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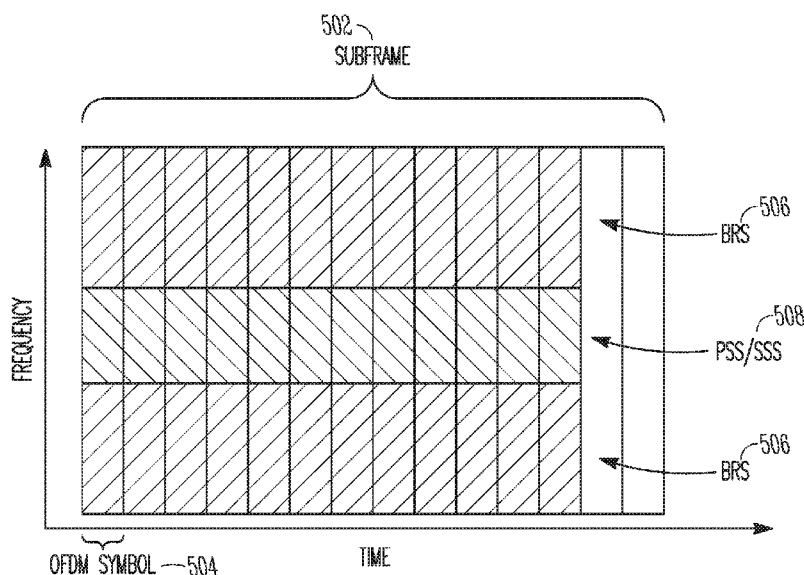


FIG. 5

(57) Abstract: Devices and methods of providing a cell search-related resource mapping structure are generally described. The UE selects one of multiple simultaneous MIMO beams. Each beam contains a PSS, BRS and xPBCH and may contain an SSS. The signals are FDM mapped in a symbol in a subframe such that the BRS is adjacent to and surrounds the PSS or PSS/SSS. The information in the signals enables the UE to acquire timing and cell ID information and confirm at least some of the information using the xPBCH before communicating with the eNB.



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DEVICES AND METHODS FOR INITIAL ACCESS IN MASSIVE MIMO
SYSTEM

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PRIORITY CLAIM

[0001] This application is a continuation of and claims priority under 35
U.S.C. §120 to International Application No. PCT/CN2015/098393, filed
December 23, 2015, and entitled "INITIAL ACCESS SIGNAL STRUCTURE
10 IN MASSIVE MIMO SYSTEM," which is incorporated herein by reference in
its entirety.

TECHNICAL FIELD

[0002] Embodiments pertain to Multiple Input Multiple Output (MIMO)
15 communication in cellular networks. Some embodiments relate to initial access
in MIMO communication in cellular and wireless local area network (WLAN)
networks, including Third Generation Partnership Project Long Term Evolution
(3GPP LTE) networks and LTE advanced (LTE-A) networks as well as 4th
generation (4G) networks and 5th generation (5G) networks.

20

BACKGROUND

[0003] With the ever-increasing demand for bandwidth, system operators
have turned to Multiple Input Multiple Output (MIMO) systems to increase the
amount of data simultaneously delivered. MIMO uses multipath signal
25 propagation to communicate with a user equipment (UE) via multiple signals on
the same or on overlapping frequencies that would interfere with each other if
they were on the same path. This increase in uplink or downlink data may be
dedicated to one UE, increasing the effective bandwidth for that UE by the
number of spatial streams (Single User MIMO or SU-MIMO) or may be spread
30 across multiple UEs using different spatial streams for each UE (Multiple User
MIMO or MU-MIMO). MU-MIMO systems may use beamforming, in which
multiple signals may be transmitted in parallel in different directions. UEs may

acquire system information through different mechanisms, which is becoming increasingly complicated with the new generation (5G) LTE system when multiple beams of a MIMO are used.

5 **BRIEF DESCRIPTION OF THE FIGURES**

[0004] In the figures, which are not necessarily drawn to scale, like numerals may describe similar components in different views. Like numerals having different letter suffixes may represent different instances of similar components. The figures illustrate generally, by way of example, but not by way
10 of limitation, various embodiments discussed in the present document.

[0005] FIG. 1 is a functional diagram of a wireless network in accordance with some embodiments.

[0006] FIG. 2 illustrates components of a communication device in accordance with some embodiments.

15 [0007] FIG. 3 illustrates a block diagram of a communication device in accordance with some embodiments.

[0008] FIG. 4 illustrates another block diagram of a communication device in accordance with some embodiments.

[0009] FIG. 5 illustrates a resource mapping structure in accordance with
20 some embodiments.

[0010] FIG. 6 illustrates a mapping structure for a Primary Synchronization Signal (PSS) and Secondary Synchronization Signal (SSS) in accordance with some embodiments.

[0011] FIG. 7 illustrates generation of a 5G Physical Broadcast Channel
25 (xPBCH) in accordance with some embodiments.

DETAILED DESCRIPTION

[0012] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other
30 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.

[0013] FIG. 1 shows an example of a portion of an end-to-end network architecture of a Long Term Evolution (LTE) network with various components of the network in accordance with some embodiments. As used herein, an LTE network refers to both LTE and LTE Advanced (LTE-A) networks as well as other versions of LTE networks to be developed. The network 100 may comprise a radio access network (RAN) (e.g., as depicted, the evolved universal terrestrial radio access network (E-UTRAN) 101 and core network 120 (e.g., shown as an evolved packet core (EPC)) coupled together through an S1 interface 115. For convenience and brevity, only a portion of the core network 120, as well as the RAN 101, is shown in the example.

[0014] The core network 120 may include a mobility management entity (MME) 122, serving gateway (serving GW) 124, and packet data network gateway (PDN GW) 126. The RAN 101 may include evolved node Bs (eNBs) 104 (which may operate as base stations) for communicating with user equipment (UE) 102. The eNBs 104 may include macro eNBs 104a and low power (LP) eNBs 104b. The eNBs 104 and UEs 102 may employ the synchronization techniques as described herein.

[0015] The MME 122 may be similar in function to the control plane of legacy Serving GPRS Support Nodes (SGSN). The MME 122 may manage mobility aspects in access such as gateway selection and tracking area list management. The serving GW 124 may terminate the interface toward the RAN 101, and route data packets between the RAN 101 and the core network 120. In addition, the serving GW 124 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 intercept, charging, and some policy enforcement. The serving GW 124 may serve as the local mobility anchor for data bearers when a UE 102 moves between eNBs 104. The serving GW 124 may retain information about the bearers when the UE 102 is in idle state

(known as ECM_IDLE) and temporarily buffer downlink data while the MME 122 initiates paging of the UE 102 to re-establish the bearers.

[0016] The serving GW 124 and the MME 122 may be implemented in one physical node or separate physical nodes. The MME 122 may be connected
5 with a Home Subscriber Server (HSS) 128 that contains user-related and subscription-related information. The HSS 128 may support mobility management, call and session establishment support, user authentication and access authorization. The protocols running between the UE 102 and the EPC 124 are known as the Non-Access Stratum (NAS) protocol. Other protocols,
10 including RRC, Packet Data Convergence Protocol (PDCP), Radio Layer Control (RLC), Media Access Control (MAC) and Physical Layer (PHY), are terminated in the eNB 104. The NAS layer performs EPS bearer management, authentication for LTE, mobility support for idle mode UEs, paging origination for idle mode UEs, and security handling.

[0017] The RRC layer may provide radio resource management, RRC connection management, and mobility support for connected mode UEs 102. As the RRC control message between the eNB 104 and the UE 102, the RRC layer may handle the broadcast of system information, which is cell-specific, and a dedicated RRC control message, which is UE-specific. In addition, the RRC
20 layer may perform paging, radio bearer control, and control of UE measurement reporting, among others. The PDCP layer may process RRC messages in the control plane and IP packets in the user plane. Depending on the radio bearer, the PDCP layer may perform header compression, security (integrity protection and ciphering), and support for reordering and retransmission during handover.
25 There may be one PDCP entity per radio bearer. The RLC layer may provide segmentation and reassembly of upper layer packets to adapt the packets to a size that can actually be transmitted over the radio interface. For a radio bearer using error-free transmission, the RLC layer may also perform retransmission to recover from packet losses. Additionally, the RLC layer may perform
30 reordering to compensate for out-of-order reception due to HARQ (Hybrid Automatic Repeat reQuest) operation in the layer below. There may be one

RLC entity per radio bearer. The MAC layer may multiplex the data from different radio bearers. By deciding the amount of data that can be transmitted from each radio bearer and instructing the RLC layer as to the size of packets to provide, the MAC layer aims to achieve the negotiated QoS (Quality of Service) for each radio bearer. For the uplink, this process may include reporting to the eNB 104 the amount of buffered data for transmission. The PHY layer may perform CRC insertion, channel coding, physical channel HARQ processing, channel interleaving, scrambling, modulation, layer mapping and pre-coding for transport channels. Power control and cell search procedures are also performed as the PHY functions.

[0018] The PDN GW 126 may terminate a SGi interface toward the packet data network (PDN). The PDN GW 126 may route data packets between the EPC 120 and the external PDN, and may perform policy enforcement and charging data collection. The PDN GW 126 may be responsible for IP address allocation for the UEs 102, as well as QoS enforcement and flow-based charging according to the rules from the PCRF (Policy and Charging Rules Functions). The PDN GW 126 may also provide an anchor point for mobility devices with non-LTE access. 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 a single physical node or separate physical nodes.

[0019] The eNBs 104 (macro and micro) may terminate the air interface 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 101 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 accordance with embodiments, UEs 102 may be configured to communicate orthogonal frequency division multiplexed (OFDM) communication signals with an eNB 104 over a multicarrier communication channel in accordance with an

OFDMA communication technique. The OFDM signals may comprise a plurality of orthogonal subcarriers.

[0020] The S1 interface 115 may be the interface that separates the RAN 101 and the EPC 120. It may be split into two parts: the S1-U, which may carry
5 traffic data between the eNBs 104 and the serving GW 124, and the S1-MME, which may be a signaling interface between the eNBs 104 and the MME 122. The X2 interface may be the interface between eNBs 104. The X2 interface may comprise two parts, the X2-C and X2-U. The X2-C may be the control plane interface between the eNBs 104, while the X2-U may be the user plane interface
10 between the eNBs 104.

[0021] With cellular networks, LP cells 104b may be typically used to extend coverage to indoor areas where outdoor signals do not reach well, or to add network capacity in areas with dense usage. In particular, it may be desirable to enhance the coverage of a wireless communication system using
15 cells of different sizes, macrocells, microcells, picocells, and femtocells, to boost system performance. The cells of different sizes may operate on the same frequency band, or may operate on different frequency bands with each cell operating in a different frequency band or only cells of different sizes operating on different frequency bands. As used herein, the term LP eNB refers to any
20 suitable relatively LP eNB for implementing a smaller cell (smaller than a macro cell) such as a femtocell, a picocell, or a microcell. Femtocell eNBs may be typically provided by a mobile network operator to its residential or enterprise customers. A femtocell may be typically the size of a residential gateway or smaller and generally connect to a broadband line. The femtocell may connect
25 to the mobile operator's mobile network and provide extra coverage in a range of typically 30 to 50 meters. Thus, a LP eNB 104b might be a femtocell eNB since it is coupled through the PDN GW 126. Similarly, a picocell may be 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
30 picocell eNB may 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 may be coupled to a macro eNB 104a via an X2 interface. Picocell eNBs or other LP eNBs LP eNB 104b may incorporate some or all functionality of a macro eNB LP eNB 104a. In some cases, this may be referred to as an access point base station or enterprise femtocell.

