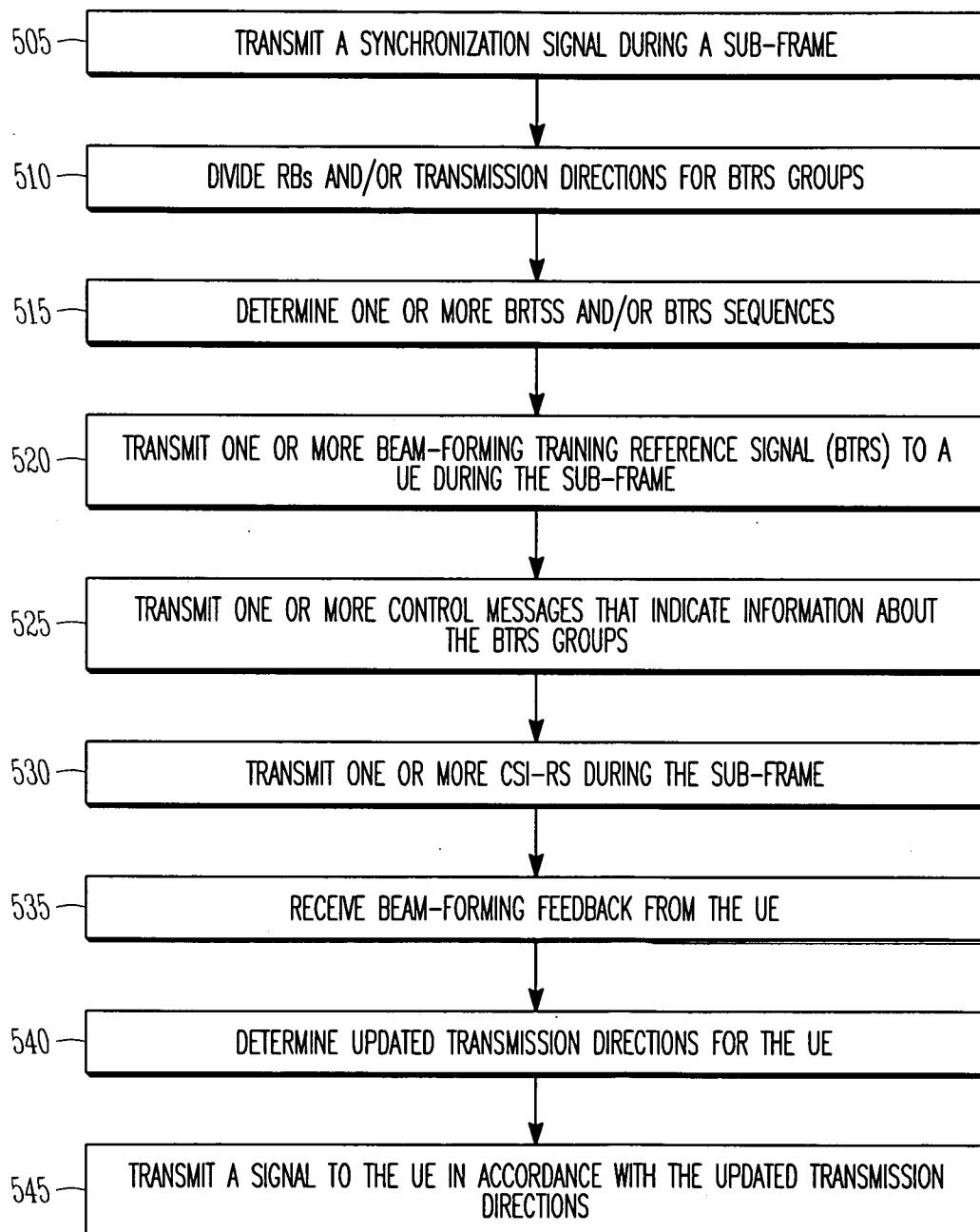


FIG. 4

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500**FIG. 5**

