



- (51) **International Patent Classification:**
H04L 5/00 (2006.01) *H04W 76/04* (2009.01)
- (21) **International Application Number:**
PCT/US2016/035276
- (22) **International Filing Date:**
1 June 2016 (01.06.2016)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
62/287,791 27 January 2016 (27.01.2016) US
- (71) **Applicant:** INTEL IP CORPORATION [US/US]; 2200 Mission College Boulevard, Santa Clara, California 95054 (US).
- (72) **Inventors:** XIONG, Gang; 16682 NW Arizona Dr., Beaverton, Oregon 97006 (US). ZHU, Yuan; Room 605, Building 16, Mo Li Yuan, Bei Yuan Jia Yuan, Chaoyang, Beijing 100013 (CN). ZHANG, Yushu; Raycom Building A 8F, No. 2, Kexueyuan South Road, Beijing 100190 (CN). FWU, Jong-Kae; 1519 Dominion Ave., Sunnyvale, California 94087 (US).
- (74) **Agents:** PERDOK, Monique M., et al.; Schwegman, Lundberg & Woessner, P.A., P.O. Box 2938, Minneapolis, Minnesota 55402 (US).

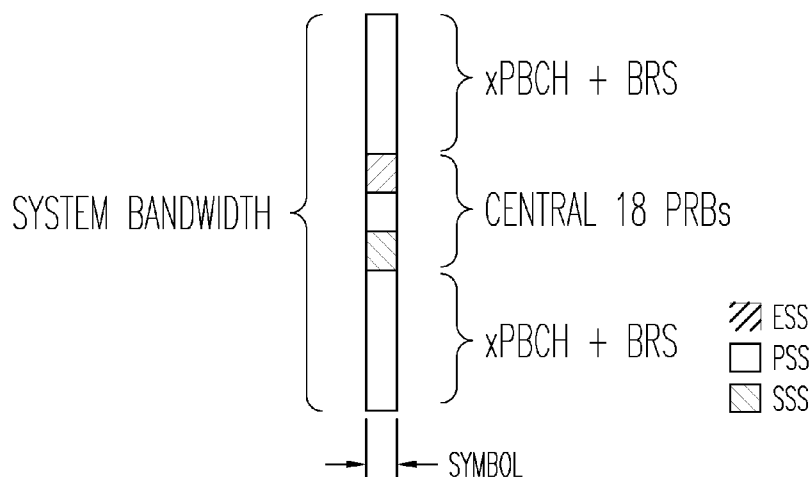
(81) **Designated States** (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) **Title:** REFERENCE SIGNALS AND PHYSICAL BROADCAST CHANNEL FOR 5G SYSTEMS

*Fig. 3*

(57) **Abstract:** Methods and apparatus are described for transmitting beamforming reference signals (BRS) and a physical broadcast channel (PBCH) in 5G systems. Schemes for mapping the BRS and the PBCH to resource elements are also described. In some embodiments, BRS and PBCH resource elements are mapped to a single OFDM symbol. The BRS may be used for demodulation of the PBCH or dedicated demodulation reference signals may be employed for that purpose.



REFERENCE SIGNALS AND PHYSICAL BROADCAST CHANNEL FOR 5G SYSTEMS

Priority Claim

- 5 **[0001]** This application claims priority to United States Provisional Patent Application Serial No.62/287,791 filed on January 27, 2016, which is incorporated herein by reference in its entirety.

Technical Field

- 10 **[0002]** Embodiments described herein relate generally to wireless networks and communications systems. Some embodiments relate to cellular communication networks including 3GPP (Third Generation Partnership Project) networks, 3GPP LTE (Long Term Evolution) networks, and 3GPP LTE-A (LTE Advanced) networks, although the scope of the embodiments is
15 not limited in this respect.

Background

- [0003]** Mobile communication has evolved significantly from early voice systems to today's highly sophisticated integrated communication platform.
20 Fourth generation (4G) LTE networks are now widely deployed to provide service in various spectrum band allocations depending on the spectrum regime. Recently, significant momentum has started to build around the idea of a next generation, i.e. fifth generation (5G), wireless communications technology.

- [0004]** The next generation wireless communication system, 5G, will provide
25 access to information and sharing of data anywhere, anytime by various users and applications. 5G is expected to be a unified network/system that target to meet vastly different and sometime conflicting performance dimensions and services. In general, 5G will evolve based on 3GPP LTE-Advanced with additional potential new radio access technologies (RATs) to provide better, simpler, and
30 more seamless wireless connectivity solutions.

[0005] High frequency band communication has attracted significantly attention from the industry, since it can provide wider bandwidth to support the future integrated communication system. Beamforming is a critical technology for the implementation of high frequency band systems. Beamforming gain can
5 compensate for the severe path loss caused by atmospheric attenuation, improve the SNR, and enlarge the coverage area. By aligning the transmission beam to the target UE, the radiated energy is focused for higher energy efficiency, and the mutual UE interference is suppressed. A primary concern of the present disclosure is the transmission of broadcast signals and beamformed reference signals.

10

Brief Description of the Drawings

- [0006] Fig. 1 illustrates an example UE and eNB according to some embodiments.
- [0007] Fig. 2 illustrates an example of synchronization signal resource
15 mapping according to some embodiments.
- [0008] Fig. 3 illustrates resource mapping for the transmission of synchronization signals, BRSs and the PBCH within one OFDM symbol according to some embodiments.
- [0009] Fig. 4 illustrates an example of a PBCH and BRS resource mapping
20 scheme according to some embodiments.
- [0010] Fig. 5 illustrates an example of a DM-RS pattern for PBCH demodulation according to some embodiments.
- [0011] Fig. 6 illustrates an example of a DM-RS pattern for PBCH demodulation according to some embodiments.
- [0012] Fig. 7 illustrates an example of a DM-RS pattern for PBCH
25 demodulation according to some embodiments.
- [0013] Fig. 8 illustrates an example of a transmit diversity transmission scheme for PBCH transmission according to some embodiments.
- [0014] Fig. 9 illustrates an example of resource mapping of BRS and PBCH
30 according to some embodiments.

[0015] Fig. 10 illustrates an example of resource mapping of BRS and PBCH according to some embodiments.

[0016] Fig. 11 illustrates an example of resource mapping of BRS and PBCH according to some embodiments.

5 [0017] Fig. 12 illustrates an example of resource mapping of BRS and PBCH according to some embodiments.

[0018] Fig. 13 illustrates an example of resource mapping of BRS and PBCH according to some embodiments.

[0019] Fig. 14 illustrates an example of resource mapping of BRS and
10 PBCH according to some embodiments.

[0020] Fig. 15 illustrates an example of resource mapping of BRS and PBCH according to some embodiments.

[0021] Fig. 16 illustrates an example of frequency hopping for PBCH transmission according to some embodiments.

15 [0022] Fig. 17 illustrates an example of a user equipment device according to some embodiments.

[0023] Fig. 18 illustrates an example of a computing machine according to some embodiments.

20 Detailed Description

[0024] In Long Term Evolution (LTE) systems, a mobile terminal (referred to as a User Equipment or UE) connects to a cell served by a base station (referred to as an evolved Node B or eNB) via an air interface. Fig. 1 illustrates
25 an example of the components of a UE 400 and a base station or eNB 300. The eNB 300 includes processing circuitry 301 connected to a radio transceiver 302 for providing an air interface. The UE 400 includes processing circuitry 401 connected to a radio transceiver 402 for providing an interface. Each of the transceivers in the devices is connected to antennas 55.

30 [0025] The physical layer of LTE is based upon orthogonal frequency division multiplexing (OFDM) for the downlink and a related technique, single carrier frequency division multiplexing (SC-FDM), for the uplink. In OFDM/SC-FDM, complex modulation symbols according to a modulation

scheme such as QAM (quadrature amplitude modulation) are each individually mapped to a particular OFDM/SC-FDM subcarrier transmitted during an OFDM/SC-FDM symbol, referred to as a resource element (RE). An RE is the smallest physical resource in LTE. LTE also provides for MIMO (multi-input
5 multi-output) operation where multiple layers of data are transmitted and received by multiple antennas and where each of the complex modulation symbols is mapped into one of the multiple transmission layers and then mapped to a particular antenna port. Each RE is then uniquely identified by the antenna port, sub-carrier position, and OFDM symbol index within a radio frame as
10 explained below.

[0026] LTE transmissions in the time domain are organized into radio frames, each having a duration of 10 ms. Each radio frame consists of 10 sub-frames, and each sub-frame consists of two consecutive 0.5 ms slots. Each slot comprises six indexed OFDM symbols for an extended cyclic prefix and seven
15 indexed OFDM symbols for a normal cyclic prefix. A group of resource elements corresponding to twelve consecutive subcarriers within a single slot is referred to as a resource block (RB) or, with reference to the physical layer, a physical resource block (PRB).

[0027] In order to access a cell served by an eNB, a UE needs to synchronize
20 with the cell and acquire particular system information. For this purpose, the eNB reserves REs for the periodic downlink transmission of a primary synchronization signal (PSS) and a secondary synchronization signal (SSS) to allow a UE to acquire frequency and symbol synchronization as well as frame timing. The eNB also reserves REs for the transmission of system information
25 needed for access over a physical broadcast channel (PBCH). The PBCH carries the master information block (MIB) that includes information relating to the cell's bandwidth and control channel configuration.

[0028] Described below are methods and apparatus are for transmitting beamforming reference signals (BRS) and a physical broadcast channel
30 (PBCH) in 5G systems. Schemes for mapping the BRS and the PBCH to resource elements are also described. In the descriptions that follow, references to the PBCH and MIB should generally be interpreted as referring to a 5G PBCH and MIB, respectively, and not to the PBCH and

MIB currently used in LTE. In the figures, the 5G PBCH is designated as the xPBCH.

[0029] In one embodiment for a 5G system, synchronization signals, beamforming reference signal (BRSs) and a 5G physical broadcast channel (PBCH) may be designed as follows. The primary synchronization signal (PSS) is the same as currently defined in LTE. The secondary synchronization signal (SSS), which is used to derive the physical cell identity (PCI) occupies 6 consecutive physical resource blocks with the same sequence as currently defined in LTE. An extended synchronization signal (ESS) is also provided with at least 12 or 14 sequences used to support subframe timing (symbol within subframe, ie., 0, 1, ..., 11 or 0, 1, ..., 13). The ESS uses the same sequence as defined for the SSS and occupies 6 consecutive PRBs. The resource mapping for the synchronization signals (PSS/SSS/ESS) is illustrated in Fig. 2.

[0030] In one embodiment, a distributed BRS sequence spans the entire band excluding the middle 18 PRBs occupied by PSS, ESS, and SSS (i.e., the “synchronization region”). The BRS REs are interleaved for different beamformed antenna ports using frequency division multiplexing (FDM). The PBCH is frequency division multiplexed with the PSS/ESS/SSS/distributed-BRS within a single OFDM symbol. Fig. 3 illustrates the resource mapping for the transmission of synchronization signals, BRSs and the PBCH within one OFDM symbol. Note that for BRS transmission, different beamformed antenna ports are multiplexed in a frequency division multiplexing (FDM) manner. Assuming K APs are defined for BRS transmission in each symbol, and N_{sym} OFDM symbols are allocated for BRS transmission within one subframe, the total number of APs for BRS transmission within one subframe can be calculated as $K \cdot N_{sym}$.