[0022] Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. FIG. 2 illustrates components of a UE in accordance with some embodiments. At least some of the components shown may be used in an eNB or MME, for example, such as the UE 102 or eNB 104 shown in FIG. 1. The UE 200 and other components may be configured to use the synchronization signals as described herein. The UE 200 may be one of the UEs 102 shown in FIG. 1 and may be a stationary, non-mobile device or may be a mobile device. In some embodiments, the UE 200 may include application circuitry 202, baseband circuitry 204, Radio Frequency (RF) circuitry 206, front-end module (FEM) circuitry 208 and one or more antennas 210, coupled together at least as shown. At least some of the baseband circuitry 204, RF circuitry 206, and FEM circuitry 208 may form a transceiver. In some embodiments, other network elements, such as the eNB may contain some or all of the components shown in FIG. 2. Other of the network elements, such as the MME, may contain an interface, such as the S1 interface, to communicate with the eNB over a wired connection regarding the UE.

[0023] The application or processing circuitry 202 may include one or more application processors. For example, the application circuitry 202 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.

[0024] The baseband circuitry 204 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 204 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 206 and to generate baseband signals for a transmit signal path of the RF circuitry 206. Baseband processing circuitry 204 may interface with the application circuitry 202 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 206. For example, in some embodiments, the baseband circuitry 204 may include a second generation (2G) baseband processor 204a, third generation (3G) baseband processor 204b, fourth generation (4G) baseband processor 204c, and/or other baseband processor(s) 204d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 204 (e.g., one or more of baseband processors 204a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 206. 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 204 may include FFT, precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 204 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.

[0025] In some embodiments, the baseband circuitry 204 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) 204e of the baseband circuitry 204 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) 204f. The audio DSP(s) 204f 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 204 and the application circuitry 202 may be implemented together such as, for example, on a system on a chip (SOC).

[0026] In some embodiments, the baseband circuitry 204 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 204 may support communication with an evolved universal terrestrial radio access network (E-UTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 204 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry. In some embodiments, the device can be configured to operate in accordance with communication standards or other protocols or standards, including Institute of Electrical and Electronic Engineers (IEEE) 802.16 wireless technology (WiMax), IEEE 802.11 wireless technology (WiFi) including IEEE 802.11 ad, which operates in the 60 GHz millimeter wave spectrum, various other wireless technologies such as global system for mobile communications (GSM), enhanced data rates for GSM evolution (EDGE), GSM EDGE radio access network (GERAN), universal mobile telecommunications system (UMTS), UMTS terrestrial radio access network (UTRAN), or other 2G, 3G, 4G, 5G, etc. technologies either already developed or to be developed.

[0027] RF circuitry 206 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 206 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network.

5 RF circuitry 206 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 208 and provide baseband signals to the baseband circuitry 204. RF circuitry 206 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 204 and provide RF output
10 signals to the FEM circuitry 208 for transmission.

[0028] In some embodiments, the RF circuitry 206 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 206 may include mixer circuitry 206a, amplifier circuitry 206b and filter circuitry 206c. The transmit signal path of the RF circuitry 206 may include
15 filter circuitry 206c and mixer circuitry 206a. RF circuitry 206 may also include synthesizer circuitry 206d for synthesizing a frequency for use by the mixer circuitry 206a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 206a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 208
20 based on the synthesized frequency provided by synthesizer circuitry 206d. The amplifier circuitry 206b may be configured to amplify the down-converted signals and the filter circuitry 206c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be
25 provided to the baseband circuitry 204 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 206a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

30 [0029] In some embodiments, the mixer circuitry 206a of the transmit signal path may be configured to up-convert input baseband signals based on the

synthesized frequency provided by the synthesizer circuitry 206d to generate RF output signals for the FEM circuitry 208. The baseband signals may be provided by the baseband circuitry 204 and may be filtered by filter circuitry 206c. The filter circuitry 206c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

[0030] In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and/or upconversion respectively. In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a 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 206a of the receive signal path and the mixer circuitry 206a may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a of the transmit signal path may be configured for super-heterodyne operation.

[0031] 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 206 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 204 may include a digital baseband interface to communicate with the RF circuitry 206.

[0032] 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.

[0033] In some embodiments, the synthesizer circuitry 206d 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 206d may be a

delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[0034] The synthesizer circuitry 206d may be configured to synthesize an output frequency for use by the mixer circuitry 206a of the RF circuitry 206 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 206d may be a fractional $N/N+1$ synthesizer.

[0035] 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 204 or the applications processor 202 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 202.

[0036] Synthesizer circuitry 206d of the RF circuitry 206 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or $N+1$ (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into N_d equal packets of phase, where N_d is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

[0037] In some embodiments, synthesizer circuitry 206d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency may be a LO frequency

(f_{LO}). In some embodiments, the RF circuitry 206 may include an IQ/polar converter.

[0038] FEM circuitry 208 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 210, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 206 for further processing. FEM circuitry 208 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 206 for transmission by one or more of the one or more antennas 210.

10 [0039] In some embodiments, the FEM circuitry 208 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 206). The transmit signal path of the FEM circuitry 208 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 206), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 210).

20 [0040] In some embodiments, the UE 200 may include additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface as described in more detail below. In some embodiments, the UE 200 described herein may be part of 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 wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, 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, 25 the UE 200 may include one or more user interfaces designed to enable user interaction with the system and/or peripheral component interfaces designed to

enable peripheral component interaction with the system. For example, the UE 200 may include one or more of a keyboard, a keypad, a touchpad, a display, a sensor, a non-volatile memory port, a universal serial bus (USB) port, an audio jack, a power supply interface, one or more antennas, a graphics processor, an application processor, a speaker, a microphone, and other I/O components. The display may be an LCD or LED screen including a touch screen. The sensor may include a gyro sensor, an accelerometer, a proximity sensor, an ambient light sensor, and a positioning unit. The positioning unit may communicate with components of a positioning network, e.g., a global positioning system (GPS) satellite.

[0041] The antennas 210 may comprise one or more 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 210 may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result.

[0042] Although the UE 200 is illustrated as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, 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.

[0043] 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-
5 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.

[0044] FIG. 3 is a block diagram of a communication device in

10 accordance with some embodiments. The device may be a UE or eNB, for example, such as the UE 102 or eNB 104 shown in FIG. 1 that may be configured to track the UE as described herein. 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.
15 The communication device 300 may also include medium access control layer (MAC) circuitry 304 for controlling access to the wireless medium. The communication device 300 may also include processing circuitry 306, such as one or more single-core or multi-core processors, and memory 308 arranged to perform the operations described herein. The physical layer circuitry 302, MAC
20 circuitry 304 and processing circuitry 306 may handle various radio control functions that enable communication with one or more radio networks compatible with one or more radio technologies and, for example, may contain an LTE stack. The radio control functions may include signal modulation, encoding, decoding, radio frequency shifting, etc. For example, similar to the
25 device shown in FIG. 2, in some embodiments, communication may be enabled with one or more of a WMAN, a WLAN, and a WPAN. In some embodiments, the communication device 300 can be configured to operate in accordance with 3GPP standards or other protocols or standards, including WiMax, WiFi, WiGig, GSM, EDGE, GERAN, UMTS, UTRAN, or other 3G, 3G, 4G, 5G, etc.
30 technologies either already developed or to be developed. The communication device 300 may include transceiver circuitry 312 to enable communication with

other external devices wirelessly and interfaces 314 to enable wired communication with other external devices. As another example, the transceiver circuitry 312 may perform various transmission and reception functions such as conversion of signals between a baseband range and a Radio Frequency (RF) range.

[0045] The antennas 301 may comprise one or more 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 MIMO embodiments, the antennas 301 may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result.

[0046] Although the communication device 300 is illustrated as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including DSPs, and/or other hardware elements. For example, some elements may comprise one or more microprocessors, DSPs, FPGAs, ASICs, 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. 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.

[0047] FIG. 4 illustrates another block diagram of a communication device in accordance with some embodiments. In alternative embodiments, the communication device 400 may operate as a standalone device or may be connected (e.g., networked) to other communication devices. In a networked deployment, the communication device 400 may operate in the capacity of a server communication device, a client communication device, or both in server-client network environments. In an example, the communication device 400

may act as a peer communication device in peer-to-peer (P2P) (or other distributed) network environment. The communication device 400 may be a UE, eNB, PC, a tablet PC, a STB, a PDA, a mobile telephone, a smart phone, a web appliance, a network router, switch or bridge, or any communication device
5 capable of executing instructions (sequential or otherwise) that specify actions to be taken by that communication device. Further, while only a single communication device is illustrated, the term "communication device" shall also be taken to include any collection of communication devices that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more
10 of the methodologies discussed herein, such as cloud computing, software as a service (SaaS), other computer cluster configurations.

[0048] 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
15 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
20 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 communication device readable medium. In an example, the software, when executed by the underlying hardware of the module, causes the hardware to perform the specified operations.

25 [0049] 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
30 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.

[0050] Communication device (e.g., computer system) 400 may include a hardware processor 402 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 404 and a static memory 406, some or all of which may communicate with each other via an interlink (e.g., bus) 408. The communication device 400 may further include a display unit 410, an alphanumeric input device 412 (e.g., a keyboard), and a user interface (UI) navigation device 414 (e.g., a mouse). In an example, the display unit 410, input device 412 and UI navigation device 414 may be a touch screen display. The communication device 400 may additionally include a storage device (e.g., drive unit) 416, a signal generation device 418 (e.g., a speaker), a network interface device 420, and one or more sensors 421, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The communication device 400 may include an output controller 428, 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.).

[0051] The storage device 416 may include a communication device readable medium 422 on which is stored one or more sets of data structures or instructions 424 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 424 may also reside, completely or at least partially, within the main memory 404, within static memory 406, or within the hardware processor 402 during execution thereof by the communication device 400. In an example, one or any combination of the hardware processor 402, the main memory 404, the static memory 406, or the storage device 416 may constitute communication device readable media.

[0052] While the communication device readable medium 422 is illustrated as a single medium, the term "communication device 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 424.

[0053] The term "communication device readable medium" may include any medium that is capable of storing, encoding, or carrying instructions for execution by the communication device 400 and that cause the communication device 400 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 communication device readable medium examples may include solid-state memories, and optical and magnetic media. Specific examples of communication device readable media may include: 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 disks. In some examples, communication device readable media may include non-transitory communication device readable media. In some examples, communication device readable media may include communication device readable media that is not a transitory propagating signal.

[0054] The instructions 424 may further be transmitted or received over a communications network 426 using a transmission medium via the network interface device 420 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 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 System (UMTS) family of standards, peer-to-peer (P2P) networks, among
5 others. In an example, the network interface device 420 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 426. In an example, the network interface device 420 may include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), MIMO,
10 or multiple-input single-output (MISO) techniques. In some examples, the network interface device 420 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 communication device 400, and includes digital
15 or analog communications signals or other intangible medium to facilitate communication of such software.

[0055] As above, due to the complexity of the next generation of LTE systems (5G), it would be desirable for a number of issues to be resolved before deployment. One of these issues may arise from the acquisition of cell
20 information by a UE. Before the UE of any of FIGS. 1-4 is able to communicate with the eNB, the UE may perform cell search to obtain the cell information and cell selection using the cell information. Each cell in an LTE system may be identified by a physical layer cell identity (ID). There are 504 possible physical layer cell IDs available in LTE. The physical layer cell IDs are divided into 168
25 unique cell ID groups ($NID^{(1)}$), and each group has 3 cell IDs ($NID^{(2)}$). To perform cell search and selection, the UE may obtain information regarding specific physical signals and downlink channels, to acquire the physical layer cell ID and communicate with the eNB.

[0056] Specifically, the UE may acquire the timing and cell ID
30 information using the Primary Synchronization Signal (PSS) and the Secondary Synchronization Signal (SSS) and a MIMO reference signal (called a Beam

Reference Signal (BRS)) in the same subframe. The PSS may be constructed from a frequency-domain Zadoff-Chu sequence of length 63. The PSS may be used by the UE for slot timing detection and to determine which of the 3 cell IDs is used by the eNB. The SSS may then be used by the UE to determine the radio
 5 frame timing and obtain the cell ID group, as well as the cyclic prefix length (symbol boundary acquisition). The physical layer cell ID can then be obtained by using a combination of the cell ID and the cell ID group, $NID_{cell} = 3NID^{(1)} + NID^{(2)}$.