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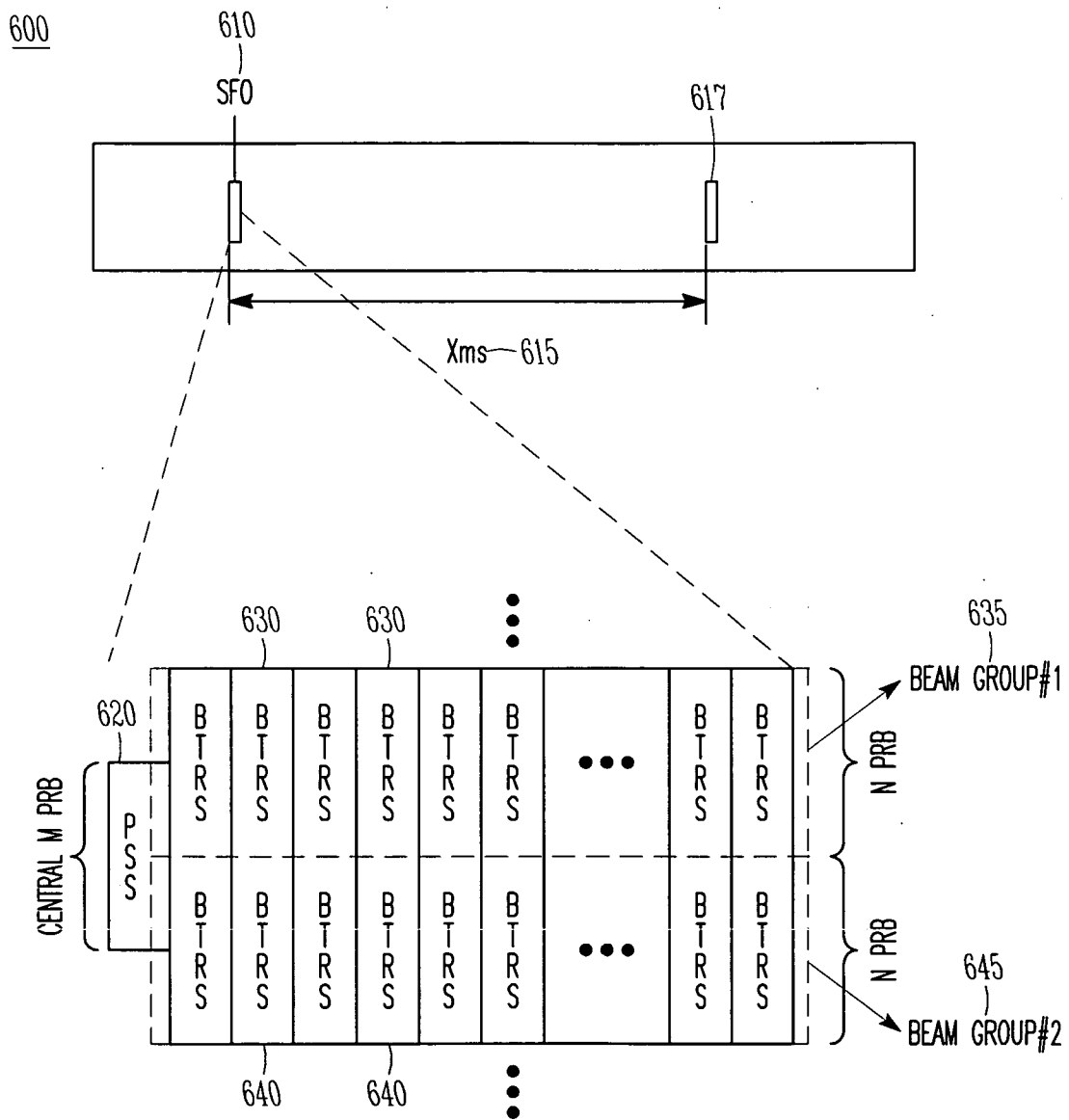