[0031] As mentioned above, the PBCH may be transmitted within one symbol. Depending on whether BRS can be used for the channel estimation for the PBCH, different embodiments relating to the transmission scheme for the PBCH are described below.

Transmission schemes for PBCH

[0032] In one embodiment, no dedicated reference signal is embedded within the PBCH transmission with BRSs being used for PBCH channel estimation instead. Fig. 4 illustrates one example of a PBCH and BRS resource mapping scheme. In this example, BRSs are transmitted between two PBCH transmission blocks, and the BRSs in the middle can be used for the channel estimation for the PBCH. For PBCH demodulation and decoding, the relationship between the transmit (Tx) beam or antenna port (AP) for BRS transmission and the AP used for PBCH transmission can be predefined in the specification or configured by higher layers via RRC signaling from the primary cell or an LTE cell in a non-standalone deployment scenario. In other words, UE may derive the channel estimation for PBCH based on the channel estimation from the BRS. For PBCH transmission, single AP or multiple APs, e.g., 2 can be used. In the former case, denote the AP for the transmission of the PBCH as AP #100; while for the latter case, denote the APs for the transmission of the PBCH as AP#100 and AP#101, respectively. In one example, assuming $K = 4$ and $N_{sym} = 12$, in the case when single AP is used for xPBCH transmission, channel estimation for xPBCH AP#100 on n_{sym} th symbol ($n_{sym} = 0, \dots, 11$) can be derived from BRS AP# $(0 + 4 \cdot n_{sym}) \bmod K$ and AP# $(1 + 4 \cdot n_{sym}) \bmod K$, where *mod* is the modulo operation. In another example, assuming $K = 8$ and $N_{sym} = 12$, in the case when two APs are used for PBCH transmission, channel estimation for PBCH AP#100 can be derived from BRS AP# $(0 + 8 \cdot n_{sym}) \bmod 8$ and AP# $(1 + 8 \cdot n_{sym}) \bmod 8$; while channel estimation for PBCH AP#101 can be derived from BRS AP# $(4 + 8 \cdot n_{sym}) \bmod 8$ and AP# $(5 + 8 \cdot n_{sym}) \bmod 8$. Alternatively, the PBCH may use aggregated Tx beams from the BRS APs. For example, assuming $K = 4$ and $N_{sym} = 12$, the first block of the PBCH may use the aggregated beams from BRS AP 0 and 1 and the second block of the PBCH may use the beams from BRS AP 2 and 3. The estimated channel can be obtained as

$$\text{Estimated PBCH channel} = \tilde{H} \begin{bmatrix} 1/\sqrt{2} \\ 1/\sqrt{2} \end{bmatrix},$$

30

where $\tilde{H}$ indicates the estimated channel from two BRS APs.

[0033] In another embodiment, dedicated demodulation reference signals (DM-RS) are defined for PBCH channel estimation. Further, depending on the number of APs used for the PBCH, different transmission schemes can be considered. In the case when one AP is used for PBCH transmission, a single port transmission scheme can be adopted for the PBCH. In the case when two or more APs are used for PBCH transmission, space frequency block code (SFBC) or per-RE cyclic based transmit diversity can be adopted. The DM-RS can be generated based on a pseudo-random sequence such as defined in the LTE specifications. Further, the pseudo-random sequence generator may be initialized as a function of OFDM symbol number and/or physical cell ID or virtual physical cell ID.

[0034] Depending on the number of resource elements allocated for each PBCH block and the number of APs for PBCH transmission, different options for the DM-RS pattern can be provided. Figs. 5 and 6 illustrate the examples of DM-RS pattern for single port transmission when PBCH occupies 8 REs and 12 REs, respectively. Note that a similar pattern can be defined for two port PBCH transmission. Fig. 7 illustrates one example of a DM-RS pattern for a PBCH transmitted with two APs when the PBCH occupies 12 REs. the DM-RS for these two APs can be multiplexed using frequency division multiplexing (FDM) or code division multiplexing (CDM). In the case of CDM multiplexing between two APs, orthogonal cover code (OCC) is applied on each AP can be defined as in Table 1 below.

Table 1. OCC for two APs

Antenna port p	$[w_p(0) \ w_p(1)]$
100	[1 1]
101	[1 -1]

[0035] In the case when SFBC is applied for PBCH transmission, two consecutive REs may be used for PBCH transmission. In the case when per-RE cyclic based transmit diversity is applied for PBCH transmission, half of REs in one AP may be used for PBCH transmission while another half of REs remain unused. Fig. 8 illustrates one example of a Tx diversity transmission scheme for

PBCH transmission. In this example, 0 indicates the REs associated with AP#100, while 1 indicates the REs associated with AP #101. The physical cell ID may be included in the 5G master information block (MIB) carried by the PBCH or masked with the cyclic redundancy check (CRC) to allow the UE to verify whether the PBCH is successfully decoded and/or used to generate the dedicated DM-RS associated with the PBCH. Further, to reduce UE power consumption, the same Tx beams may be applied for both synchronization signal and PBCH transmission.

Resource mapping for BRS and PBCH

[0036] As described above, distributed BRS and PBCH may multiplexed in an FDM manner with other synchronization signals, i.e., PSS, SSS and ESS within one OFDM symbol. Further, BRS and PBCH are transmitted in the frequency resource excluding the middle 18 PRBs which are reserved for synchronization signals. To allow proper decoding of the PBCH, the number of REs allocated for each PBCH transmission block may be predefined in the specification. Further, the PBCH block may span the whole system bandwidth for better link budget. Embodiments relating to resource mapping schemes for BRS and PBCH transmission are described below.

[0037] In one embodiment, the PBCH is transmitted adjacent to synchronization signals which include PSS/SSS/ESS. Further, BRS occupies the remaining REs in one OFDM symbol. Given that the PBCH and BRS are transmitted with different frequency resources, dedicated DM-RS may need to be inserted for the PBCH. Fig. 9 illustrates one example of resource mapping of BRS and the PBCH which will be denoted as option 1.

[0038] In another embodiment, BRS and PBCH REs are interleaved in the frequency domain. Further, the number of REs, e.g., K_{max} allocated for each BRS block may fixed in the specification, where K_{max} can be considered as the maximum number of Tx beams which can be supported at eNB within one symbol. Depending on the eNB architecture capability, the eNB may only transmit the BRS with K ($K < K_{max}$) beamformed APs within one symbol. In this case, $(K_{max} - K)$ REs can be left unused within one BRS block. Fig. 10 illustrates the resource mapping of BRS and PBCH transmission for an example denoted as option 2. Note that in this option, the number of APs used for BRS transmission,

i.e., K can be indicated in the 5G master information block (MIB) carried by the PBCH or scrambled with the CRC for PBCH transmission or configured by higher layers via an LTE link. In one example, $K_{max} = 12$, $K = 8$ and the number of REs allocated for each PBCH is fixed to 12. Fig. 11 illustrates another example of resource mapping of BRS and the PBCH for the option 2. In this example, 4 REs are left unused within one BRS block.

[0039] In another embodiment, BRS and the PBCH are interleaved in the frequency domain. Further, the number of APs, i.e., K used for BRS transmission within one symbol may be indicated via high layers from primary LTE cell. Fig. 12 illustrates an example of resource mapping of BRS and PBCH transmission denoted as option 3. Note that compared to option 2, no unused REs are inserted between BRS and PBCH blocks. In one example, $K = 8$ and the number of REs allocated for each xPBCH is fixed to 8. Fig. 13 illustrates another example of resource mapping of BRS and PBCH for option 3.

[0040] In another embodiment, BRS and xPBCH are interleaved in the frequency domain. Further, additional unused REs are inserted between xPBCH and BRS blocks. Similar to the option 2 and 3, K_{max} can be fixed in the specification and K can be included in the xPBCH or configured by higher layers via LTE link. Fig. 14 illustrates an example of this scheme for resource mapping of BRS and PBCH transmission denoted as option 4. In one example, $K_{max} = 12$, $K = 8$ and the number of REs allocated for each PBCH is fixed to 8. Fig. 15 illustrates another example of resource mapping of BRS and PBCH for option 4. In this example, 8 unused REs are inserted between BRS and PBCH blocks.

[0041] Note that for option 4, the frequency position for the PBCH block may be same or different for different OFDM symbols. In the latter case, a frequency hopping pattern can be defined as a function of the physical cell ID and symbol index so as to achieve inter-cell interference randomization. In particular, the starting frequency position for each PBCH block transmission may be defined as

$$I_{PBCH} = f(N_{cell}^{ID}, n_{sym})$$

30

where N_{cell}^{ID} is the physical cell ID and n_{sym} is the symbol index. Fig. 16 illustrates one example of frequency hopping for PBCH transmission. Alternatively, the

starting frequency position for each PBCH block transmission may be determined by the physical cell ID, symbol index and the subframe index, which can be used as a validation for the cell search result.

5 *Example UE Description*

[0042] As used herein, the term "circuitry" may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational
10 logic circuit, and/or other suitable hardware components that provide the described functionality. In some embodiments, the circuitry may be implemented in, or functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware.

15 [0043] Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. Fig. 17 illustrates, for one embodiment, example components of a User Equipment (UE) device 100. In some embodiments, the UE device 100 may include application circuitry 102, baseband circuitry 104, Radio Frequency (RF) circuitry 106, front-end module (FEM) circuitry 108 and one or more antennas 110, coupled together
20 at least as shown.

[0044] The application circuitry 102 may include one or more application processors. For example, the application circuitry 102 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The
25 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.

30 [0045] The baseband circuitry 104 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 104 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 106 and to generate baseband signals for a transmit signal path of the RF circuitry 106. Baseband processing circuitry 104 may interface with the application circuitry 102 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 106. For example, in some
5 embodiments, the baseband circuitry 104 may include a second generation (2G) baseband processor 104a, third generation (3G) baseband processor 104b, fourth generation (4G) baseband processor 104c, and/or other baseband processor(s) 104d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband
10 circuitry 104 (e.g., one or more of baseband processors 104a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 106. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments,
15 modulation/demodulation circuitry of the baseband circuitry 104 may include Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 104 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC)
20 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.

[0046] In some embodiments, the baseband circuitry 104 may include elements of a protocol stack such as, for example, elements of an evolved
25 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) 104e of the baseband circuitry 104 may be configured to run elements of the protocol stack for signaling of the
30 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) 104f. The audio DSP(s) 104f 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 104 and the application circuitry 102 may be implemented together such as, for example, on a system on a chip (SOC).

[0047] In some embodiments, the baseband circuitry 104 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 104 may support communication with an evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 104 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[0048] RF circuitry 106 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 106 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 106 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 108 and provide baseband signals to the baseband circuitry 104. RF circuitry 106 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 104 and provide RF output signals to the FEM circuitry 108 for transmission.