[0057] In some embodiments, the PSS and SSS may be multiplexed using frequency division multiplexing (FDM). In particular, the PSS and SSS
 10 may be multiplexed at the first 12 OFDM symbols of one subframe, with the SSS adjacent to the PSS. The SSS may be an interleaved concatenation of two length-31 binary sequences (BPSK-modulated secondary synchronization codes). To randomize the interference from the neighboring cells, the
 15 concatenated sequence may be scrambled with a scrambling sequence given by the PSS. In one example, the SSS may be transmitted in subframe 0 and 25. The combination of two length-31 sequences defining the SSS may differ between the subframe 0 and subframe 25 according to:

$$d(2n) = \begin{cases} s_0^{(m_0)}(n)c_0(n) & \text{in subframe 0} \\ s_1^{(m_1)}(n)c_0(n) & \text{in subframe 25} \end{cases}$$

$$20 \quad d(2n+1) = \begin{cases} s_1^{(m_1)}(n)c_1(n)z_1^{(m_0)}(n) & \text{in subframe 0} \\ s_0^{(m_0)}(n)c_1(n)z_1^{(m_1)}(n) & \text{in subframe 25} \end{cases}$$

[0058] where $s(n)$ is the SSS sequence, $c(n)$ and $z(n)$ are the scrambling sequence, and the indices m_0 and m_1 are derived from cell ID group $N_{ID}^{(1)}$.

[0059] FIG. 5 illustrates a resource mapping structure in accordance with some embodiments. The resource mapping structure shows a single subframe 502 that includes PSS/SSS 508 in a majority of the OFDM symbols 504 in the center of the frequency band. The frequency band may be all subcarriers able to be allocated by the eNB. The subframe 502 may also contain a Beam Reference Signal (BRS) 506, described in more detail below. As shown, the PSS/SSS 508 and BRS 506 each cover adjacent symbols in each subcarrier and are spread across a plurality of subcarriers in a particular symbol position. In some embodiments, the final two OFDM symbols 504 in the subframe 502 may be reserved as a guard period to ensure sufficient isolation between uplink and downlink transmissions. This permits a UE to be able to acquire cell information as the cell information carried by the PSS/SSS 508 and BRS 506 is in a known set of resource blocks (as the PSS/SSS 508 and BRS 506 also appear periodically in time at a known timing).

[0060] In addition to obtaining the system information from multiple signals (the PSS, SSS and xPBCH), the UE may determine information particular to MIMO systems for network communication. In a MIMO system, the eNB may transmit these and other signals using a plurality of beams. Each beam may be transmitted using a different antenna panel of the eNB and, unlike the PSS and SSS, may have a different BRS, such as the BRS 506 shown in FIG. 5. BRSs may be transmitted by the eNB in each beam for power measurement by the UEs serviced by the eNB and beam selection by the UEs. The structure of the BRS 506 may be increasingly complicated for massive MIMO systems (e.g., containing 64-128 or more antennas). The BRS sequence, as well as the location, may differ from beam to beam, subframe to subframe or, as below, symbol to symbol, for example. The BRS sequence, like the SSS, may be composed of a binary phase shifting key (BPSK)-modulated base sequence. The UE may select a particular beam and acquire timing and cell ID information using that beam. In some embodiments, the UE may use multiple beams to acquire the timing and cell ID information. The BRS may have a BRS ID as well as be a member of a group of BRSs and thus have a BRS group ID.

[0061] As above, the PSS/SSS 508 may be used for cell ID and symbol boundary acquisition, while the BRS 506 may be used to carry the symbol index and transmit beam information (based on the BRS sequence). In some embodiments, the PSS/SSS 508 and BRS 506 may be mapped in a FDM manner. In this case, the PSS and SSS 508 may occupy the central resource blocks of the frequency band $N_{RB}^{PSS} + N_{RB}^{SSS}$ as shown in FIG. 5, with the BRS 506 mapped to the other N_{RB}^{BRS} resource blocks in the subframe 502. In some embodiments, the PSS 508 may occupy the central resource blocks of the frequency band, with the SSS 508 on at least one side of the PSS 508 and/or the BRS 506 surrounding the PSS 508 (and SSS if present). The number of resource blocks N_{RB}^{PSS} and N_{RB}^{SSS} may be predefined by the system, and N_{RB}^{BRS} may be predefined by the system or configured by higher layer (RRC) signaling. Unlike some embodiments, in which the PSS and SSS may be located in only certain symbols and in certain subframes, the PSS and SSS 508 in FIG. 5 may be repeatedly transmitted in each OFDM symbol 504 in the subframe 502 (other than the guard symbols, if any). In some embodiments, the BRS sequence may be determined by the symbol index. The BRS 506 may, as shown in the embodiment of FIG. 5, be disposed in the subcarriers and resource blocks surrounding the PSS and SSS 508. Multiple beams may be aggregated to provide the PSS and SSS 508 and BRS 506 in one symbol 504. Different beams may thus be applied to form different symbols 504 for all reference signals.

[0062] Although the PSS and SSS are shown in FIG. 5 as disposed in the center resource blocks of the subframe, the PSS and SSS may be in different resource blocks within this location. FIG. 6 illustrates a mapping structure for PSS and SSS in accordance with some embodiments. As shown in FIG. 6, the PSS 602 and the SSS 604 may be located in different resource blocks. As above, the PSS 602 may occupy N_{RB}^{PSS} resource blocks and the SSS 604 may occupy N_{RB}^{SSS} resource blocks, where the number of resource blocks for each of the PSS 602 and the SSS 604 may be the same (such as 6) or may be

different. In either case, the number of resource blocks may be defined by the system and thus may not change from eNB to eNB.

- [0063] As shown in FIG. 6, while the PSS 602 may remain disposed in the center resource blocks of the symbol, the SSS 604 may be disposed in alternate locations adjacent to the PSS 602. Specifically, FIG. 6 illustrates three options for mapping of the PSS 602 and the SSS 604 within a symbol. In a first option, the SSS 604 is disposed in resource blocks above (i.e., at a higher frequency than) the resource blocks of the PSS 602. In a second option, the SSS 604 is disposed in resource blocks below (i.e., at a lower frequency than) the resource blocks of the PSS 602. In a third option, the SSS 604 is disposed in resource blocks surrounding the resource blocks of the PSS 602. In some embodiments, the SSS 604 may be divided equally such that the resource blocks of the SSS 604 symmetrically surround the PSS 602. In some embodiments, the SSS 604 may be divided unequally such that one of the resource blocks of the SSS 604 surrounding the PSS 602 is larger than the other of the resource blocks of the SSS 604. The larger resource block may be disposed either in higher frequency subcarriers or lower frequency subcarriers than the PSS 602. In each of the various options however, the resource blocks of the SSS 604 may remain adjacent to the resource blocks of the PSS 602.
- [0064] In some embodiments, a BRS sequence may be mapped to the resource element (k,l) by:

$$\alpha_{k,l} = d^l(n), n = -5, -4, \dots, 65, 66$$

$$k = n - 31 + \frac{N_{RB}^{DL} N_{SC}^{RB}}{2} + 72m + N_{SC}^{RB} x N_{SRS} x m_0$$

25

- [0065] where $d^l(n)$ may denote the BRS sequence in symbol l , which may be generated based on a BRS group ID $BGID$; N_{RB}^{DL} may indicate the number of total resource blocks in the downlink subframe; N_{SC}^{RB} may indicate

the number of subcarriers in one resource block; m can be determined by N_{BRS} the number of BRS resource block groups and may be configured by the eNB; N_{SRS} is the number of sounding reference signals; and m_0 can be determined by the cell ID or cell ID group index. As above, the total number n is 72 as the middle 72 subcarriers in the symbols that carry the PSS and SSS are reserved for the PSS and SSS. In one example, $m_0 = N_{ID}^{(1)} \bmod N_{BRS}^{shift,max}$, where $N_{BRS}^{shift,max}$ may be defined by the system or

$$N_{BRS}^{shift,max} = \left\lfloor N_{BRS}^{DL} / N_{BRS} \right\rfloor$$
 and N_{BRS}^{DL} may be the number of total BRS resource block groups in the subframe. In one embodiment, the SSS may not be transmitted, and $N_{ID}^{(1)}$ can be obtained by

$$N_{ID}^{(1)} = m_0 + BG_{ID} \times \left\lfloor N_{BRS}^{DL} / N_{BRS} \right\rfloor.$$
 In another embodiment, a SSS can be transmitted in which the SSS is generated based on a shortened ID N_{ID}^{SSS} , $N_{ID}^{SSS} \in [0, N_{ID}^{SSS,max} - 1]$, where $N_{ID}^{SSS,max}$ indicates the maximum number of SSS IDs and can be defined by the system. The cell ID group index can be obtained by:

$$N_{ID}^{(1)} = m_0 + BG_{ID} \times \left\lfloor N_{BRS}^{DL} / N_{BRS} \right\rfloor + N_{ID}^{SSS} \times N_{BRS}^{DL} \times \left\lfloor N_{BRS}^{DL} / N_{BRS} \right\rfloor$$

[0066] In some embodiments, the code space for the PSS, SSS, and BRS may be $N_{ID}^{PSS,max} \times N_{ID}^{SSS,max} \times N_{ID}^{BRS,max} \times N_{BRS}^{shift,max}$. In this case, $N_{ID}^{PSS,max}$ may indicate the maximum number of PSS IDs; $N_{ID}^{SSS,max}$ may denote the maximum number of SSS IDs; $N_{ID}^{BRS,max}$ may indicate the maximum number of BRS IDs; and $N_{BRS}^{shift,max}$ may represent the maximum frequency domain shift for the BRS.

[0067] The subframe index, symbol index, cell ID and number of BRS resource block groups, and other common configuration information, such as the number of consecutive OFDM symbols for one beam group can be determined by the UE through use of the PSS ID, SSS ID, BRS ID and BRS resource index in various combinations, dependent on the embodiment. For example, in some embodiments, the cell ID may be determined using the PSS ID and SSS ID; the subframe index may be determined using SSS ID; the symbol index may be determined using the BRS ID; and the number of BRS RBGs may be determined using the BRS resource index and BRS ID. In other embodiments, the cell ID may be determined using the PSS ID, BRS ID and SSS ID; the symbol index and subframe index may be determined by the UE using the SSS ID; the number of BRS RBGs may be determined by the UE using the BRS ID; and the number of consecutive OFDM symbols for one beam group may be determined by the UE using the BRS resource index. The UE may thus select a particular beam and acquire timing and cell ID information using the PSS, SSS and BRS associated with the beam.

[0068] After obtaining cell information using the PSS, SSS and BRS to synchronize to the cell, in a non-standalone eNB deployment, the UE may use the xPBCH in the same subframe to determine whether or not the cell search is correct. The xPBCH, PSS, BRS and SSS (if present) may be mapped in a frequency division multiplexing manner. The xPBCH may be mapped in consecutive FDM resource blocks adjacent to the FDM resource elements of the combination of the PSS, BRS and SSS. In some embodiments, the xPBCH may surround the combination of the PSS, BRS and SSS similar to the arrangement shown in option 3 of FIG. 6, while in other embodiments the xPBCH may be located on only one side (higher or lower frequency) than the combination of the PSS, BRS and SSS, similar to options 1 or 2 of FIG. 6.

[0069] In particular the UE may decode the xPBCH and extract information in the Master Information Block (MIB), using the associated reference signals to aid in the determination. The xPBCH may broadcast parameters for initial access of the cell. These parameters may include the beam

information, the most significant 8-bits of the System Frame Number (SFN) and/or downlink system bandwidth. However, for 5G systems. The xPBCH may occupy 6 resource blocks or 72 subcarriers of the first 4 OFDMA symbols of the second slot of every frame, less reference signal resource elements. The xPBCH may thus occupy about $(72 \times 4) - 48 = 240$ resource elements, or 480 bits when the xPBCH uses Quadrature Phase Shift Keying (QPSK) modulation. A xPBCH transmission may be spread over 4 frames (over subframe 0) to span a 40 ms period.