FIG. 6

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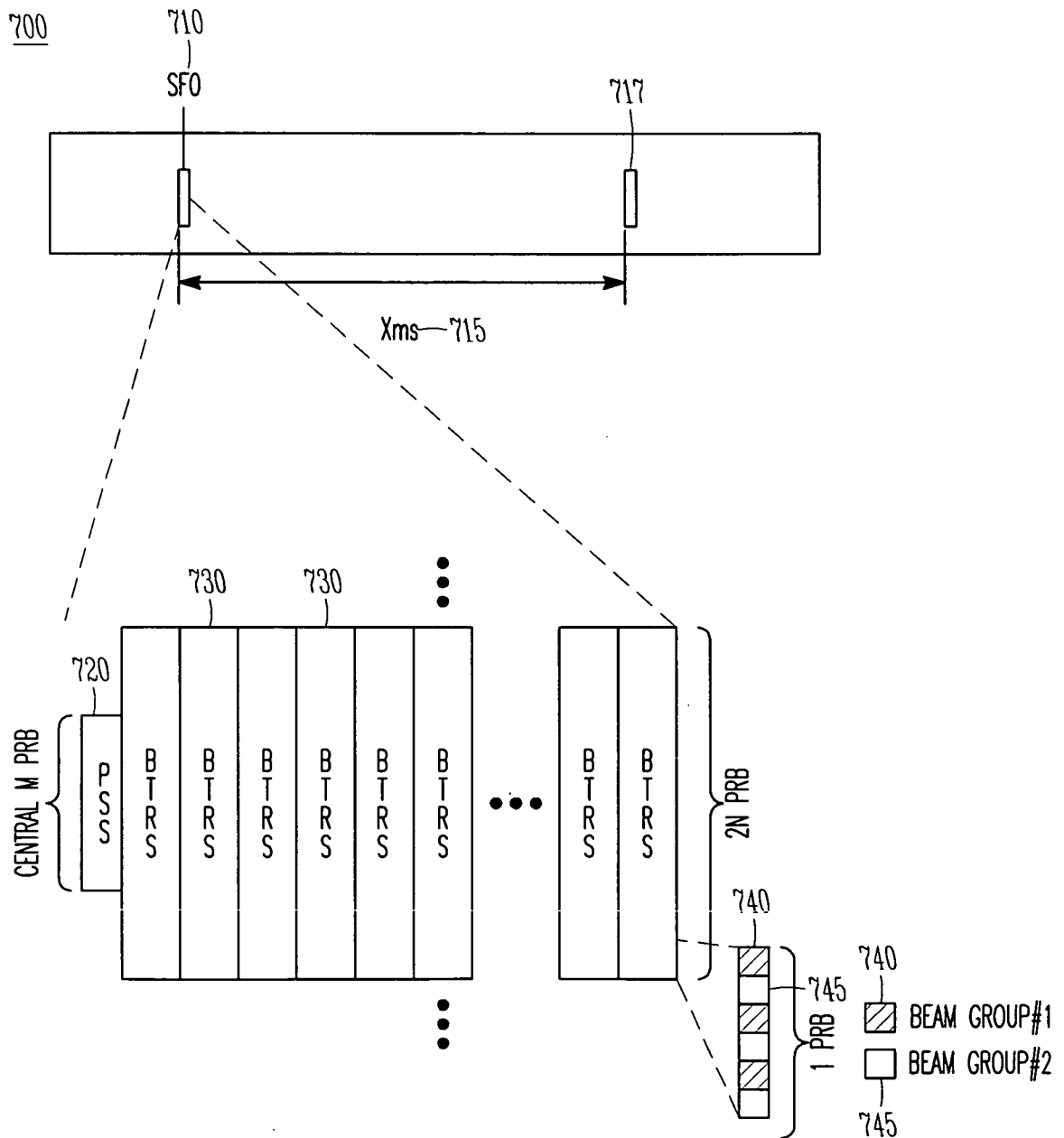