[0049] In some embodiments, the RF circuitry 106 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 106 may include mixer circuitry 106a, amplifier circuitry 106b and filter circuitry 106c. The transmit signal path of the RF circuitry 106 may include filter circuitry 106c and mixer circuitry 106a. RF circuitry 106 may also include synthesizer circuitry 106d for synthesizing a frequency for use by the mixer circuitry 106a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 106a of the receive signal path may be

configured to down-convert RF signals received from the FEM circuitry 108 based on the synthesized frequency provided by synthesizer circuitry 106d. The amplifier circuitry 106b may be configured to amplify the down-converted signals and the filter circuitry 106c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be provided to the baseband circuitry 104 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 106a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[0050] In some embodiments, the mixer circuitry 106a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 106d to generate RF output signals for the FEM circuitry 108. The baseband signals may be provided by the baseband circuitry 104 and may be filtered by filter circuitry 106c. The filter circuitry 106c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

[0051] In some embodiments, the mixer circuitry 106a of the receive signal path and the mixer circuitry 106a 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 106a of the receive signal path and the mixer circuitry 106a 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 106a of the receive signal path and the mixer circuitry 106a may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 106a of the receive signal path and the mixer circuitry 106a of the transmit signal path may be configured for super-heterodyne operation.

[0052] 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 106 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 104 may include a digital baseband interface to communicate with the RF circuitry 106.

- 5 **[0053]** In some dual-mode embodiments, a separate radio IC circuitry may be provided for processing signals for each spectrum, although the scope of the embodiments is not limited in this respect.

10 **[0054]** In some embodiments, the synthesizer circuitry 106d 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 106d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

15 **[0055]** The synthesizer circuitry 106d may be configured to synthesize an output frequency for use by the mixer circuitry 106a of the RF circuitry 106 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 106d may be a fractional $N/N+1$ synthesizer.

20 **[0056]** 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 104 or the applications processor 102 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 102.

25 **[0057]** Synthesizer circuitry 106d of the RF circuitry 106 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or $N+1$ (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these
30 embodiments, the delay elements may be configured to break a VCO period up into 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.

[0058] In some embodiments, synthesizer circuitry 106d may be configured to generate a carrier frequency as the output frequency, while in other
5 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
10 (f_{LO}). In some embodiments, the RF circuitry 106 may include an IQ/polar converter.

[0059] FEM circuitry 108 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 110, amplify the received signals and provide the amplified versions of
15 the received signals to the RF circuitry 106 for further processing. FEM circuitry 108 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 106 for transmission by one or more of the one or more antennas 110.

[0060] In some embodiments, the FEM circuitry 108 may include a TX/RX
20 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 106). The transmit signal path of
25 the FEM circuitry 108 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 106), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 110).

[0061] In some embodiments, the UE device 100 may include additional
30 elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface.

Example Machine Description

[0062] Fig. 18 illustrates a block diagram of an example machine 500 upon which any one or more of the techniques (e.g., methodologies) discussed herein may perform. In alternative embodiments, the machine 500 may operate as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine 500 may operate in the capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine 500 may act as a peer machine in peer-to-peer (P2P) (or other distributed) network environment. The machine 500 may be a user equipment (UE), evolved Node B (eNB), Wi-Fi access point (AP), Wi-Fi station (STA), personal computer (PC), a tablet PC, a set-top box (STB), a personal digital assistant (PDA), a mobile telephone, a smart phone, a web appliance, a network router, switch or bridge, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine. Further, while only a single machine is illustrated, the term “machine” shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein, such as cloud computing, software as a service (SaaS), other computer cluster configurations.

[0063] Examples, as described herein, may include, or may operate on, logic or a number of components, modules, or mechanisms. Modules are tangible entities (e.g., hardware) capable of performing specified operations and may be configured or arranged in a certain manner. In an example, circuits may be arranged (e.g., internally or with respect to external entities such as other circuits) in a specified manner as a module. In an example, the whole or part of one or more computer systems (e.g., a standalone, client or server computer system) or one or more hardware processors may be configured by firmware or software (e.g., instructions, an application portion, or an application) as a module that operates to perform specified operations. In an example, the software may reside on a machine readable medium. In an example, the software, when executed by the underlying hardware of the module, causes the hardware to perform the specified operations.

[0064] Accordingly, the term “module” is understood to encompass a tangible entity, be that an entity that is physically constructed, specifically

configured (e.g., hardwired), or temporarily (e.g., transitorily) configured (e.g., programmed) to operate in a specified manner or to perform part or all of any operation described herein. Considering examples in which modules are temporarily configured, each of the modules need not be instantiated at any one moment in time. For example, where the modules comprise a general-purpose hardware processor configured using software, the general-purpose hardware processor may be configured as respective different modules at different times. Software may accordingly configure a hardware processor, for example, to constitute a particular module at one instance of time and to constitute a different module at a different instance of time.

[0065] Machine (e.g., computer system) 500 may include a hardware processor 502 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 504 and a static memory 506, some or all of which may communicate with each other via an interlink (e.g., bus) 508. The machine 500 may further include a display unit 510, an alphanumeric input device 512 (e.g., a keyboard), and a user interface (UI) navigation device 514 (e.g., a mouse). In an example, the display unit 510, input device 512 and UI navigation device 514 may be a touch screen display. The machine 500 may additionally include a storage device (e.g., drive unit) 516, a signal generation device 518 (e.g., a speaker), a network interface device 520, and one or more sensors 521, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The machine 500 may include an output controller 528, 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.).

[0066] The storage device 516 may include a machine readable medium 522 on which is stored one or more sets of data structures or instructions 524 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 524 may also reside, completely or at least partially, within the main memory 504, within static memory 506, or within the hardware processor 502 during execution thereof by the machine 500. In an example, one or any combination of the hardware processor 502, the main

memory 504, the static memory 506, or the storage device 516 may constitute machine readable media.

[0067] While the machine readable medium 522 is illustrated as a single medium, the term "machine readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated
5 caches and servers) configured to store the one or more instructions 524.

[0068] The term "machine readable medium" may include any medium that is capable of storing, encoding, or carrying instructions for execution by the machine 500 and that cause the machine 500 to perform any one or more of the
10 techniques of the present disclosure, or that is capable of storing, encoding or carrying data structures used by or associated with such instructions. Non-limiting machine readable medium examples may include solid-state memories, and optical and magnetic media. Specific examples of machine readable media may include: non-volatile memory, such as semiconductor memory devices (e.g.,
15 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, machine readable media may include non-transitory machine
20 readable media. In some examples, machine readable media may include machine readable media that is not a transitory propagating signal.

[0069] The instructions 524 may further be transmitted or received over a communications network 526 using a transmission medium via the network interface device 520 utilizing any one of a number of transfer protocols (e.g.,
25 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
30 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 others. In an example, the network interface device 520 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 526. In an example, the
5 network interface device 520 may include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), multiple-input multiple-output (MIMO), or multiple-input single-output (MISO) techniques. In some examples, the network interface device 520 may wirelessly communicate using Multiple User MIMO techniques. The term “transmission
10 medium” shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution by the machine 500, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

15 *Additional Notes and Examples*

[0070] In Example 1, an apparatus for an evolved Node B (eNB), comprises: processing circuitry and memory to configure the eNB to provide an air interface to user equipments (UEs); wherein the circuitry is further to: generate beamforming reference signals (BRSs) that correspond
20 to a plurality of beamformed antenna ports (APs); encode a master information block (MIB) for transmission over a physical broadcast channel (PBCH); and, map the BRSs and PBCH to time-frequency resource elements (REs) that are frequency-division multiplexed in the same orthogonal frequency-division multiplexing (OFDM) symbol.

25 [0071] In Example 2, the subject matter of any of the Examples herein may optionally include wherein the relationship between an AP used for a BRS transmission and an AP used for PBCH transmission is predefined to allow a UE to derive channel estimation for the PBCH based on channel estimation for one or more BRS APs.

30 [0072] In Example 3, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to inform the UE via radio resource control (RRC) signaling of the relationship between an AP used for BRS transmission and an AP used for PBCH transmission to allow a

UE to derive channel estimation for the PBCH based on channel estimation for one or more BRS APs.

[0073] In Example 4, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure the eNB to map multiple PBCHs to REs in an OFDM symbol with each such PBCH transmitted from an AP that corresponds to one or more BRS APs.

[0074] In Example 5, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure the eNB to map PBCHs to REs so as to be transmitted from an aggregate of APs with each such AP defined by one or more BRSs.

[0075] In Example 6, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure the eNB to map demodulation reference signals (DM-RS) to REs corresponding to the same AP as the PBCH and in the same OFDM symbol as the PBCH to allow a UE to derive channel estimation for the PBCH based on the DM-RS.

[0076] In Example 6a, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure the eNB to transmit the DM-RS generated based on pseudo-random sequence that is initialized as a function of OFDM symbol number and/or physical cell ID or virtual physical cell ID.

[0077] In Example 7, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure the eNB to map multiple DM-RS to REs corresponding to multiple APs and wherein the multiple DM-RS are frequency division multiplexed or code division multiplexed within an OFDM symbol.

[0078] In Example 8, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure the eNB to map the PBCH to REs corresponding to two or more APs using space frequency block coding (SFBC) or per-RE cyclic based transmit diversity.

[0079] In Example 8a, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure the eNB such that, for SFBC, two consecutive REs are grouped for PBCH transmission.

[0080] In Example 8b, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure the eNB such that, for per-RE cyclic based transmit diversity, half of REs in one AP is used for PBCH transmission while another half of REs remain unused.

5 **[0081]** In Example 8c, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure the eNB to transmit a physical cell ID included in a master information block (MIB) carried by the PBCH or masked with a cyclic redundancy check (CRC).

[0082] In Example 9, the subject matter of any of the Examples herein
10 may optionally include wherein the processing circuitry is further to configure the eNB to map to REs of a same OFDM symbol, the PBCH, BRS, and synchronization signals which include a primary synchronization signal (PSS), a secondary synchronization signal (SSS) and an extended synchronization signal (ESS).

15 **[0083]** In Example 10, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure the eNB to the PBCH to REs adjacent to the synchronization signals and wherein BRS occupies the remaining REs in the OFDM symbol.

[0084] In Example 11, the subject matter of any of the Examples herein
20 may optionally include wherein the processing circuitry is further to interleave the BRS and PBCH in the frequency domain.

[0085] In Example 11a, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure the eNB such that a maximum number of REs allowed to be allocated for each
25 BRS block is predefined as K_{max} and wherein, when the eNB transmits the BRS with K ($K < K_{max}$) beamformed APs within one OFDM symbol, $K_{max} - K$ REs are left unused within one BRS block.

[0086] In Example 11b, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure
30 the eNB to transmit the number of APs used for BRS transmission, K , is indicated in the master information block (MIB) carried by the PBCH or scrambled with a cyclic redundancy check CRC for PBCH transmission.

[0087] In Example 11c, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure the eNB to insert unused REs between the PBCH and BRS blocks in an OFDM symbol.

5 **[0088]** In Example 12, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure the eNB to map the PBCH to REs at different frequency positions in different OFDM symbols according to a defined frequency hopping pattern.

[0089] In Example 12a, the subject matter of any of the Examples herein
10 may optionally include wherein the frequency hopping pattern is defined as a function of the physical cell ID and symbol index and/or subframe index and wherein the starting frequency position for each PBCH block transmission is defined as:

$$I_{xPBCH} = f(N_{cell}^{ID}, n_{sym})$$

15 where N_{cell}^{ID} is the physical cell ID and n_{sym} is the symbol index.