[0070] FIG. 7 illustrates generation of a 5G Physical Broadcast Channel (xPBCH) in accordance with some embodiments. The xPBCH may be used to carry common configuration information, which may be transmitted in the subframe where the PSS and SSS is enabled. In one example, the common configuration can contain number of total BRS resource block groups and the number of consecutive OFDM symbols in one beam group and/or system bandwidth. The cell search information may be carried by xPBCH signal generation – the manner in which the xPBCH may carry this information. This may permit the UE to determine whether or not the cell search is correct.

[0071] As shown in FIG. 7, a Cyclic Redundancy Code (CRC) 702 may be applied to the configuration information. The CRC sequence may be determined by the cell ID N_{ID}^{cell} or cell ID group index $N_{ID}^{(I)}$ or index within a cell ID group. In one example, the CRC sequence can be 8 bits and its value is equal to $N_{ID}^{(I)}$. In another example, the CRC sequence can be generated by a 16 bit or 24 bit sequence defined by the system and scrambled by the cell ID N_{ID}^{cell} or cell ID group index $N_{ID}^{(I)}$. The CRC may indicate the number of antennas used for transmission of the xPBCH.

[0072] After applying the CRC 702 to individual bits, a Tailed Biting Conventional Code (TBCC) 704 may be applied to blocks of bits for xPBCH channel coding to produce coded bits. The TBCC 704 may use QPSK and have a coding rate of 1/3. The coded bits may be transmitted in K consecutive

xPBCH subframes, where K can be pre-defined by the system. In one example, K can be 8 and the xPBCH can be transmitted every 25 subframes.

[0073] The coded bits may be scrambled at a scrambler 706 to produce scrambled bits. The scrambling may be based on a pseudorandom sequence
 5 initialized using at least some of the cell information obtained from the PSS/SSS and BRS. For example, the pseudorandom sequence may be initialized using the cell ID, the cell ID group index or index within a cell ID group. In some embodiments, the pseudorandom sequence may be initialized using the symbol index and/or subframe index in addition to or instead of the cell ID/index. In
 10 one embodiment, the pseudorandom sequence may be initialized with the cell ID or cell ID and symbol index.

[0074] The scrambled bits may then be modulated at a modulator 708. In some embodiments, the modulator 708 may use QPSK to modulate the scrambled bits and produce xPBCH bits.

15 [0075] After the scrambled bits are modulated, the modulated signal may be mapped at a resource mapper 710. In some embodiments, similar to the PSS/SSS resource block arrangement described above, the xPBCH bits may be mapped by the resource mapper 710 to the N_{RB}^{xPBCH} resource blocks surrounding the PSS and SSS. In other embodiments, the xPBCH bits may be
 20 mapped by the resource mapper 710 to consecutive resource blocks above or below the PSS and SSS resource blocks. N_{RB}^{xPBCH} can be defined by the system. For example, N_{RB}^{xPBCH} can be 4.

[0076] A Demodulation Reference Signal (DMRS) may be associated with the xPBCH. The DMRS may facilitate coherent demodulation at the eNB.
 25 The DMRS may be associated with transmission of xPBCH. The DMRS may be generated based on a pseudorandom sequence initialized using one or more of the same variations provided with regard to the CRC, such as the cell ID, subframe number, SFN, symbol index or slot index. The resource mapping of the DMRS may be determined by the index in cell ID group $N_{ID}^{(1)}$. In some
 30 embodiment, the resource mapping subcarrier offset sequence of the DMRS

associated with the xPBCH may be determined by the same variations as above – e.g., the cell ID, cell ID group index or index within a cell ID group, and/or symbol index and/or subframe index.

[0077] In some embodiments, to perform a cell search procedure the UE
5 may first check for power levels of different LTE bands to select one with an acceptable power level. The UE may then perform a cyclic prefix correlation to obtain the symbol boundary. After a cyclic prefix correlation peak has been found, the UE may search for the PSS, SSS and BRS to obtain the cell ID and timing information. The information may be extracted or otherwise derived,
10 including $N_{ID}^{(1)}$, $N_{ID}^{(2)}$, the physical layer cell ID, the duplexing mode (TDD or FDD), the slot boundary and the subframe number, subframe index, symbol index, number of BRS resource block groups, and the number of consecutive OFDM symbols for one beam group. The UE may next decode the MIB information transmitted on the xPBCH. The xPBCH may provide system frame
15 number, beam information and the number of transmit antennas used by the eNB. The xPBCH may also provide at least some duplicate information such as the number of BRS resource block groups, the number of consecutive OFDM symbols in one beam group, and/or the system bandwidth. The PSS/SSS, BRS and PBCH are always mapped to the center of the bandwidth, hence the UE can
20 decode these, even without knowing the system bandwidth. After determining the information, the UE may be able to decode other control and data channels and the SIB information, which is transmitted on the PDSCH with a corresponding PDCCH scrambled with a predetermined SI-RNTI value using the number of control symbols in the current subframe, obtained from decoding
25 the PCFICH. The PDCCH may provide the SIB scheduling information within the subframe, modulation scheme, resource allocation type for the SIB, the redundancy version, a new data indicator and HARQ process number, among others. The UE may subsequently perform a channel estimation/equalization on the PDSCH complex symbols. The SIB1 message is then decoded to obtain the
30 scheduling of other SIB messages, which may provide additional network

information, such as PUCCH formats, PLMN ID and others. The UE may then initiate an Initial Attach procedure with the eNB.

[0078] Example 1 is an apparatus of user equipment (UE) comprising: a transceiver configured to communicate with an evolved Node-B (eNB); and
5 processing circuitry arranged to: configure the transceiver to receive a particular beam from a plurality of simultaneous beams transmitted by an eNB using multiple input multiple output (MIMO), each beam comprising a Primary Synchronization Signal (PSS) and a Beam Reference Signal (BRS) Frequency Domain Multiplexing (FDM) mapped across a plurality of subcarriers in a
10 symbol position in a subframe; in response to the received beam further comprising a Secondary Synchronization Signal (SSS), acquire timing and cell identification (ID) information through the PSS, the SSS and the BRS, the PSS, the SSS and BRS FDM mapped in the plurality of subcarriers in the symbol position in the subframe, and otherwise acquire the timing and cell ID
15 information through the PSS and the BRS; and communicate with the eNB based on the acquired timing and cell ID information.

[0079] In Example 2, the subject matter of Example 1 optionally includes that the processing circuitry is further arranged to: acquire timing and cell ID information by use of the PSS and SSS for cell ID and symbol boundary
20 acquisition, and the BRS for symbol index and beam information.

[0080] In Example 3, the subject matter of any one or more of Examples 1–2 optionally include that: the SSS is mapped in consecutive FDM resource blocks adjacent to the PSS, the PSS disposed in a set of FDM resource blocks in a center of a frequency band over which the eNB is able to communicate.

25 [0081] In Example 4, the subject matter of Example 3 optionally includes that: the BRS is mapped in consecutive FDM resource blocks surrounding the PSS and the SSS.

[0082] In Example 5, the subject matter of any one or more of Examples 1–4 optionally include that the processing circuitry is further arranged to:
30 determine a cell ID, a subframe index, a symbol index, a number of total BRS resource block groups and a number of consecutive OFDM symbols for a beam

group through use of at least one of a PSS ID, a SSS ID, a BRS ID and a BRS resource mapping offset.

[0083] In Example 6, the subject matter of Example 5 optionally includes that the processing circuitry is further arranged to: determine the cell ID through use of the PSS ID and one of: the BRS ID, and the BRS group ID and the BRS resource mapping offset, wherein the cell ID is determined free from use of SSS information independent of whether the cell ID is determined using either the BRS ID or the BRS group ID and the BRS resource mapping offset, and the SSS ID, a BRS group ID and the BRS resource mapping offset.

[0084] In Example 7, the subject matter of any one or more of Examples 5–6 optionally include that the processing circuitry is further arranged to: determine, free from use of PSS information, at least one of: the subframe index and the symbol index through use of one of the SSS ID and the BRS ID, the number of total BRS resource block groups through use of at least one of the SSS ID and BRS ID, and the number of consecutive OFDM symbols for one transmitting beam group through use of at least one of the SSS ID, the BRS ID and the BRS resource mapping offset.

[0085] In Example 8, the subject matter of any one or more of Examples 1–7 optionally include that the processing circuitry is further arranged to: configure the transceiver to receive a 5th generation (5G) Physical Broadcast Channel (xPBCH) in the subframe; decode the xPBCH to obtain a master information block (MIB); and confirm at least some of the timing and cell ID information using the xPBCH.

[0086] In Example 9, the subject matter of Example undefined optionally includes that: the xPBCH comprises configuration information comprising a number of BRS resource block groups and a number of consecutive OFDM symbols in one beam group.

[0087] In Example 10, the subject matter of Example 9 optionally includes that: a Cyclic Redundancy Code (CRC) of the configuration information comprises a CRC sequence determined through use of at least one of a cell ID NID_{cell} and a cell ID group index $NID(1)$.

[0088] In Example 11, the subject matter of any one or more of Examples 9–10 optionally include that: the configuration information is scrambled based on a pseudorandom sequence initialized with a cell ID or a cell ID and symbol index.

5 [0089] In Example 12, the subject matter of any one or more of Examples 8–11 optionally include that: the xPBCH is mapped in consecutive FDM resource blocks adjacent to resource blocks of a combination of the PSS, BRS and, when present, SSS.

[0090] In Example 13, the subject matter of any one or more of
10 Examples 8–12 optionally include that the processing circuitry is further arranged to: configure the transceiver to receive a Demodulation Reference Signal (DMRS) associated with the xPBCH, the DMRS generated based on a pseudorandom sequence initialized using one or more of a cell ID, a subframe number, a system frame number, a symbol index and slot index, and resource
15 mapping of the DMRS determined by a cell ID group index NID(1).

[0091] In Example 14, the subject matter of any one or more of Examples 1–13 optionally include, further comprising: an antenna configured to provide communications between the apparatus and the eNB.

[0092] Example 15 is an apparatus of an evolved NodeB (eNB)
20 comprising: a transceiver configured to communicate with a equipment (UE); and processing circuitry arranged to: generate a plurality of simultaneous beams using multiple input multiple output (MIMO), each beam comprising one of: a first combination comprising a Primary Synchronization Signal (PSS), a Beam Reference Signal (BRS) and a 5th generation (5G) Physical Broadcast Channel
25 (xPBCH) Frequency Domain Multiplexing (FDM) mapped through in a plurality of subcarriers in a symbol position in a subframe, and a second combination comprising the PSS, a Secondary Synchronization Signal (SSS), the BRS and the xPBCH FDM mapped in the plurality of subcarriers in the symbol position in the subframe, wherein each of the first and second combination comprises
30 information to enable acquisition of timing and cell identification (ID) and confirm at least some of the timing and cell ID information through the xPBCH;

and configure the transceiver to transmit the plurality of simultaneous beams to the UE; and in response to transmission of the plurality of simultaneous beams, receive communications from the UE based on timing and cell ID information provided by the plurality of simultaneous beams.

5 [0093] In Example 16, the subject matter of Example 15 optionally includes that: the PSS and SSS is configured to provide cell ID and symbol boundary acquisition, and the BRS is configured to provide symbol index and beam information.

[0094] In Example 17, the subject matter of any one or more of
10 Examples 15–16 optionally include that: a cell ID, a subframe index, a symbol index, a number of total BRS resource block groups and a number of consecutive OFDM symbols for a beam group are provided through use of at least one of a PSS ID, a SSS ID, a BRS ID and a BRS resource mapping offset, such that the cell ID is provided through the PSS ID and one of: one of: the BRS
15 ID, and the BRS group ID and the BRS resource mapping offset, wherein the cell ID is able to be determined free from SSS information independent of whether the cell ID is able to be determined through either the BRS ID or the BRS group ID and the BRS resource mapping offset, and the SSS ID, a BRS group ID and the BRS resource mapping offset.