FIG. 7

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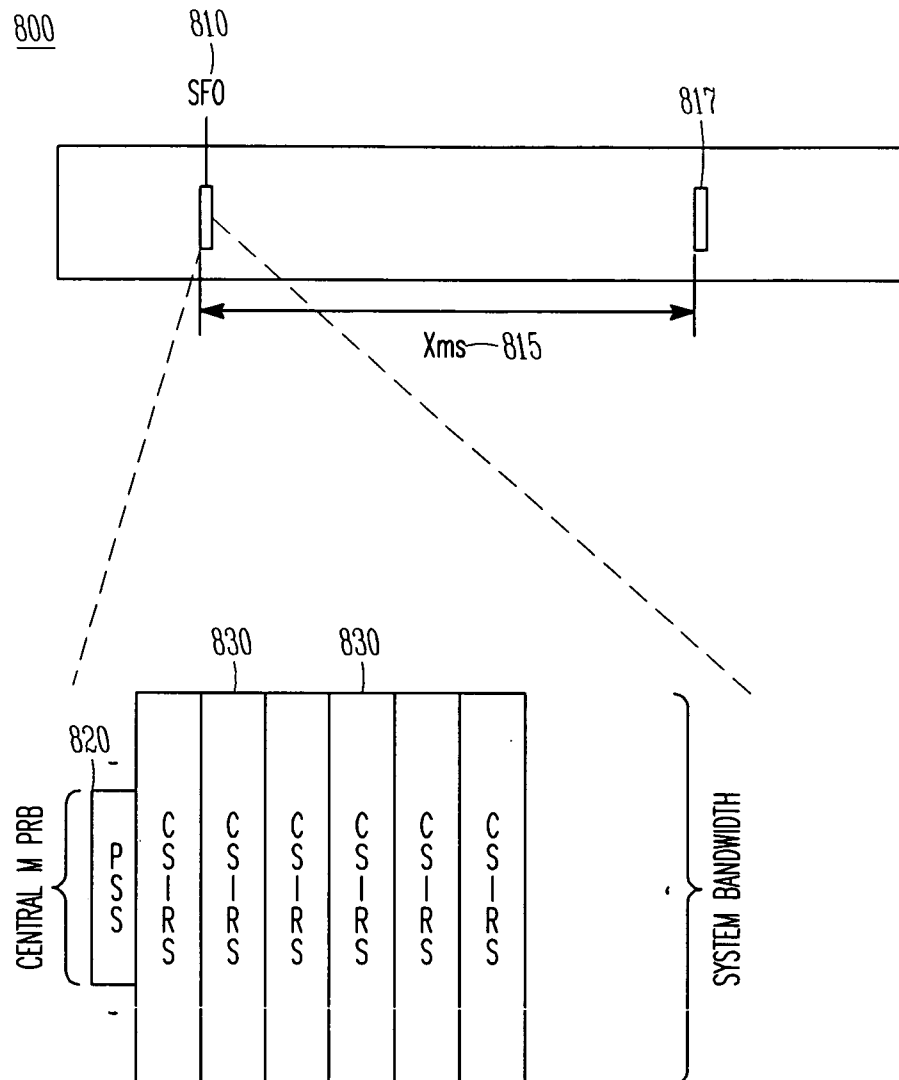