[0090] In Example 13, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure the eNB to map the PBCH and synchronization signals which include a primary synchronization signal (PSS), a secondary synchronization signal (SSS) and an
20 extended synchronization signal (ESS) to REs corresponding to the same AP or APs.

[0091] In Example 14, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry includes a baseband processor.

25 **[0092]** In Example 15, the subject matter of any of the Examples herein may optionally include: a radio transceiver connected to the processing circuitry; a directional antenna array connected to the radio transceiver and operated by the processing circuitry to provide APs for beamforming.

[0093] In Example 16, an apparatus for a UE (user equipment), comprises:
30 memory and processing circuitry to configure the UE to: demodulate beamforming reference signals (BRSs) and a physical broadcast channel (PBCH) from time-frequency resource elements (REs) that are frequency-division multiplexed in the same orthogonal frequency-division multiplexing (OFDM)

symbol; decode a master information block (MIB) from the PBCH; and, derive beamformed antenna ports (APs) corresponding to the BRSs.

[0094] In Example 17, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is to decode radio
5 resource control (RRC) signaling information relating to the relationship between an AP used for BRS transmission and an AP used for PBCH transmission to allow the UE to derive channel estimation for the PBCH based on channel estimation for one or more BRS APs.

[0095] In Example 18, the subject matter of any of the Examples herein
10 may optionally include wherein the processing circuitry is further to demodulate the PBCHs in an OFDM symbol where the PBCH is transmitted from an AP that corresponds to one or more BRSs.

[0096] In Example 19, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is demodulate
15 demodulation reference signals (DM-RS) transmitted from the same AP as the PBCH and in the same OFDM symbol as the PBCH to allow the UE to derive channel estimation for the PBCH from the DM-RS.

[0097] In Example 20, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to
20 demodulate multiple DM-RS corresponding to multiple APs and wherein the multiple DM-RS are frequency division multiplexed or code division multiplexed within an OFDM symbol.

[0098] In Example 20a, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure
25 the UE to receive the PBCH from two or more APs using space frequency block coding or per-RE cyclic based transmit diversity.

[0099] In Example 20b, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure the UE to receive, in a same OFDM symbol, the PBCH, BRS, and
30 synchronization signals which include a primary synchronization signal (PSS), a secondary synchronization signal (SSS) and an extended synchronization signal (ESS).

[00100] In Example 20c, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure the UE to receive, in the same OFDM symbol, the PBCH adjacent to the synchronization signals and wherein BRSs occupy the remaining REs in the OFDM symbol.

[00101] In Example 20d, the subject matter of any of the Examples herein may optionally include wherein the processing circuitry is further to configure the UE to receive the PBCH at different frequency positions in different OFDM symbols according to a defined frequency hopping pattern.

[00102] In Example 20e, the subject matter of any of the Examples herein may optionally include wherein the frequency hopping pattern is defined as a function of the physical cell ID and symbol index and/or subframe index and wherein the starting frequency position for each PBCH block transmission is defined as:

$$I_{xPBCH} = f(N_{cell}^{ID}, n_{sym})$$

where N_{cell}^{ID} is the physical cell ID and n_{sym} is the symbol index.

[00103] In Example 21, a computer-readable medium comprises instructions to cause a user equipment (UE), upon execution of the instructions by processing circuitry of the UE, to: receive beamforming reference signals (BRSs) that correspond to a plurality of beamformed antenna ports (APs); receive a master information block (MIB) over a physical broadcast channel (PBCH); and, receive the BRSs and PBCH mapped to time-frequency resource elements (REs) that are frequency-division multiplexed in the same orthogonal frequency-division multiplexing (OFDM) symbol.

[00104] In Example 22, the subject matter of Example 21 any of the Examples herein may optionally include instructions to receive via radio resource control (RRC) signaling information relating to the relationship between an AP used for BRS transmission and an AP used for PBCH transmission to allow the UE to derive channel estimation for the PBCH based on channel estimation for one or more BRS APs.

[00105] In Example 23, the subject matter of Example 21 any of the Examples herein may optionally include instructions to receive the PBCH in

an OFDM symbol where the PBCH is transmitted from an AP that corresponds to one or more BRSs.

[00106] In Example 24, the subject matter of Example 21 any of the Examples herein may optionally include instructions to receive demodulation
5 reference signals (DM-RS) from the same AP as the PBCH and in the same OFDM symbol as the PBCH to allow a UE to derive channel estimation for the PBCH based on channel estimation for the DM-RS.

[00107] In Example 25, the subject matter of Example 21 any of the Examples herein may optionally include instructions to receive multiple DM-
10 RS corresponding to multiple APs and wherein the multiple DM-RS are frequency division multiplexed or code division multiplexed within an OFDM symbol.

[00108] In Example 25a, the subject matter of Example 21 any of the Examples herein may optionally include instructions to configure the UE to
15 receive the PBCH from two or more APs using space frequency block coding or per-RE cyclic based transmit diversity.

[00109] In Example 25b, the subject matter of Example 21 any of the Examples herein may optionally include instructions to configure the UE to
20 receive, in a same OFDM symbol, the PBCH, BRS, and synchronization signals which include a primary synchronization signal (PSS), a secondary synchronization signal (SSS) and an extended synchronization signal (ESS).

[00110] In Example 25c, the subject matter of Example 21 any of the Examples herein may optionally include instructions to configure the UE to
25 receive, in the same OFDM symbol, the PBCH adjacent to the synchronization signals and wherein BRSs occupy the remaining REs in the OFDM symbol.

[00111] In Example 25d, the subject matter of Example 21 any of the Examples herein may optionally include instructions to configure the UE to
receive the PBCH at different frequency positions in different OFDM symbols according to a defined frequency hopping pattern.

[00112] In Example 25e, the subject matter of Example 21 any of the Examples herein may optionally include wherein the frequency hopping
30 pattern is defined as a function of the physical cell ID and symbol index and/or

subframe index and wherein the starting frequency position for each PBCH block transmission is defined as:

$$I_{xPBCH} = f(N_{cell}^{ID}, n_{sym})$$

where N_{cell}^{ID} is the physical cell ID and n_{sym} is the symbol index.

- 5 [00113] In Example 26, a method of operating an eNB comprises executing the functions of the processing circuitry as recited in any of Examples 1-15.

[00114] In Example 27, an apparatus for an eNB comprises means for performing the functions of the processing circuitry as recited in any of Examples 1-15.

- 10 [00115] In Example 28, a computer-readable medium comprises instructions to cause an evolved Node B (eNB), upon execution of the instructions by processing circuitry of the eNB, to perform functions of the processing circuitry as recited in any of Examples 1-15.

- [00116] In Example 29, a method of operating a UE comprising executing the
15 functions of the processing circuitry as recited in any of Examples 16-20e.

[00117] In Example 30, an apparatus for a UE comprises means for performing the functions of the processing circuitry as recited in any of Examples 16-20e.

[00118] The above detailed description includes references to the accompanying drawings, which form a part of the detailed description. The drawings show, by way of illustration, specific embodiments that may be practiced. These embodiments are also referred to herein as “examples.” Such examples may include elements in addition to those shown or described. However, also contemplated are examples that include the elements shown or described. Moreover, also contemplate are examples using any combination or permutation of those elements shown or described (or one or more aspects thereof), either with respect to a particular example (or one or more aspects thereof), or with respect to other examples (or one or more aspects thereof) shown or described herein.

[00119] Publications, patents, and patent documents referred to in this document are incorporated by reference herein in their entirety, as though individually incorporated by reference. In the event of inconsistent usages between this document and those documents so incorporated by reference, the

usage in the incorporated reference(s) are supplementary to that of this document; for irreconcilable inconsistencies, the usage in this document controls.

[00120] 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 the appended claims, the terms “including” and “in which” are used as the plain-English 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, device, article, 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 terms “first,” “second,” and “third,” etc. are used merely as labels, and are not intended to suggest a numerical order for their objects.

[00121] The embodiments as described above may be implemented in various hardware configurations that may include a processor for executing instructions that perform the techniques described. Such instructions may be contained in a machine-readable medium such as a suitable storage medium or a memory or other processor-executable medium.

[00122] The embodiments as described herein may be implemented in a number of environments such as part of a wireless local area network (WLAN), 3rd Generation Partnership Project (3GPP) Universal Terrestrial Radio Access Network (UTRAN), or Long-Term-Evolution (LTE) or a Long-Term-Evolution (LTE) communication system, although the scope of the invention is not limited in this respect. An example LTE system includes a number of mobile stations, defined by the LTE specification as User Equipment (UE), communicating with a base station, defined by the LTE specifications as an eNB.

[00123] Antennas referred to herein 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 embodiments, instead

of two or more antennas, a single antenna with multiple apertures may be used. In these embodiments, each aperture may be considered a separate antenna. In some multiple-input multiple-output (MIMO) embodiments, antennas may be effectively separated to take advantage of spatial diversity and the different
5 channel characteristics that may result between each of antennas and the antennas of a transmitting station. In some MIMO embodiments, antennas may be separated by up to 1/10 of a wavelength or more.

[00124] In some embodiments, a receiver as described herein may be configured to receive signals in accordance with specific communication
10 standards, such as the Institute of Electrical and Electronics Engineers (IEEE) standards including IEEE 802.11 standards and/or proposed specifications for WLANs, although the scope of the invention is not limited in this respect as they may also be suitable to transmit and/or receive communications in accordance with other techniques and standards. In some embodiments, the receiver may be
15 configured to receive signals in accordance with the IEEE 802.16-2004, the IEEE 802.16(e) and/or IEEE 802.16(m) standards for wireless metropolitan area networks (WMANs) including variations and evolutions thereof, although the scope of the invention is not limited in this respect as they may also be suitable to transmit and/or receive communications in accordance with other techniques
20 and standards. In some embodiments, the receiver may be configured to receive signals in accordance with the Universal Terrestrial Radio Access Network (UTRAN) LTE communication standards. For more information with respect to the IEEE 802.11 and IEEE 802.16 standards, please refer to “IEEE Standards for Information Technology -- Telecommunications and Information Exchange
25 between Systems” - Local Area Networks - Specific Requirements – Part 11 “Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY), ISO/IEC 8802-11: 1999”, and Metropolitan Area Networks - Specific Requirements – Part 16: “Air Interface for Fixed Broadband Wireless Access Systems,” May 2005 and related amendments/versions. For more information
30 with respect to UTRAN LTE standards, see the 3rd Generation Partnership Project (3GPP) standards for UTRAN-LTE, including variations and evolutions thereof.