20 [0095] In Example 18, the subject matter of any one or more of Examples 15–17 optionally include that: a cell ID, a subframe index, a symbol index, a number of total BRS resource block groups and a number of consecutive OFDM symbols for a beam group are provided through use of at least one of a PSS ID, a SSS ID, a BRS ID and a BRS resource mapping offset,
25 such that, free from use of PSS information, at least one of: the subframe index and the symbol index is able to be determined through one of the SSS ID and the BRS ID, the number of total BRS resource block groups is able to be determined through at least one of the SSS ID and BRS ID, and the number of consecutive OFDM symbols for one transmitting beam group is able to be determined
30 through at least one of the SSS ID, the BRS ID and the BRS resource mapping offset.

[0096] In Example 19, the subject matter of any one or more of Examples 15–18 optionally include that: each BRS sequence is mapped to a resource element (k,l) by: each BRS sequence is mapped to a resource element (k,l) by:

$$5 \quad \alpha_{k,l} = d^l(n), n = -5, -4, \dots, 65, 66$$

$$k = n - 31 + \frac{N_{RB}^{DL} N_{SC}^{RB}}{2} + 72m + N_{SC}^{RB} x N_{SRS} x m_0$$

[0097] where $d^l(n)$ is the BRS sequence in symbol l , generated based on a BRS group ID BG_{ID} , N_{RB}^{DL} is a number of resource blocks in the subframe;

10 N_{SC}^{RB} is a number of subcarriers in one resource block; N_{SRS} is a number of sounding reference signals; m is determined based on a number of BRS resource block groups N_{BRS} and is configured by the eNB; and m_0 is determined based on one of a cell ID and a cell ID group index.

[0098] In Example 20, the subject matter of Example 19 optionally

15 includes that: $m_0 = N_{ID}^{(1)} \bmod N_{BRS}^{shift,max}$, where $N_{BRS}^{shift,max} =$

$\left\lfloor N_{BRS}^{DL} / N_{BRS} \right\rfloor$ and N_{BRS}^{DL} is a total number of BRS resource block groups in the subframe.

[0099] In Example 21, the subject matter of Example 20 optionally

includes that: each beam is free from the SSS, and $N_{ID}^{(1)} = m_0 + BG_{ID}$

20 $x \left\lfloor N_{BRS}^{DL} / N_{BRS} \right\rfloor$.

[00100] In Example 22, the subject matter of any one or more of Examples 20–21 optionally include that: each beam comprises the SSS, the SSS is generated based on a shortened ID NID_{SSS} ,

$N_{ID}^{SSS} \in [0, N_{ID}^{SSS, max} - 1]$, where $N_{ID}^{SSS, max}$ is a maximum number of SSS IDs defined by the system, and a cell ID group index is:

$$N_{ID}^{(1)} = m_0 + BG_{ID} x \left\lfloor N_{BRS}^{DL} / N_{BRS} \right\rfloor + N_{ID}^{SSS} x N_{BRS}^{DL} \left\lfloor N_{BRS}^{DL} / N_{BRS} \right\rfloor.$$

[00101] In Example 23, the subject matter of any one or more of

- 5 Examples 15–22 optionally include that: the xPBCH comprises configuration information comprising a number of BRS resource block groups and a number of consecutive OFDM symbols in one beam group, and at least one of: a Cyclic Redundancy Code (CRC) of the configuration information comprises a CRC sequence determined through at least one of a cell ID N_{ID}^{cell} and a cell ID group index $N_{ID}^{(1)}$, the configuration information is scrambled based on a pseudorandom sequence initialized with a cell ID or a cell ID and symbol index, the transceiver is configured to transmit a Demodulation Reference Signal (DMRS) associated with the xPBCH, the DMRS generated based on a pseudorandom sequence initialized using one or more of a cell ID, a subframe number, a system frame number, a symbol index and slot index, and resource mapping of the DMRS determined by a cell ID group index $N_{ID}^{(1)}$.

- [00102] Example 24 is a computer-readable storage medium that stores instructions for execution by one or more processors of a user equipment (UE) to communicate with an evolved NodeB (eNB), the one or more processors to
- 20 configure the UE to: receive a particular beam from a plurality of simultaneous beams transmitted by the eNB using multiple input multiple output (MIMO), each beam comprising one of: a first combination comprising a Primary Synchronization Signal (PSS), a Beam Reference Signal (BRS) and a 5th generation (5G) Physical Broadcast Channel (xPBCH) Frequency Domain Multiplexing (FDM) mapped through in a plurality of subcarriers in a symbol position in a subframe such that the BRS is adjacent to and surrounds the PSS, and a second combination comprising the PSS, a Secondary Synchronization Signal (SSS), the BRS and the xPBCH FDM mapped in the plurality of
- 25

subcarriers in the symbol position in the subframe such that the BRS is adjacent to and surrounds the PSS and SSS, wherein each of the first and second combination comprises information to enable the UE to acquire timing and cell identification (ID) information and confirm at least some of the timing and cell ID information through the xPBCH; acquire the timing and cell ID information; and communicate with the eNB based on the acquired timing and cell ID information.

[00103] In Example 25, the subject matter of Example 24 optionally includes that: the PSS and SSS provide cell ID and symbol boundary acquisition, and the BRS provides symbol index and beam information, and a cell ID, a subframe index, a symbol index, a number of total BRS resource block groups and a number of consecutive OFDM symbols for a beam group are provided through use of at least one of a PSS ID, a SSS ID, a BRS ID and a BRS resource mapping offset.

[00104] In Example 26, the subject matter of any one or more of Examples 24–25 optionally include that: the xPBCH comprises configuration information comprising a number of BRS resource block groups and a number of consecutive OFDM symbols in one beam group, and at least one of: a Cyclic Redundancy Code (CRC) of the configuration information comprises a CRC sequence determined through at least one of a cell ID NID_{cell} and a cell ID group index NID(1), the configuration information is scrambled based on a pseudorandom sequence initialized with a cell ID or a cell ID and symbol index, the one or more processors further configure the UE to transmit a Demodulation Reference Signal (DMRS) associated with the xPBCH, the DMRS generated based on a pseudorandom sequence initialized using one or more of a cell ID, a subframe number, a system frame number, a symbol index and slot index, and resource mapping of the DMRS determined by a cell ID group index NID(1).

[00105] Example 27 is a user equipment (UE) comprising: means for receiving a particular beam from a plurality of simultaneous beams transmitted by an evolved NodeB (eNB) using multiple input multiple output (MIMO), each beam comprising one of: a first combination comprising a Primary

Synchronization Signal (PSS), a Beam Reference Signal (BRS) and a 5th generation (5G) Physical Broadcast Channel (xPBCH) Frequency Domain Multiplexing (FDM) mapped through in a plurality of subcarriers in a symbol position in a subframe such that the BRS is adjacent to and surrounds the PSS,
 5 and a second combination comprising the PSS, a Secondary Synchronization Signal (SSS), the BRS and the xPBCH FDM mapped in the plurality of subcarriers in the symbol position in the subframe such that the BRS is adjacent to and surrounds the PSS and SSS, wherein each of the first and second combination comprises information to enable the UE to acquire timing and cell
 10 identification (ID) information and confirm at least some of the timing and cell ID information through the xPBCH; means for acquiring the timing and cell ID information; and means for communicating with the eNB based on the acquired timing and cell ID information.

[00106] In Example 28, the subject matter of Example 27 optionally
 15 includes that the PSS and SSS provide cell ID and symbol boundary acquisition, and the BRS provides symbol index and beam information, and a cell ID, a subframe index, a symbol index, a number of total BRS resource block groups and a number of consecutive OFDM symbols for a beam group are provided through use of at least one of a PSS ID, a SSS ID, a BRS ID and a BRS resource
 20 mapping offset.

[00107] In Example 29, the subject matter of any one or more of Examples 27–28 optionally include that the xPBCH comprises configuration information comprising a number of BRS resource block groups and a number of consecutive OFDM symbols in one beam group, and at least one of: a Cyclic
 25 Redundancy Code (CRC) of the configuration information comprises a CRC sequence determined through at least one of a cell ID N_{ID}^{cell} and a cell ID group index $N_{ID}^{(1)}$, the configuration information is scrambled based on a pseudorandom sequence initialized with a cell ID or a cell ID and symbol index, the UE further comprises means for transmitting a Demodulation Reference
 30 Signal (DMRS) associated with the xPBCH, the DMRS generated based on a

pseudorandom sequence initialized using one or more of a cell ID, a subframe number, a system frame number, a symbol index and slot index, and resource mapping of the DMRS determined by a cell ID group index $N_{ID}^{(1)}$.

[00108] Although an embodiment has been described with reference to
5 specific example embodiments, it will be evident that various modifications and changes may be made to these embodiments without departing from the broader spirit and scope of the present disclosure. Accordingly, the specification and drawings are to be regarded in an illustrative rather than a restrictive sense. The accompanying drawings that form a part hereof show, by way of illustration, and
10 not of limitation, specific embodiments in which the subject matter may be practiced. The embodiments illustrated are described in sufficient detail to enable those skilled in the art to practice the teachings disclosed herein. Other embodiments may be utilized and derived therefrom, such that structural and logical substitutions and changes may be made without departing from the scope
15 of this disclosure. This Detailed Description, therefore, is not to be taken in a limiting sense, and the scope of various embodiments is defined only by the appended claims, along with the full range of equivalents to which such claims are entitled.

[00109] Such embodiments of the inventive subject matter may be
20 referred to herein, individually and/or collectively, by the term "invention" merely for convenience and without intending to voluntarily limit the scope of this application to any single invention or inventive concept if more than one is in fact disclosed. Thus, although specific embodiments have been illustrated and described herein, it should be appreciated that any arrangement calculated to
25 achieve the same purpose may be substituted for the specific embodiments shown. This disclosure is intended to cover any and all adaptations or variations of various embodiments. Combinations of the above embodiments, and other embodiments not specifically described herein, will be apparent to those of skill in the art upon reviewing the above description.

30 [00110] In this document, the terms "a" or "an" are used, as is common in patent documents, to include one or more than one, independent of any other

instances or usages of "at least one" or "one or more." In this document, the term "or" is used to refer to a nonexclusive or, such that "A or B" includes "A but not B," "B but not A," and "A and B," unless otherwise indicated. In this document, the terms "including" and "in which" are used as the plain-English
5 equivalents of the respective terms "comprising" and "wherein." Also, in the following claims, the terms "including" and "comprising" are open-ended, that is, a system, UE, article, composition, formulation, or process that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim. Moreover, in the following claims, the
10 terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.

[00111] The Abstract of the Disclosure is provided to comply with 37 C.F.R. §1.72(b), requiring an abstract that will allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the
15 understanding that it will not be used to interpret or limit the scope or meaning of the claims. In addition, in the foregoing Detailed Description, it can be seen that various features are grouped together in a single embodiment for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed embodiments require more
20 features than are expressly recited in each claim. Rather, as the following claims reflect, inventive subject matter lies in less than all features of a single disclosed embodiment. Thus the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separate embodiment.

25

CLAIMS

What is claimed is:

1. An apparatus of user equipment (UE) comprising processing circuitry
5 arranged to:
 decode a particular beam from a plurality of simultaneous beams
transmitted by an evolved NodeB (eNB) using multiple input multiple output
(MIMO), each beam comprising a Primary Synchronization Signal (PSS) and a
Beam Reference Signal (BRS) Frequency Domain Multiplexing (FDM) mapped
10 across a plurality of subcarriers in a symbol position in a subframe;
 in response to the received beam further comprising a Secondary
Synchronization Signal (SSS), acquire timing and cell identification (ID)
information through the PSS, the SSS and the BRS, the PSS, the SSS and BRS
FDM mapped in the plurality of subcarriers in the symbol position in the
15 subframe, and otherwise acquire the timing and cell ID information through the
PSS and the BRS; and
 generate transmissions to the eNB based on the acquired timing and cell
ID information.
- 20 2. The apparatus of claim 1, wherein the processing circuitry is further
arranged to:
 acquire timing and cell ID information by use of the PSS and SSS for cell
ID and symbol boundary acquisition, and the BRS for symbol index and beam
information.
- 25 3. The apparatus of claim 1 or 2, wherein:
 the SSS is mapped in consecutive FDM resource blocks adjacent to the
PSS, the PSS disposed in a set of FDM resource blocks in a center of a
frequency band over which the eNB is able to communicate.
- 30 4. The apparatus of claim 3, wherein:

the BRS is mapped in consecutive FDM resource blocks surrounding the PSS and the SSS.