FIG. 8

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900

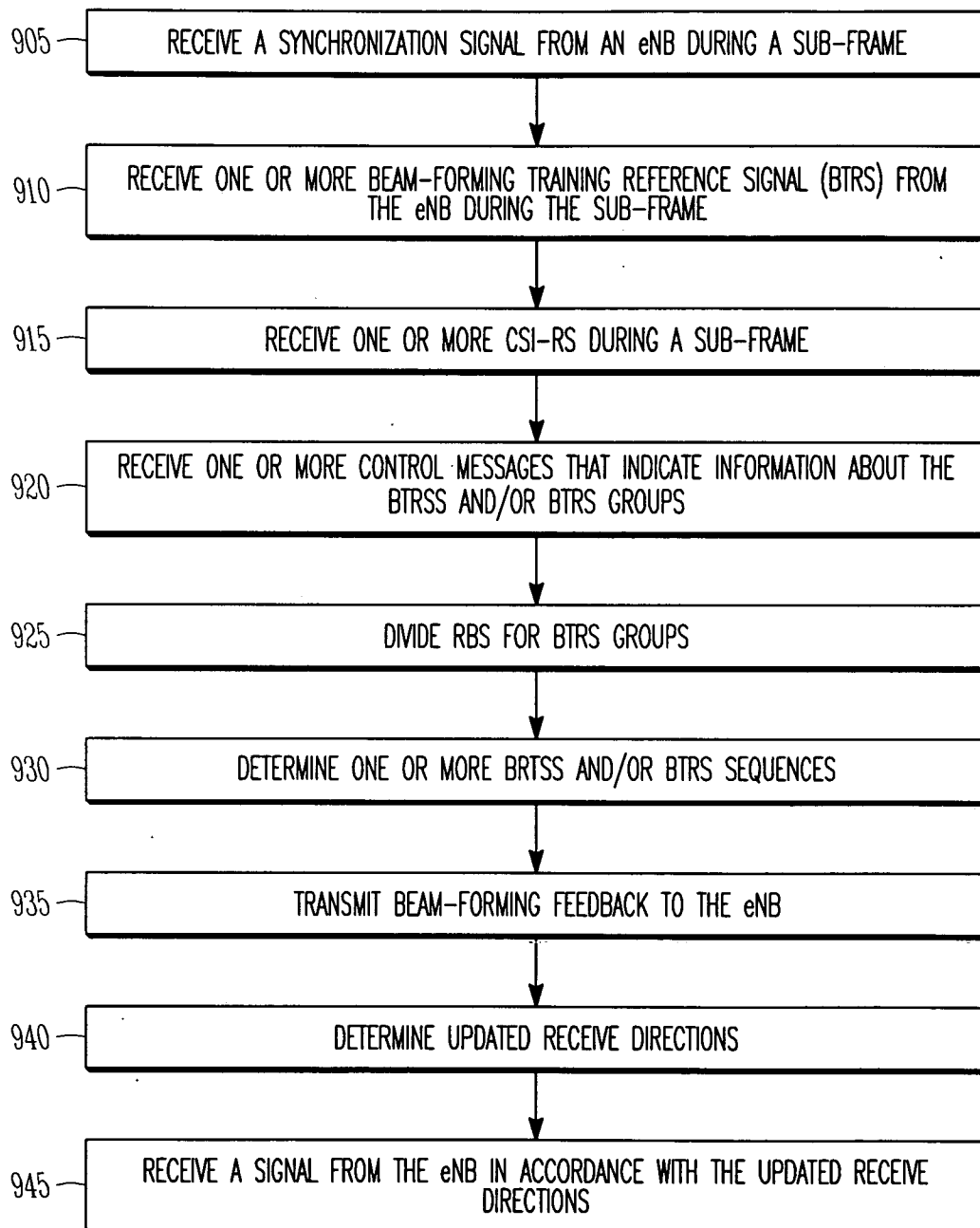


FIG. 9

## INTERNATIONAL SEARCH REPORT

International application No.  
**PCT/US2015/000232****A. CLASSIFICATION OF SUBJECT MATTER****H04L 5/00(2006.01)i, H04L 27/26(2006.01)i, H04B 7/26(2006.01)i**

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

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

H04L 5/00; H04B 7/00; H04W 88/00; H04L 27/28; H04B 1/18; H04W 72/04; H04L 27/26; H04B 7/26

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) &amp; keywords: synchronization, beam-forming training reference signal (BTRS), time resource, transmission directions, OFDM symbol period, localized, distributed, interleaved, cell identifier, virtual cell ID, sub-frame index, Zadoff-Chu sequence, m-sequence, beam tracking, CSI-RS, PSS, SSS, mmWave, cmWave

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                 | Relevant to claim No. |
|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| Y         | US 2013-0065622 A1 (PIL-YOUNG HWANG) 14 March 2013<br>See paragraphs [0004], [0039]-[0096]; and figures 4A-11.                                                                                     | 1-30                  |
| Y         | US 2007-0293172 A1 (JUN SHI et al.) 20 December 2007<br>See paragraphs [0017]-[0030]; claim 8; and figures 2-4.                                                                                    | 1-30                  |
| Y         | US 2013-0301562 A1 (MEDIATEK, INC.) 14 November 2013<br>See paragraphs [0033], [0035]; and figure 3.                                                                                               | 4, 5, 25              |
| Y         | US 2012-0002740 A1 (SEUNG HEE HAN et al.) 5 January 2012<br>See paragraphs [0019], [0069]-[0095]; and figures 7-18.                                                                                | 8-10, 14, 21, 22, 28  |
| Y         | ALCATEL-LUCENT SHANGHAI BELL et al., 'Proposal for Beamformed CSI-RS based 3D MIMO Transmission Scheme', R1-153814, 3GPP TSG RAN WG1 Meeting #82, Beijing, China, 15 August 2015<br>See section 2. | 13                    |



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents:

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**INTERNATIONAL SEARCH REPORT**

Information on patent family members

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