[00125] The above description is intended to be illustrative, and not restrictive. For example, the above-described examples (or one or more aspects thereof) may be used in combination with others. Other embodiments may be used, such as by one of ordinary skill in the art upon reviewing the above description. The Abstract is to allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. Also, in the above Detailed Description, various features may be grouped together to streamline the disclosure. However, the claims may not set forth every feature disclosed herein as embodiments may feature a subset of said features. Further, embodiments may include fewer features than those disclosed in a particular example. Thus, the following claims are hereby incorporated into the Detailed Description, with a claim standing on its own as a separate embodiment. The scope of the embodiments disclosed herein is to be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

CLAIMS

1. An apparatus for an evolved Node B (eNB), comprising:
processing circuitry and memory to configure the eNB to provide an
air interface to user equipments (UEs);
5 wherein the processing circuitry is further to:
generate beamforming reference signals (BRSs) that correspond to a
plurality of beamformed antenna ports (APs);
encode a master information block (MIB) for transmission over a
physical broadcast channel (PBCH); and,
10 map the BRSs and PBCH to time-frequency resource elements (REs)
that are frequency-division multiplexed in the same orthogonal frequency-
division multiplexing (OFDM) symbol.
2. The apparatus of claim 1 wherein the relationship between an AP used
15 for a BRS transmission and an AP used for PBCH transmission is predefined to
allow a UE to derive channel estimation for the PBCH based on channel
estimation for one or more BRS APs.
3. The apparatus of claim 1 wherein the processing circuitry is further to
20 inform the UE via radio resource control (RRC) signaling of the relationship
between an AP used for BRS transmission and an AP used for PBCH
transmission to allow a UE to derive channel estimation for the PBCH based on
channel estimation for one or more BRS APs.
- 25 4. The apparatus of claim 1 wherein the processing circuitry is further to
configure the eNB to map PBCHs to REs in an OFDM symbol with each such
PBCH transmitted from an AP that corresponds to one or more BRS APs.

5. The apparatus of claim 1 wherein the processing circuitry is further to configure the eNB to map PBCHs to REs so as to be transmitted from an aggregate of APs with each such AP defined by one or more BRSs.
- 5 6. The apparatus of claim 1 wherein the processing circuitry is further to configure the eNB to map demodulation reference signals (DM-RS) to REs corresponding to the same AP as the PBCH and in the same OFDM symbol as the PBCH to allow a UE to derive channel estimation for the PBCH based on channel estimation from the DM-RS.
- 10 7. The apparatus of claim 6 wherein the processing circuitry is further to configure the eNB to map multiple DM-RS to REs corresponding to multiple APs and wherein the multiple DM-RS are frequency division multiplexed or code division multiplexed within an OFDM symbol.
- 15 8. The apparatus of claim 1 wherein the processing circuitry is further to configure the eNB to map the PBCH to REs corresponding to two or more APs using space frequency block coding or per-RE cyclic based transmit diversity.
- 20 9. The apparatus of any of claims 1 through 8 wherein the processing circuitry is further to configure the eNB to map to REs of a same OFDM symbol the PBCH, BRS, and synchronization signals which include a primary synchronization signal (PSS), a secondary synchronization signal (SSS) and an extended synchronization signal (ESS).
- 25 10. The apparatus of claim 9 wherein the processing circuitry is further to configure the eNB to map the PBCH to REs adjacent to the synchronization signals and wherein BRSs occupy the remaining REs in the OFDM symbol.
- 30 11. The apparatus of claim 9 wherein the processing circuitry is further to interleave the BRS and PBCH in the frequency domain.

12. The apparatus of any of claims 1 through 8 wherein the processing circuitry is further to configure the eNB to map the PBCH to REs at different frequency positions in different OFDM symbols according to a defined
5 frequency hopping pattern.

13. The apparatus of any of claims 1 through 8 wherein the processing circuitry is further to configure the eNB to map the PBCH and synchronization signals which include a primary synchronization signal (PSS), a secondary
10 synchronization signal (SSS), and an extended synchronization signal (ESS) to REs corresponding to the same AP or APs.

14. The apparatus of any of claims 1 through 8 wherein the processing circuitry includes a baseband processor.

15

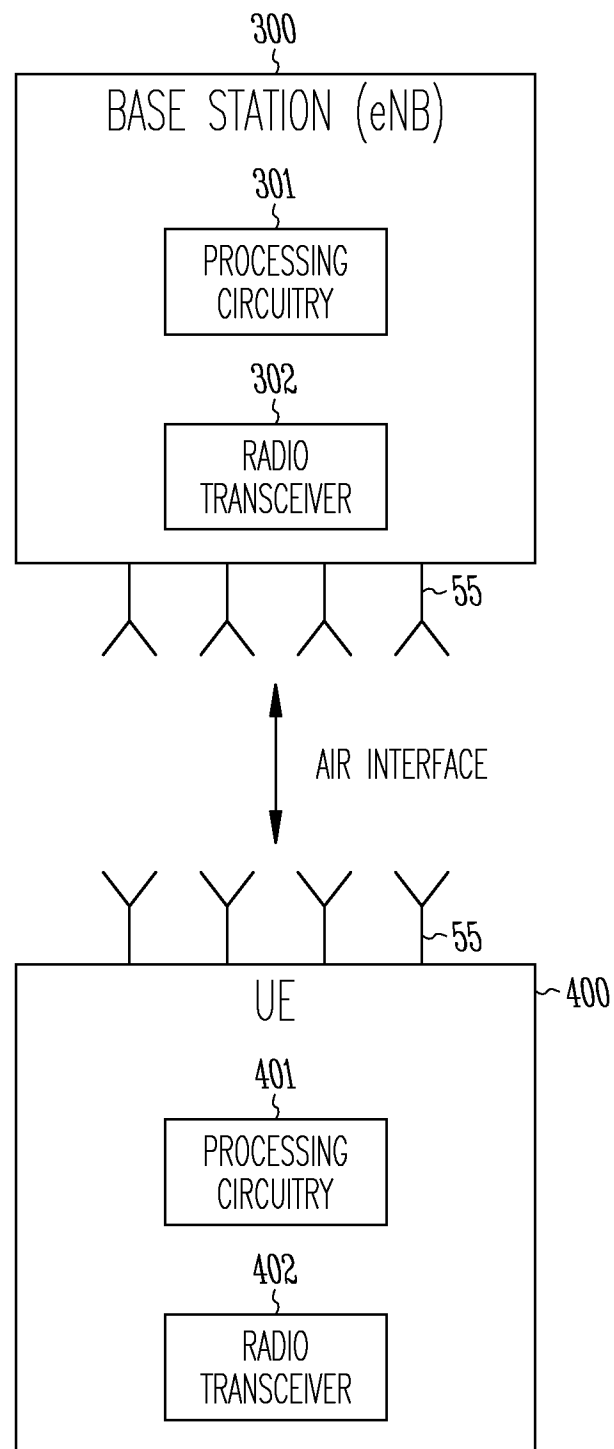
15. The apparatus of any of claims 1 through 8 further comprising:
a radio transceiver connected to the processing circuitry;
a directional antenna array connected to the radio transceiver and
operated by the processing circuitry to provide APs for beamforming.

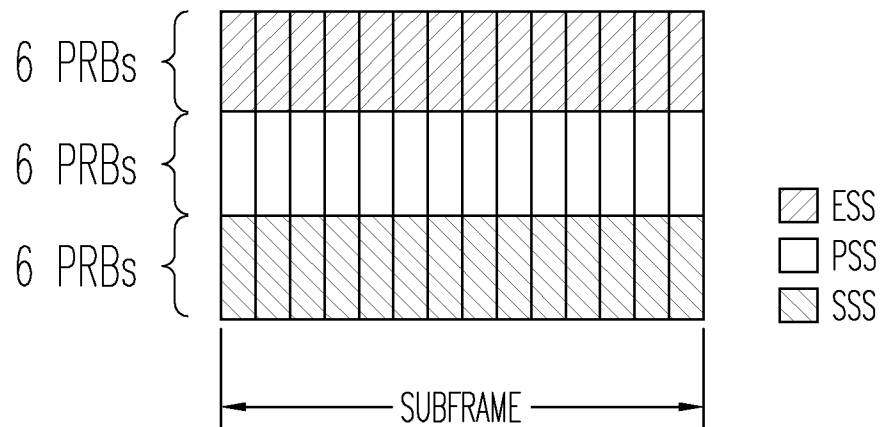
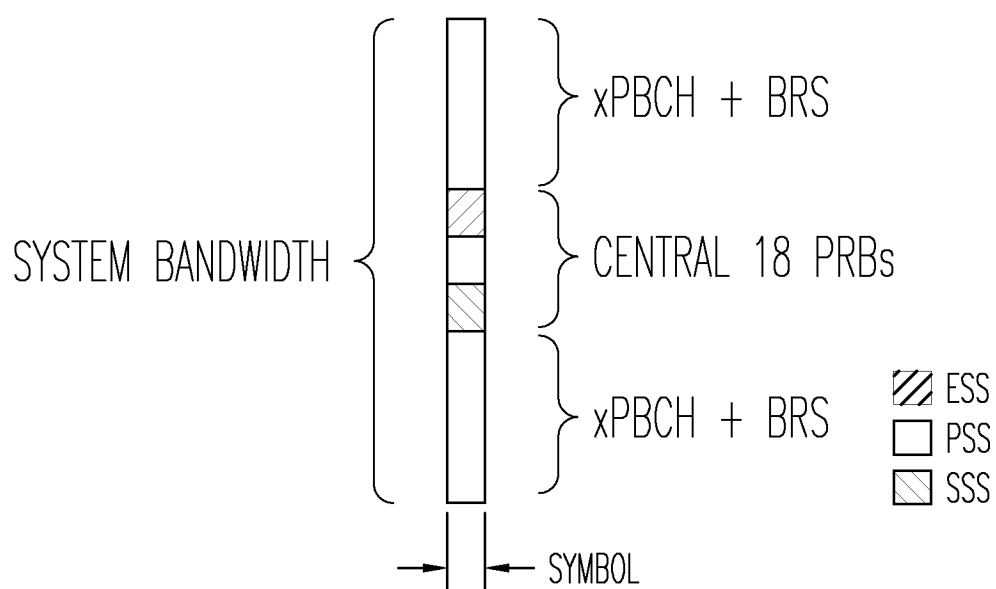
20

16. An apparatus for a UE (user equipment), comprising:
memory and processing circuitry to configure the UE to:
demodulate beamforming reference signals (BRSs) and a physical
broadcast channel (PBCH) from time-frequency resource elements (REs)
25 that are frequency-division multiplexed in the same orthogonal frequency-
division multiplexing (OFDM) symbol;
decode a master information block (MIB) from the PBCH; and,
derive beamformed antenna ports (APs) corresponding to the BRSs.