5 5. The apparatus of claim 1 or 2, wherein the processing circuitry is further arranged to:

 determine a cell ID, a subframe index, a symbol index, a number of total BRS resource block groups and a number of consecutive OFDM symbols for a beam group through use of at least one of a PSS ID, a SSS ID, a BRS ID and a BRS resource mapping offset.

10

6. The apparatus of claim 5, wherein the processing circuitry is further arranged to:

 determine the cell ID through use of the PSS ID and one of:
 one of:

15

 the BRS ID, and

 the BRS group ID and the BRS resource mapping offset,

 wherein the cell ID is determined free from use of SSS

 information independent of whether the cell ID is determined

 using either the BRS ID or the BRS group ID and the BRS

20

 resource mapping offset, and

 the SSS ID, a BRS group ID and the BRS resource mapping

 offset.

25 7. The apparatus of claim 5, wherein the processing circuitry is further arranged to:

 determine, free from use of PSS information, at least one of:

 the subframe index and the symbol index through use of one of
 the SSS ID and the BRS ID,

30 the number of total BRS resource block groups through use of at
 least one of the SSS ID and BRS ID, and

the number of consecutive OFDM symbols for one transmitting beam group through use of at least one of the SSS ID, the BRS ID and the BRS resource mapping offset.

- 5 8. The apparatus of claim 1 or 2, wherein the processing circuitry is further arranged to:
 - decode a 5th generation (5G) Physical Broadcast Channel (xPBCH) in the subframe;
 - decode the xPBCH to obtain a master information block (MIB); and
 - 10 confirm at least some of the timing and cell ID information using the xPBCH.
9. The apparatus of claim 8, wherein:
 - the xPBCH comprises configuration information comprising a number of
 - 15 BRS resource block groups and a number of consecutive OFDM symbols in one beam group.
10. The apparatus of claim 9, wherein:
 - a Cyclic Redundancy Code (CRC) of the configuration information
 - 20 comprises a CRC sequence determined through use of at least one of a cell ID N_{ID}^{cell} and a cell ID group index $N_{ID}^{(I)}$.
11. The apparatus of claim 9, wherein:
 - the configuration information is scrambled based on a pseudorandom
 - 25 sequence initialized with a cell ID or a cell ID and symbol index.
12. The apparatus of claim 8, wherein:
 - the xPBCH is mapped in consecutive FDM resource blocks adjacent to resource blocks of a combination of the PSS, BRS and, when present, SSS.
 - 30

13. The apparatus of claim 8, wherein the processing circuitry comprises baseband circuitry arranged to:
- decode a Demodulation Reference Signal (DMRS) associated with the xPBCH, the DMRS generated based on a pseudorandom sequence initialized
- 5 using one or more of a cell ID, a subframe number, a system frame number, a symbol index and slot index, and resource mapping of the DMRS determined by a cell ID group index $N_{ID}^{(1)}$.
14. The apparatus of claim 1 or 2, further comprising:
- 10 an antenna configured to provide communications between the apparatus and the eNB.
15. An apparatus of an evolved NodeB (eNB) comprising processing circuitry arranged to:
- 15 generate a plurality of simultaneous beams using multiple input multiple output (MIMO), each beam comprising one of:
- a first combination comprising a Primary Synchronization Signal (PSS), a Beam Reference Signal (BRS) and a 5th generation (5G) Physical Broadcast Channel (xPBCH) Frequency Domain Multiplexing
- 20 (FDM) mapped through in a plurality of subcarriers in a symbol position in a subframe, and
- a second combination comprising the PSS, a Secondary Synchronization Signal (SSS), the BRS and the xPBCH FDM mapped in the plurality of subcarriers in the symbol position in the subframe,
- 25 wherein each of the first and second combination comprises information to enable acquisition of timing and cell identification (ID) and confirm at least some of the timing and cell ID information through the xPBCH; and
- decode communications received based on timing and cell ID information provided by the plurality of simultaneous beams.
- 30
16. The apparatus of claim 15, wherein:

the PSS and SSS is configured to provide cell ID and symbol boundary acquisition, and the BRS is configured to provide symbol index and beam information.

- 5 17. The apparatus of claim 15 or 16, wherein:
 a cell ID, a subframe index, a symbol index, a number of total BRS
 resource block groups and a number of consecutive OFDM symbols for a beam
 group are provided through use of at least one of a PSS ID, a SSS ID, a BRS ID
 and a BRS resource mapping offset, such that the cell ID is provided through the
10 PSS ID and one of:
 one of:
 the BRS ID, and
 the BRS group ID and the BRS resource mapping offset, wherein
 the cell ID is able to be determined free from SSS information
15 independent of whether the cell ID is able to be determined through
 either the BRS ID or the BRS group ID and the BRS resource mapping
 offset, and
 the SSS ID, a BRS group ID and the BRS resource mapping offset.
- 20 18. The apparatus of claim 15 or 16, wherein:
 a cell ID, a subframe index, a symbol index, a number of total BRS
 resource block groups and a number of consecutive OFDM symbols for a beam
 group are provided through use of at least one of a PSS ID, a SSS ID, a BRS ID
 and a BRS resource mapping offset, such that, free from use of PSS information,
25 at least one of:
 the subframe index and the symbol index is able to be determined
 through one of the SSS ID and the BRS ID,
 the number of total BRS resource block groups is able to be determined
 through at least one of the SSS ID and BRS ID, and
30 the number of consecutive OFDM symbols for one transmitting beam
 group is able to be determined through at least one of the SSS ID, the BRS ID
 and the BRS resource mapping offset.

19. The apparatus of claim 15 or 16, wherein:

each BRS sequence is mapped to a resource element (k,l) by:

$$\alpha_{k,l} = d^l(n), n = -5, -4, \dots, 65, 66$$

$$5 \quad k = n - 31 + \frac{N_{RB}^{DL} N_{SC}^{RB}}{2} + 72m + N_{SC}^{RB} \times N_{SRS} \times m_0$$

where $d^l(n)$ is the BRS sequence in symbol l , generated based on a BRS group ID BG_{ID} , N_{RB}^{DL} is a number of resource blocks in the subframe; N_{SC}^{RB} is a number of subcarriers in one resource block; N_{SRS} is a number of sounding reference signals; m is determined based on a number of BRS resource block groups N_{BRS} and is configured by the eNB; and m_0 is determined based on one of a cell ID and a cell ID group index.

20. The apparatus of claim 19, wherein:

$$m_0 = N_{ID}^{(1)} \bmod N_{BRS}^{shift,max},$$

15 where $N_{BRS}^{shift,max} = \left\lfloor N_{BRS}^{DL} / N_{BRS} \right\rfloor$ and N_{BRS}^{DL} is a total number of BRS resource block groups in the subframe.

21. The apparatus of claim 20, wherein:

each beam is free from the SSS, and

$$20 \quad N_{ID}^{(1)} = m_0 + BG_{ID} \times \left\lfloor N_{BRS}^{DL} / N_{BRS} \right\rfloor.$$

22. The apparatus of claim 20, wherein:

each beam comprises the SSS,

the SSS is generated based on a shortened ID N_{ID}^{SSS} ,

$$N_{ID}^{SSS} \in \left[0, N_{ID}^{SSS, max} - 1 \right], \text{ where } N_{ID}^{SSS, max} \text{ is a maximum}$$

number of SSS IDs defined by the system, and

a cell ID group index is:

$$N_{ID}^{(1)} = m_0 + BG_{ID} x \left\lfloor N_{BRS}^{DL} / N_{BRS} \right\rfloor + N_{ID}^{SSS} x$$

$$N_{BRS}^{DL} x \left\lfloor N_{BRS}^{DL} / N_{BRS} \right\rfloor.$$

23. The apparatus of claim 15 or 16, wherein:

the xPBCH comprises configuration information comprising a number of BRS resource block groups and a number of consecutive OFDM symbols in one beam group, and at least one of:

a Cyclic Redundancy Code (CRC) of the configuration information comprises a CRC sequence determined through at least one of a cell ID N_{ID}^{cell} and a cell ID group index $N_{ID}^{(1)}$,

the configuration information is scrambled based on a pseudorandom sequence initialized with a cell ID or a cell ID and symbol index, and

the processing circuitry is arranged to decode a Demodulation Reference Signal (DMRS) associated with the xPBCH, the DMRS generated based on a pseudorandom sequence initialized using one or more of a cell ID, a subframe number, a system frame number, a symbol index and slot index, and resource mapping of the DMRS determined by a cell ID group index $N_{ID}^{(1)}$.

24. A computer-readable storage medium that stores instructions for execution by one or more processors of a user equipment (UE) to communicate with an evolved NodeB (eNB), the one or more processors to configure the UE to:

receive a particular beam from a plurality of simultaneous beams transmitted by the eNB using multiple input multiple output (MIMO), each beam comprising one of:

- 5 a first combination comprising a Primary Synchronization Signal (PSS), a Beam Reference Signal (BRS) and a 5th generation (5G) Physical Broadcast Channel (xPBCH) Frequency Domain Multiplexing (FDM) mapped through in a plurality of subcarriers in a symbol position in a subframe such that the BRS is adjacent to and surrounds the PSS, and
- 10 a second combination comprising the PSS, a Secondary Synchronization Signal (SSS), the BRS and the xPBCH FDM mapped in the plurality of subcarriers in the symbol position in the subframe such that the BRS is adjacent to and surrounds the PSS and SSS, wherein each of the first and second combination comprises information
- 15 to enable the UE to acquire timing and cell identification (ID) information and confirm at least some of the timing and cell ID information through the xPBCH; acquire the timing and cell ID information; and communicate with the eNB based on the acquired timing and cell ID information.

20

25. The medium of claim 24, wherein:
- the PSS and SSS provide cell ID and symbol boundary acquisition, and the BRS provides symbol index and beam information, and
- a cell ID, a subframe index, a symbol index, a number of total BRS resource block groups and a number of consecutive OFDM symbols for a beam
- 25 group are provided through use of at least one of a PSS ID, a SSS ID, a BRS ID and a BRS resource mapping offset.

26. The medium of claim 24 or 25, wherein:

the xPBCH comprises configuration information comprising a number of BRS resource block groups and a number of consecutive OFDM symbols in one beam group, and at least one of:

- a Cyclic Redundancy Code (CRC) of the configuration information
- 5 comprises a CRC sequence determined through at least one of a cell ID N_{ID}^{cell} and a cell ID group index $N_{ID}^{(1)}$,

the configuration information is scrambled based on a pseudorandom sequence initialized with a cell ID or a cell ID and symbol index,

- the one or more processors further configure the UE to transmit a
- 10 Demodulation Reference Signal (DMRS) associated with the xPBCH, the DMRS generated based on a pseudorandom sequence initialized using one or more of a cell ID, a subframe number, a system frame number, a symbol index and slot index, and resource mapping of the DMRS determined by a cell ID group index $N_{ID}^{(1)}$.

15

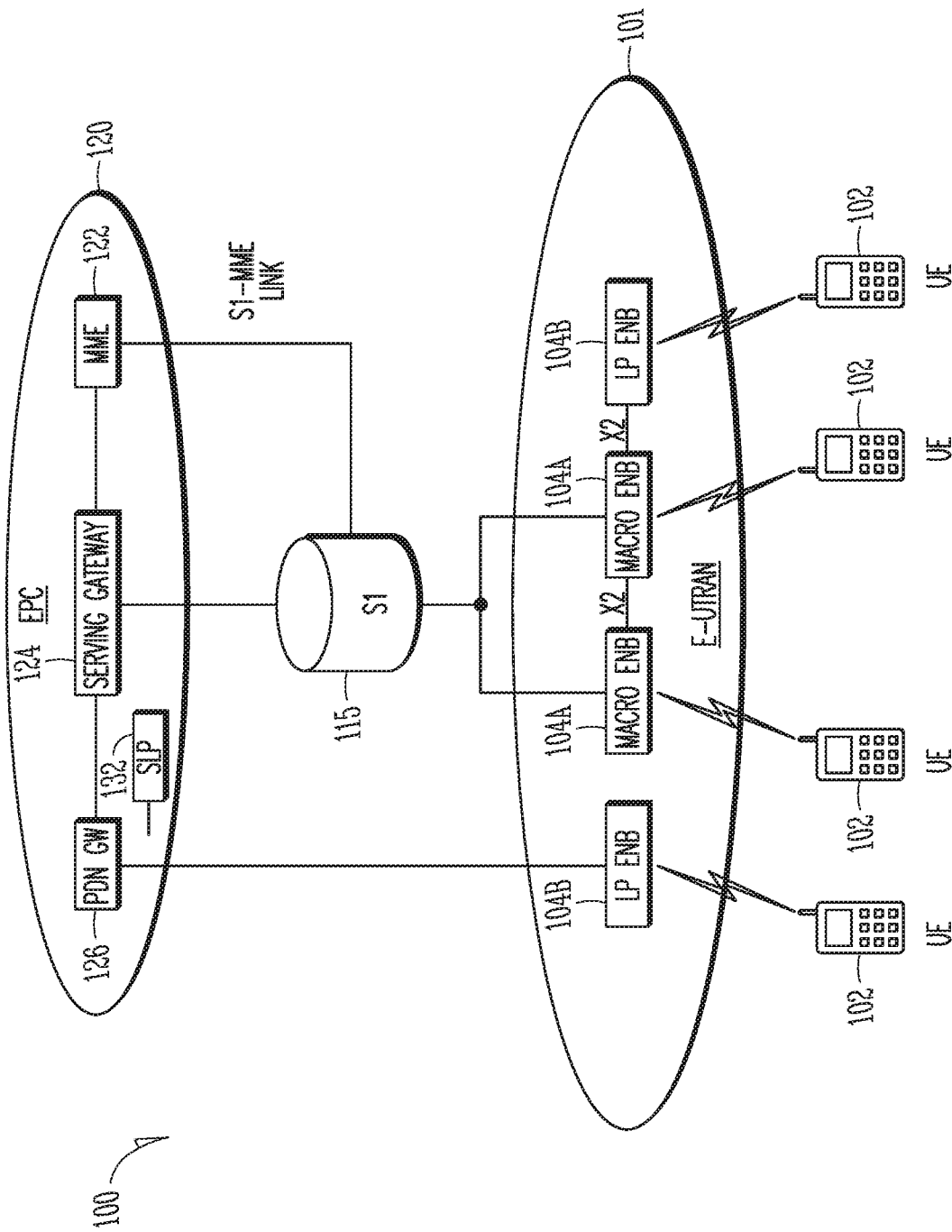


FIG. 1

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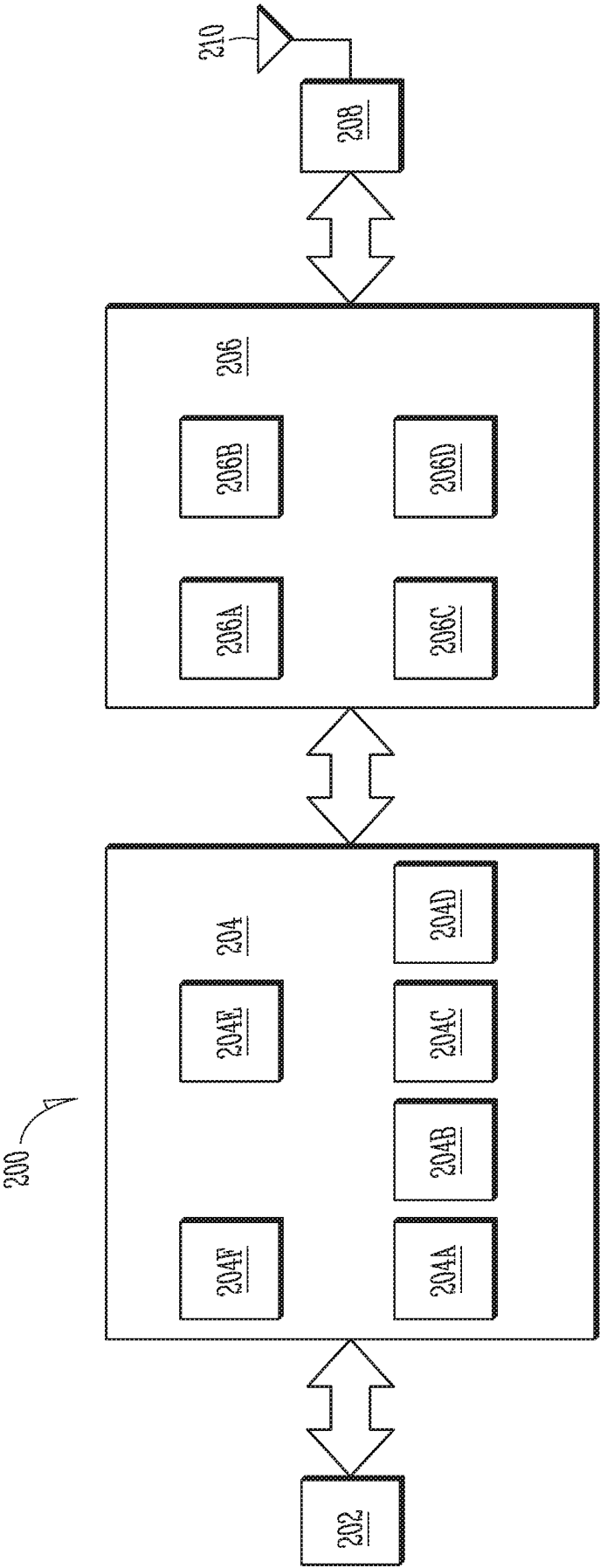
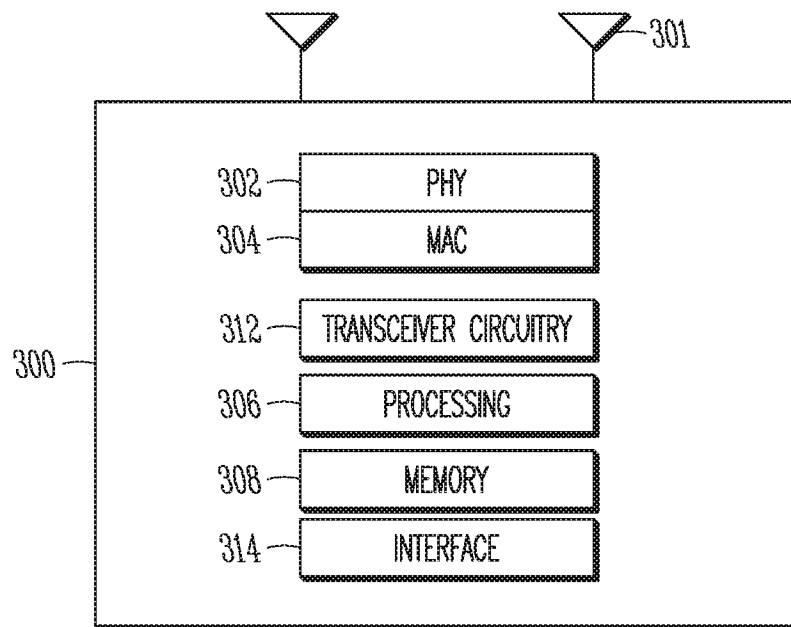


FIG. 2

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*FIG. 3*

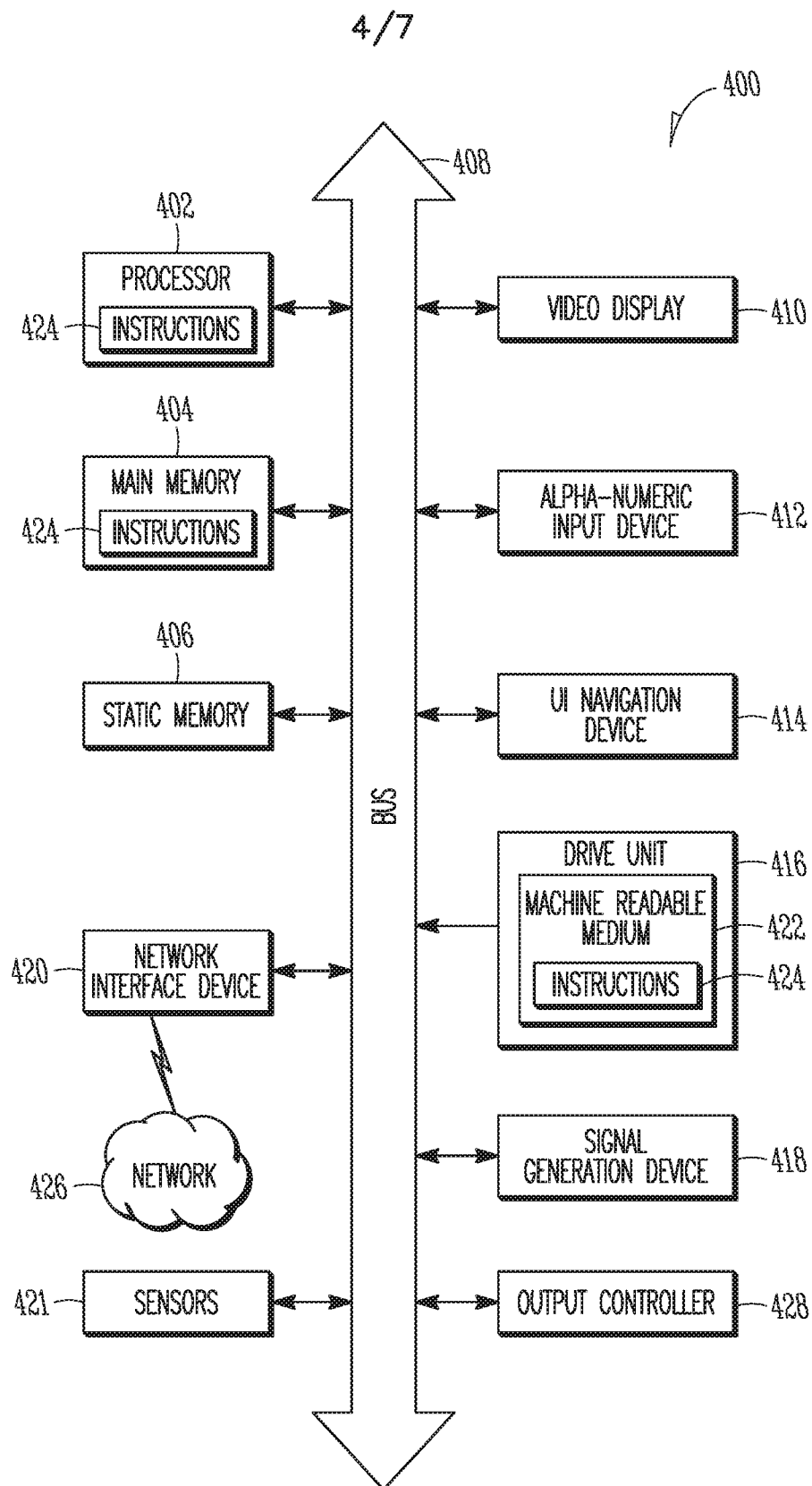
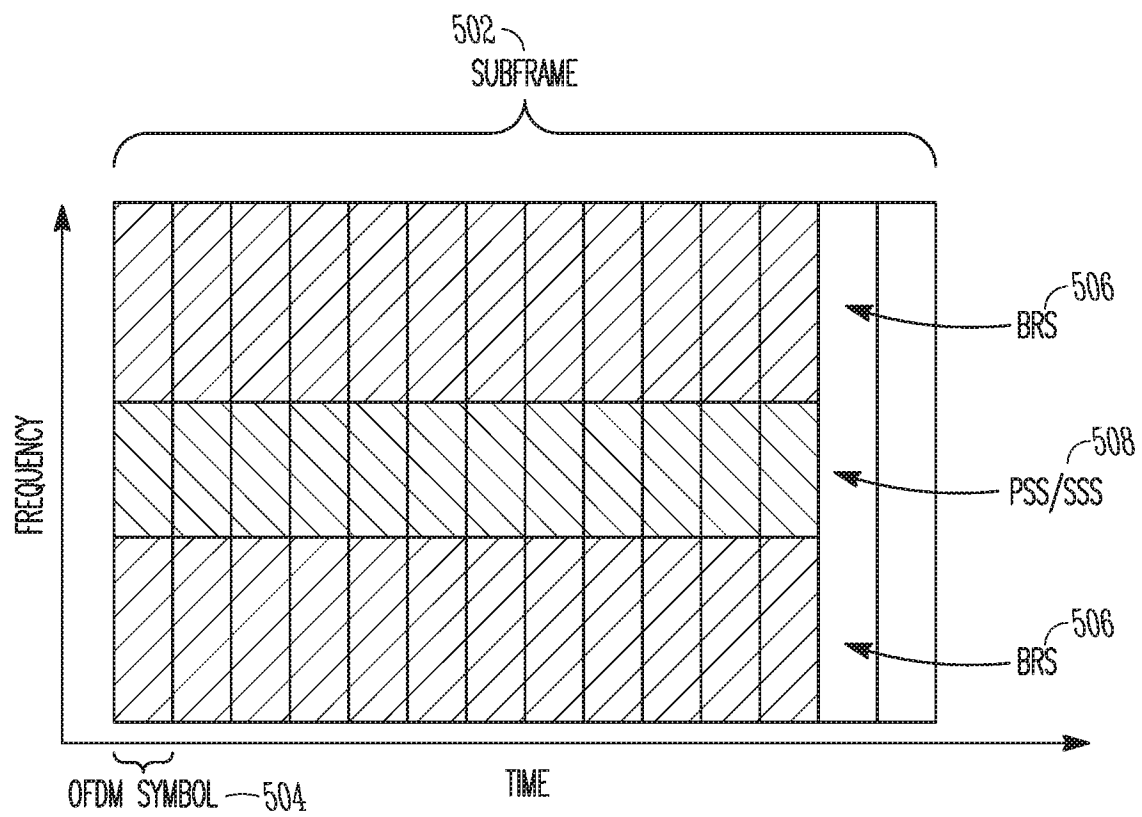