17. The apparatus of claim 16 wherein the processing circuitry is to decode radio resource control (RRC) signaling information relating to the relationship between an AP used for BRS transmission and an AP used for PBCH transmission to allow the UE to derive channel estimation for the PBCH based on channel estimation for one or more BRS APs.
18. The apparatus of claim 16 wherein the processing circuitry is further to demodulate the PBCH in an OFDM symbol where the PBCH is transmitted from an AP that corresponds to one or more BRS APs.
19. The apparatus of claim 16 wherein the processing circuitry is further to demodulate demodulation reference signals (DM-RS) transmitted from the same AP as the PBCH and in the same OFDM symbol as the PBCH to allow the UE to derive channel estimation for the PBCH from the DM-RS.
20. The apparatus of claim 16 wherein the processing circuitry is further to demodulate multiple DM-RS corresponding to multiple APs and wherein the multiple DM-RS are frequency division multiplexed or code division multiplexed within an OFDM symbol.
21. A computer-readable medium comprising instructions to cause a user equipment (UE), upon execution of the instructions by processing circuitry of the UE, to:
- receive beamforming reference signals (BRSs) that correspond to a plurality of beamformed antenna ports (APs);
- receive a master information block (MIB) over a physical broadcast channel (PBCH); and,
- receive the BRSs and PBCH as time-frequency resource elements (REs) that are frequency-division multiplexed in the same orthogonal frequency-division multiplexing (OFDM) symbol

22. The medium of claim 21 further comprising instructions to receive via radio resource control (RRC) signaling information relating to the relationship between an AP used for BRS transmission and an AP used for PBCH transmission to allow the UE to derive channel estimation for the PBCH based on channel estimation for one or more BRS APs.
23. The medium of claim 21 further comprising instructions to receive the PBCH in an OFDM symbol where the PBCH is transmitted from an AP that corresponds to one or more BRS APs.
24. The medium of claim 21 further comprising instructions to receive demodulation reference signals (DM-RS) from the same AP as the PBCH and in the same OFDM symbol as the PBCH to allow a UE to derive channel estimation for the PBCH from the DM-RS.
25. The medium of claim 21 further comprising instructions to receive multiple DM-RS corresponding to multiple APs and wherein the multiple DM-RS are frequency division multiplexed or code division multiplexed within an OFDM symbol.

*Fig. 1*

*Fig. 2**Fig. 3*

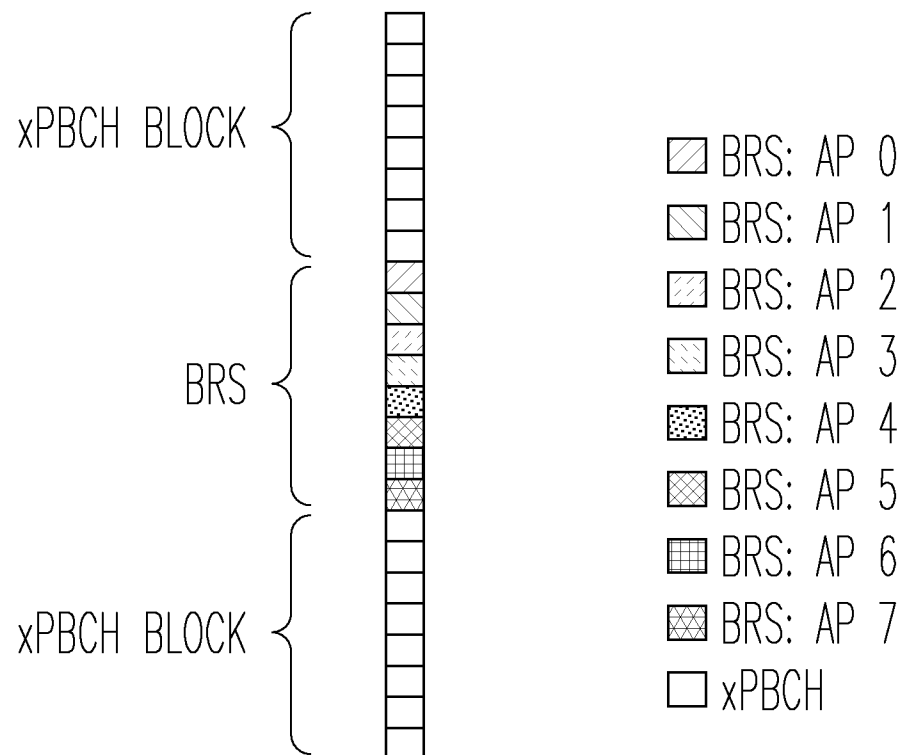


Fig. 4

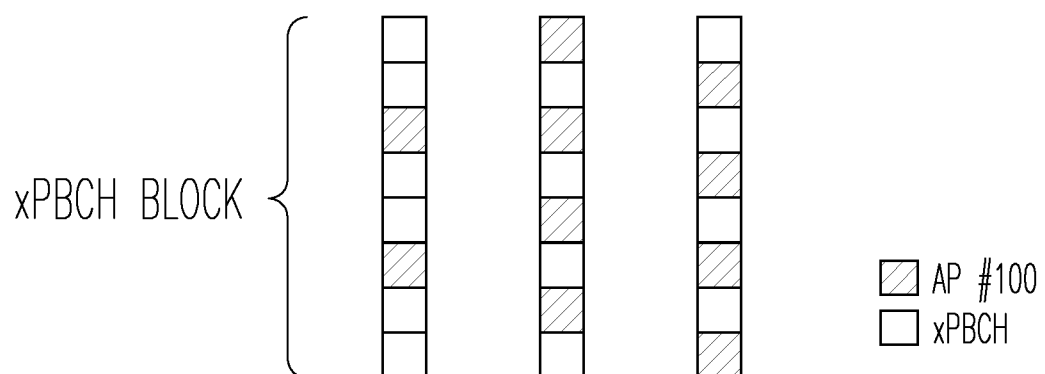
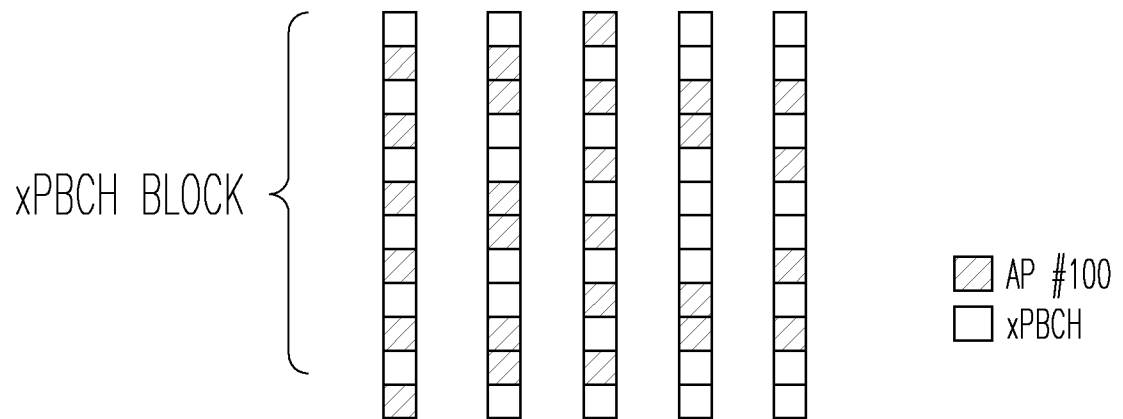
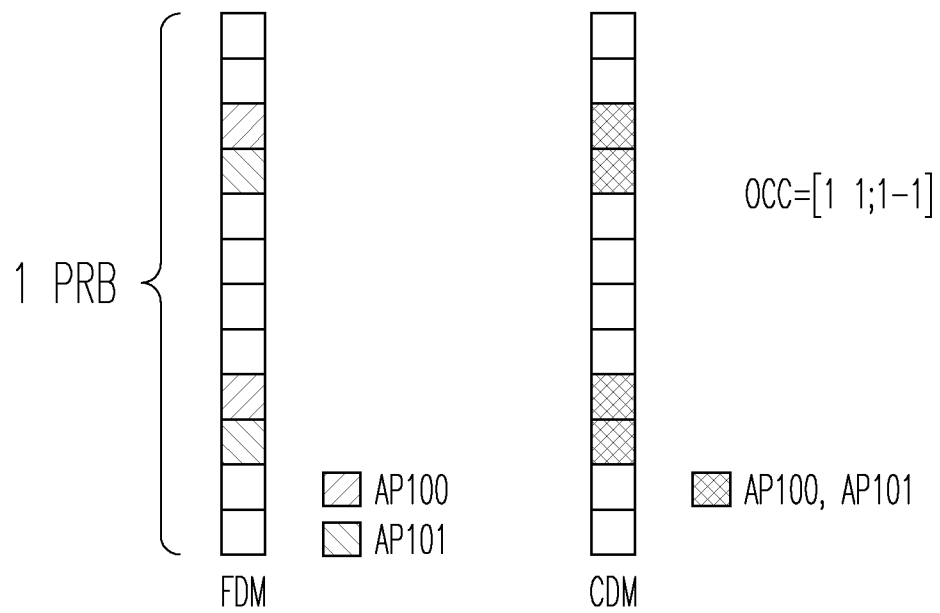