FIG. 4

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**FIG. 5**

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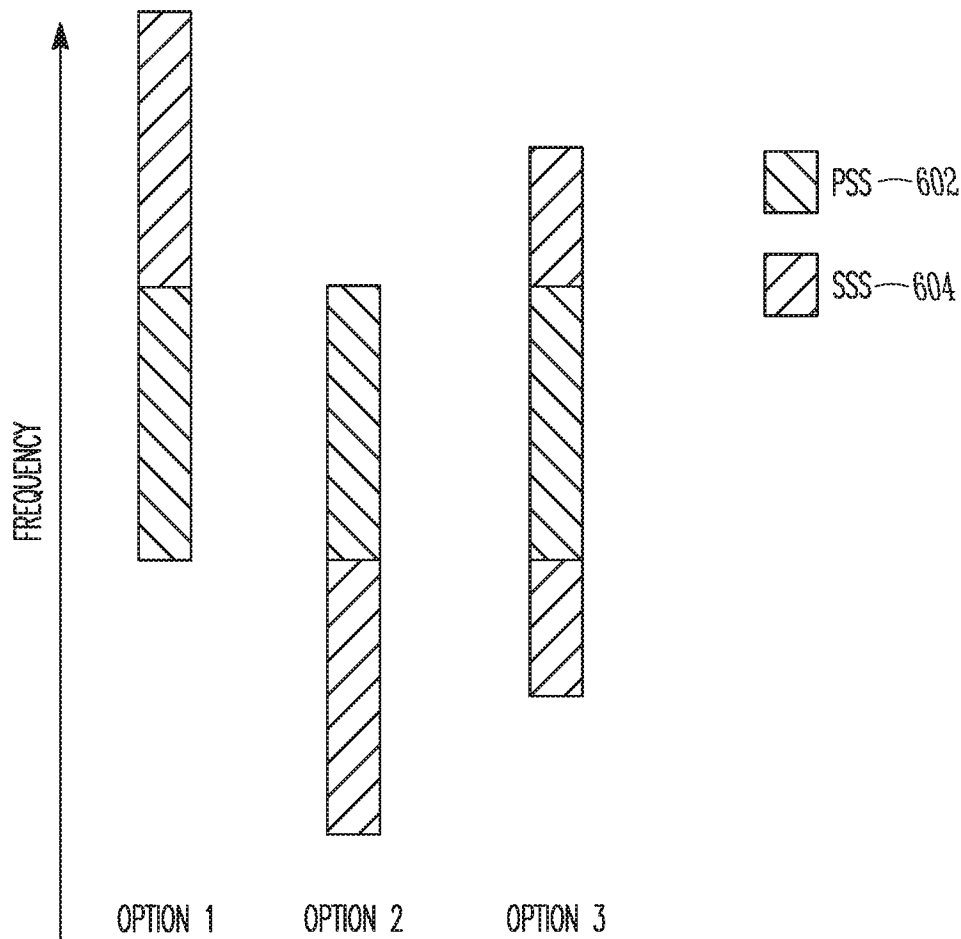


FIG. 6

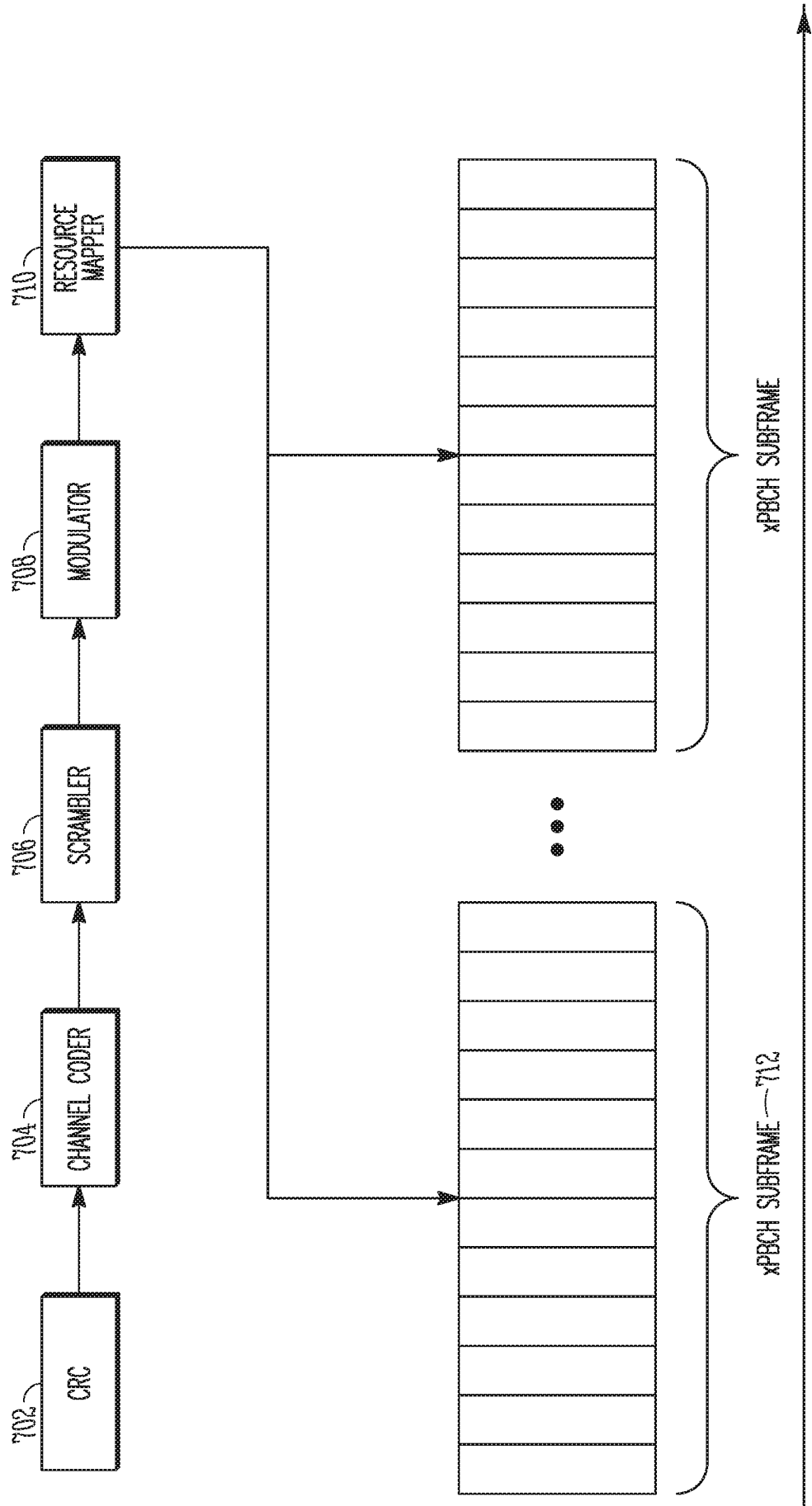


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/022603**A. CLASSIFICATION OF SUBJECT MATTER****H04J 11/00(2006.01)i, H04B 7/04(2006.01)i, H04B 7/06(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)

H04J 11/00; H04L 1/06; H04W 24/10; H04W 52/04; H04W 92/00; H04W 72/08; H04W 24/08; H04B 7/04; H04B 7/06

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) & Keywords: subframe, reference signal, subcarrier, simultaneous beam

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2015-167247 A1 (LG ELECTRONICS INC.) 05 November 2015 See page 8, line 1; page 16, line 14 - page 17, line 11; page 33, lines 12-15; page 35, lines 15-16; page 40, lines 9-11; page 41, lines 11-14; page 42, lines 6-12; page 49, lines 7-9; page 96, lines 14-15; and figures 10, 12.	1-2, 14
A		3-13, 15-26
A	US 2013-0044678 A1 (BINGYU QU et al.) 21 February 2013 See paragraphs [0089]-[0116]; and figure 7.	1-26
A	WO 2015-020291 A1 (LG ELECTRONICS INC.) 12 February 2015 See paragraphs [0067]-[0104]; and figures 8-9.	1-26
A	WO 2015-109153 A1 (INTERDIGITAL PATENT HOLDINGS, INC.) 23 July 2015 See paragraphs [0124]-[0147]; and figures 11-14.	1-26
A	WO 2014-171753 A1 (SAMSUNG ELECTRONICS CO., LTD. et al.) 23 October 2014 See paragraphs [0041]-[0056]; and figure 1.	1-26



Further documents are listed in the continuation of Box C.



See patent family annex.

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

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Date of the actual completion of the international search

06 September 2016 (06.09.2016)

Date of mailing of the international search report

07 September 2016 (07.09.2016)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea

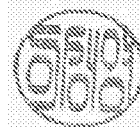


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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/022603

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2015-167247 A1	05/11/2015	None	
US 2013-0044678 A1	21/02/2013	US 8743785 B2	03/06/2014
WO 2015-020291 A1	12/02/2015	CN 105453451 A WO 2015-020290 A1	30/03/2016 12/02/2015
WO 2015-109153 A1	23/07/2015	None	
WO 2014-171753 A1	23/10/2014	KR 10-2014-0124585 A US 2016-072568 A1	27/10/2014 10/03/2016