Fig. 5

4/12

*Fig. 6**Fig. 7*

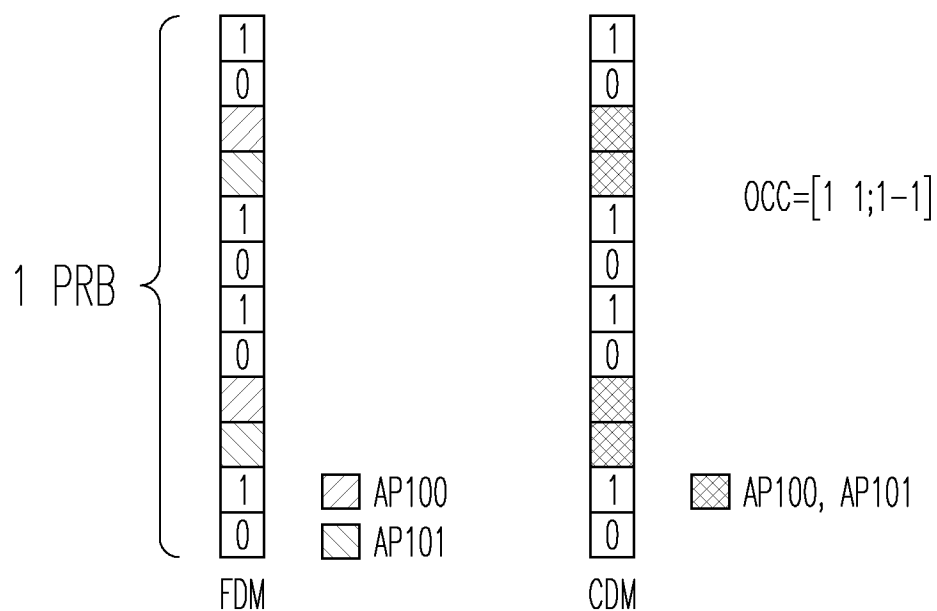


Fig. 8

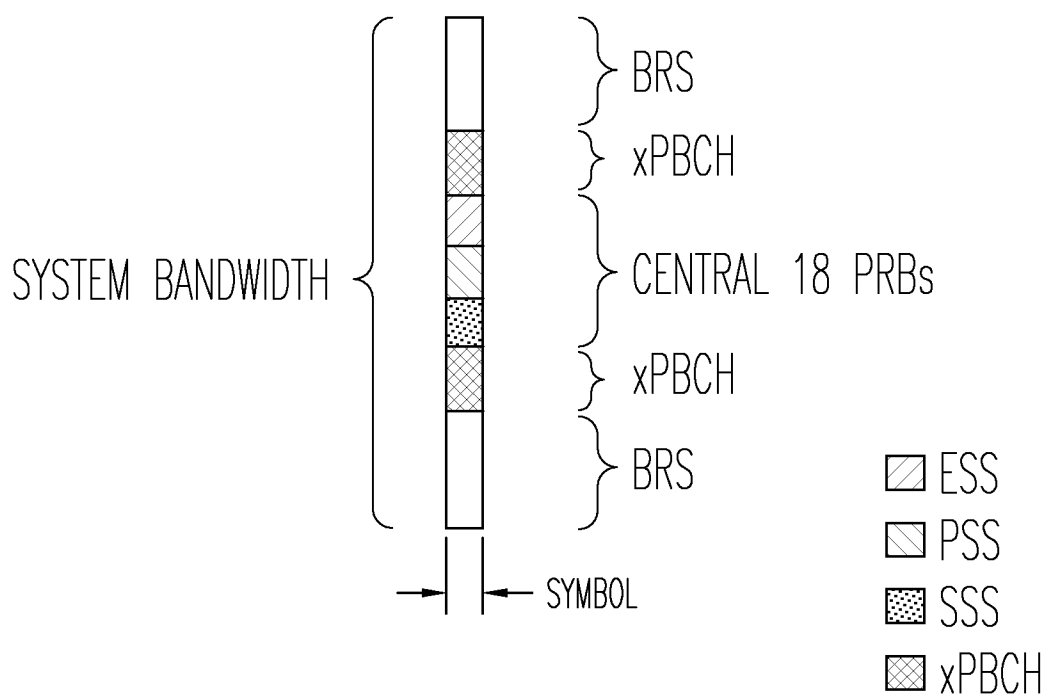
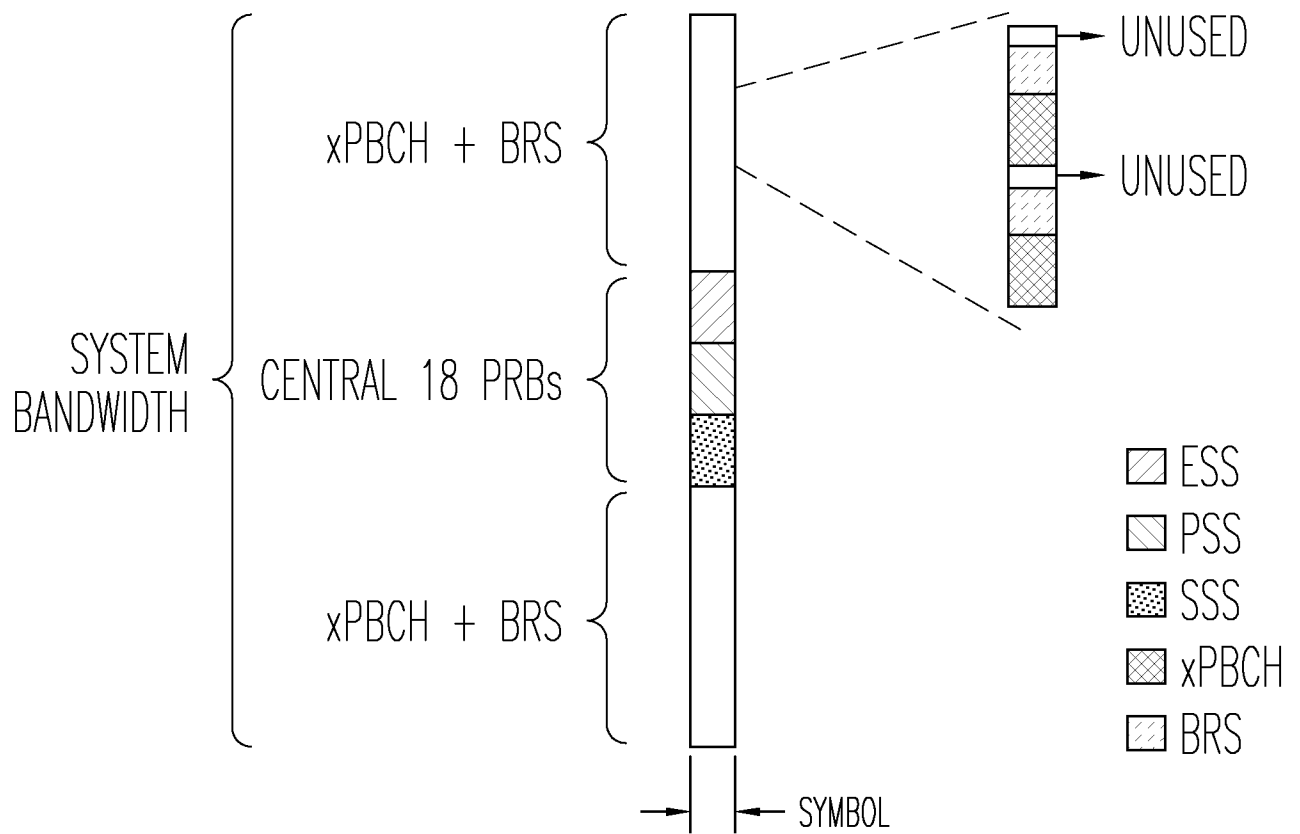
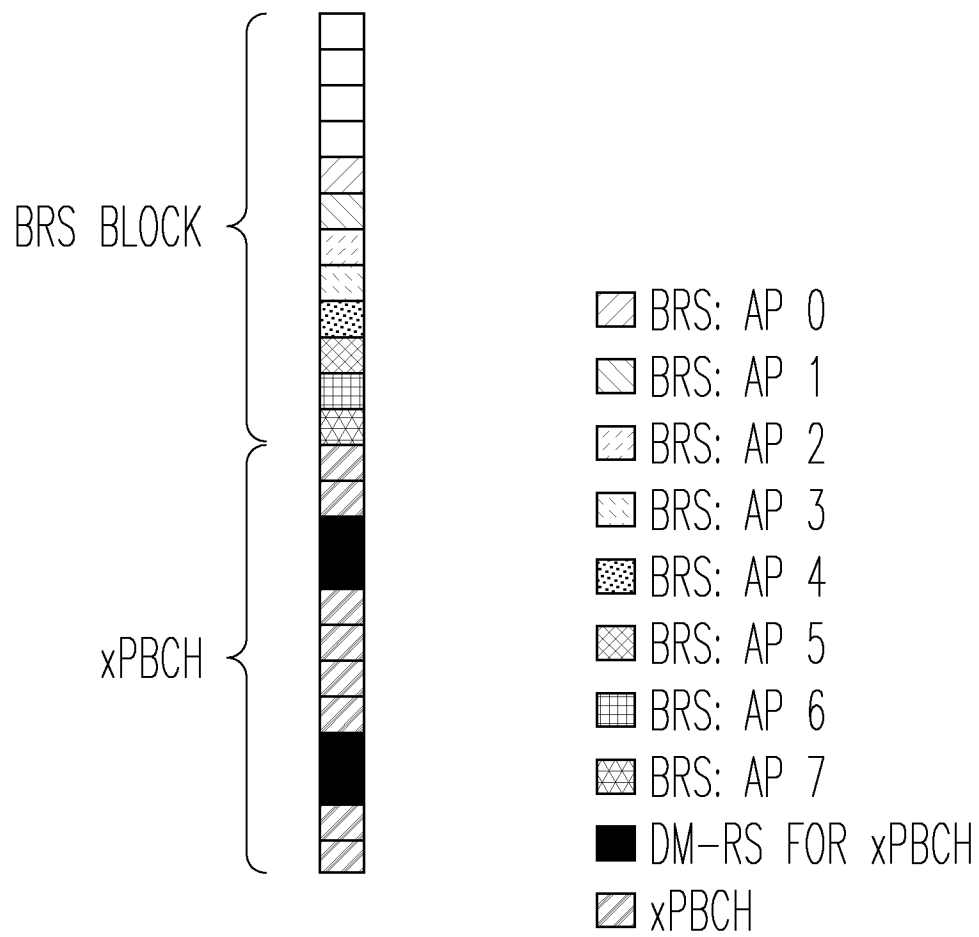


Fig. 9

*Fig. 10*

*Fig. 11*

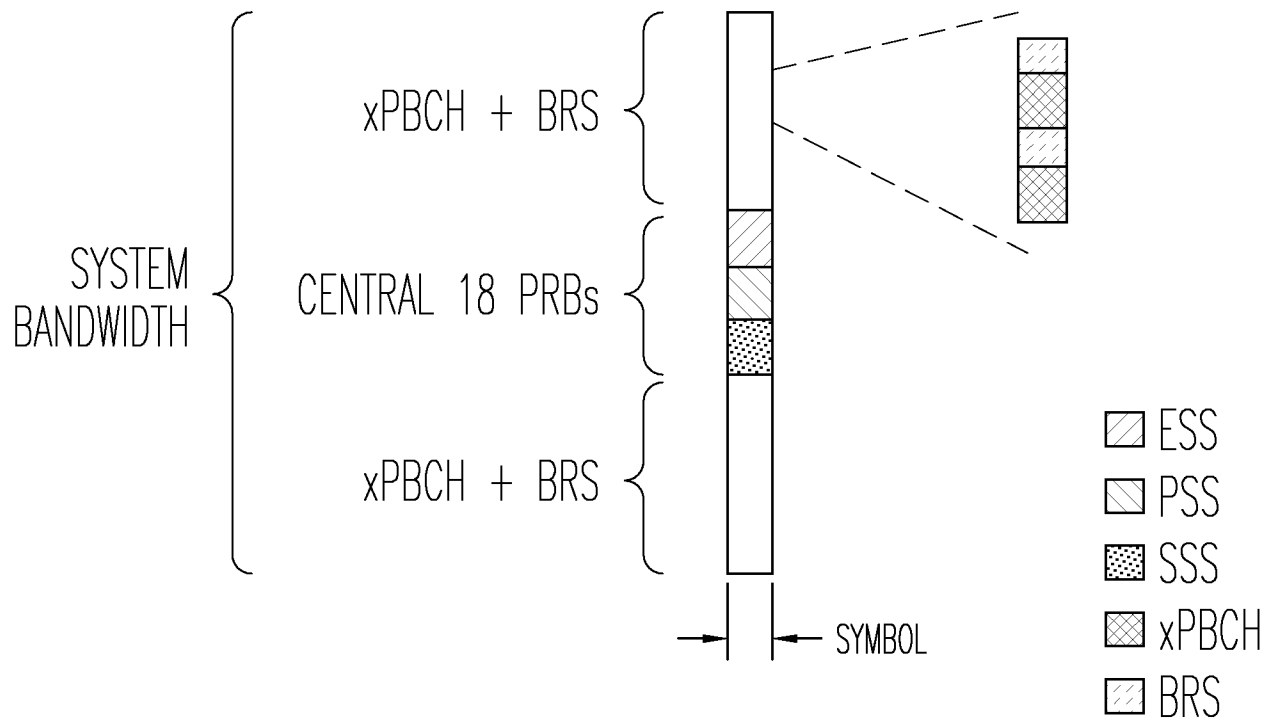


Fig. 12

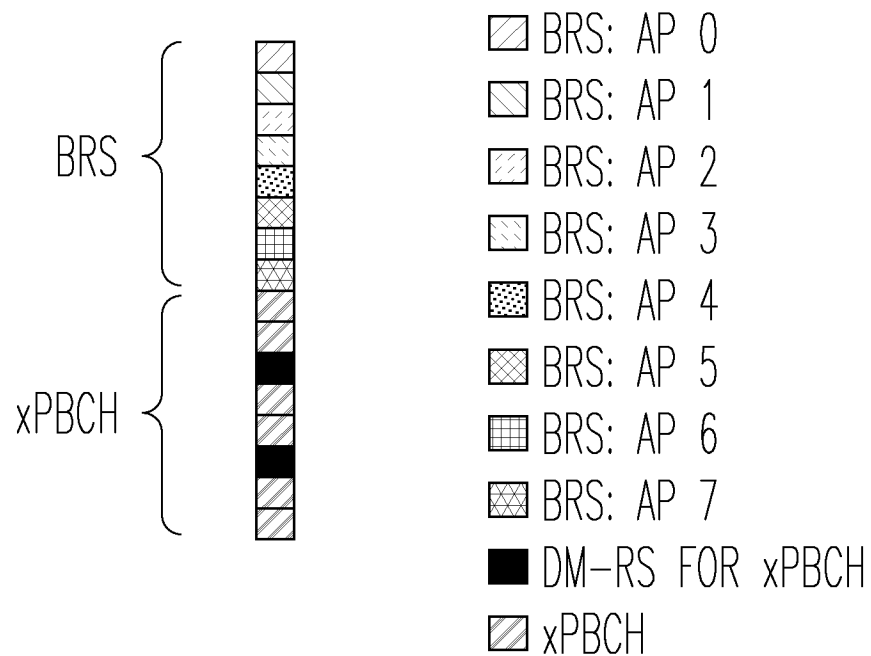


Fig. 13

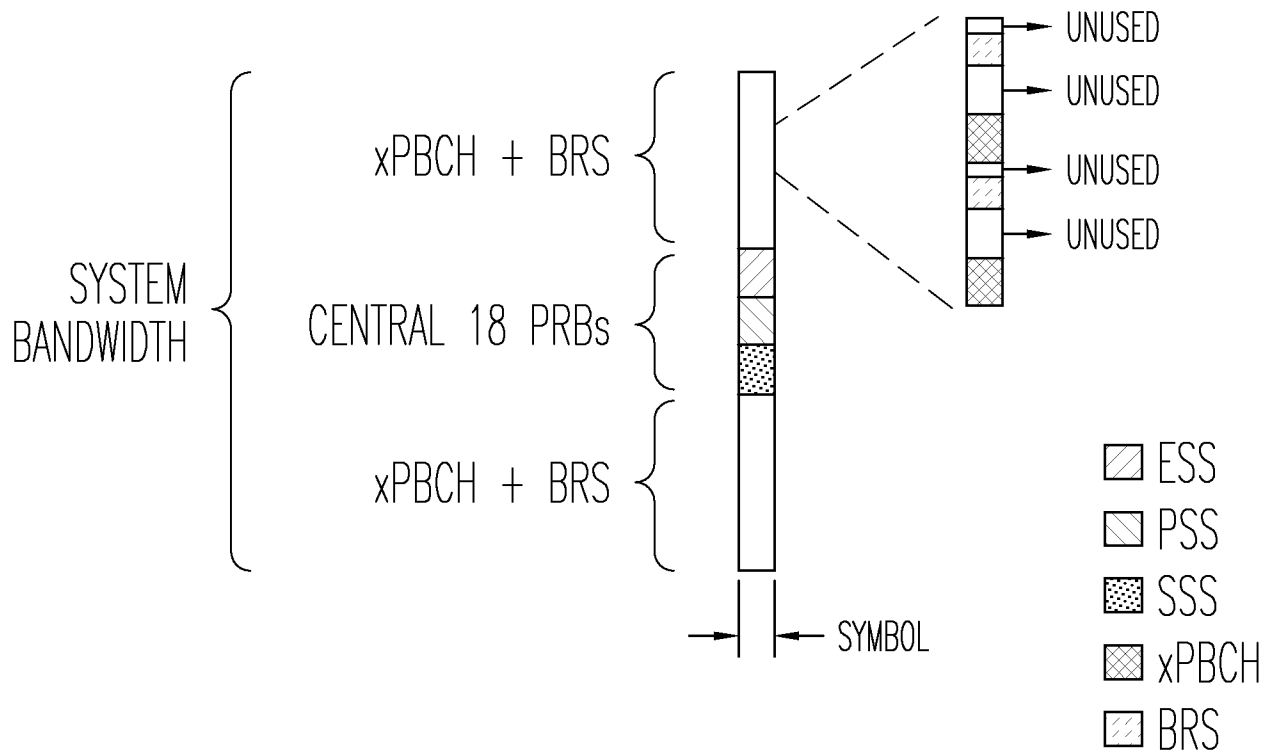


Fig. 14

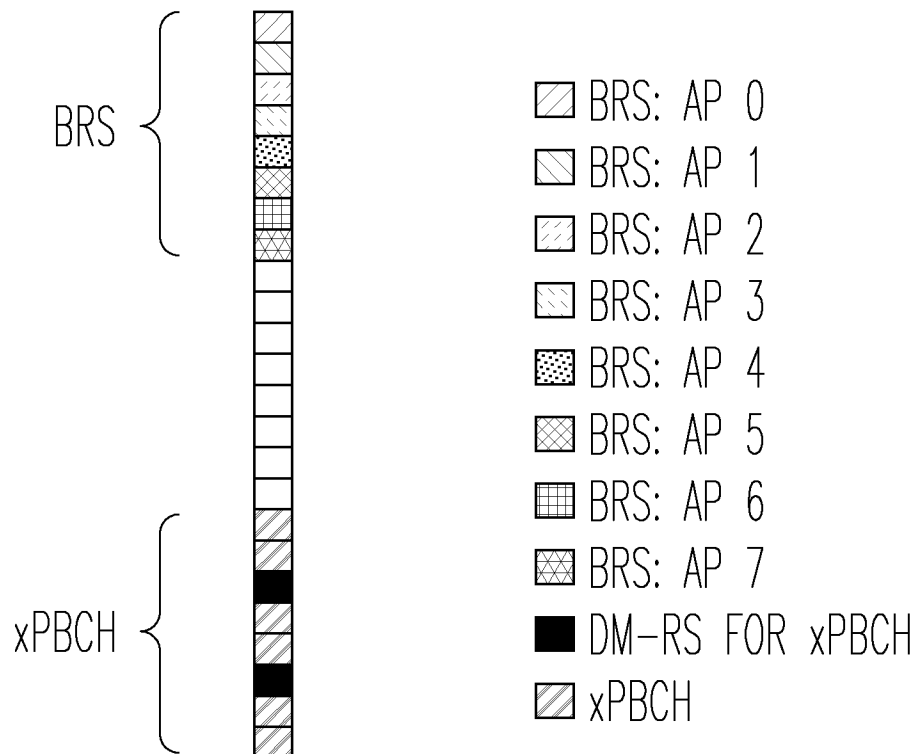


Fig. 15

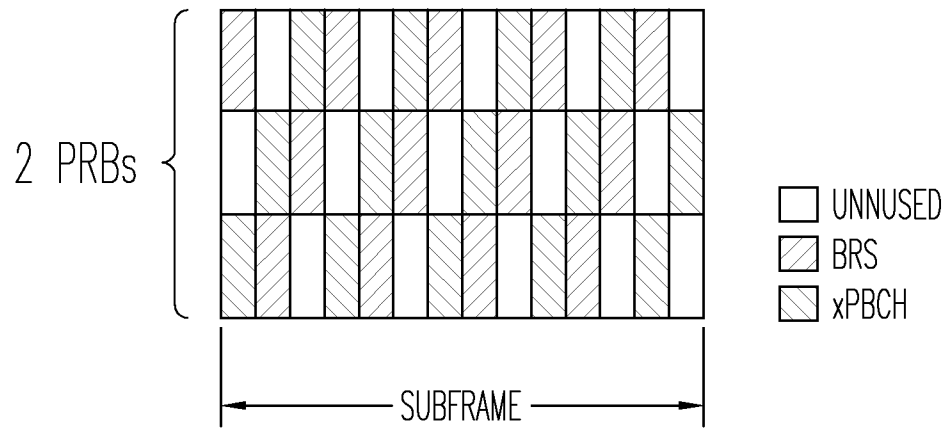


Fig. 16

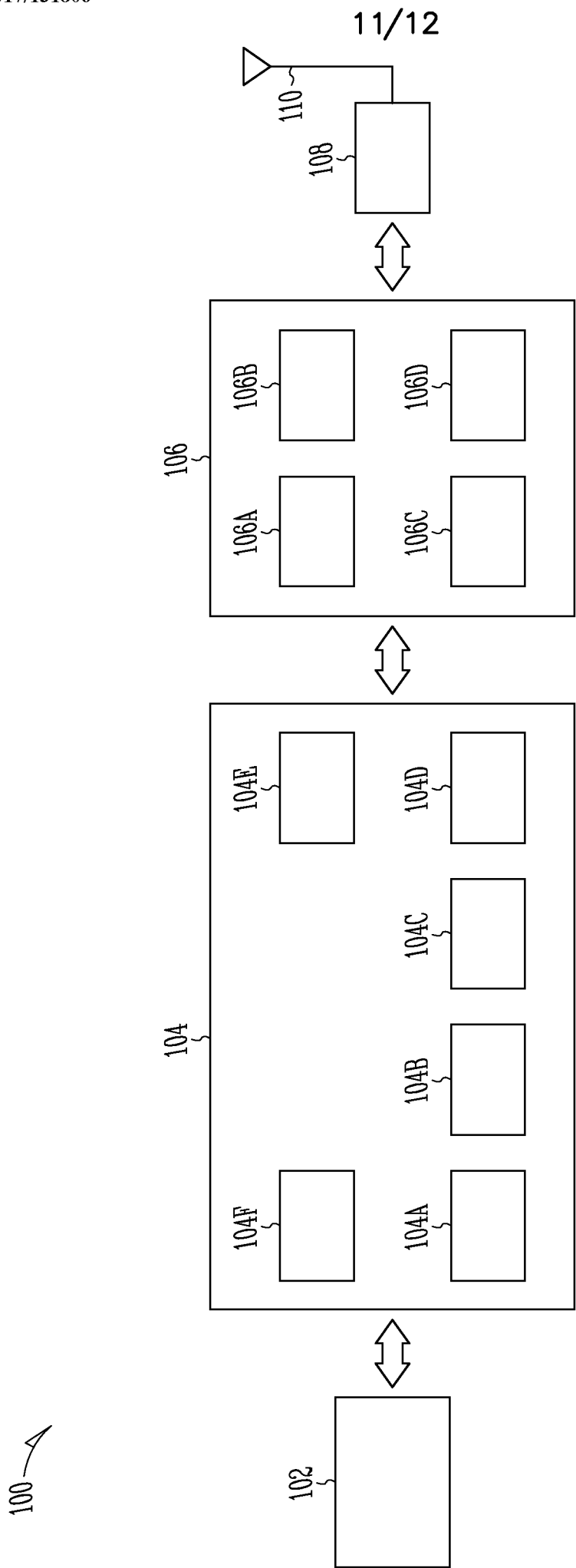
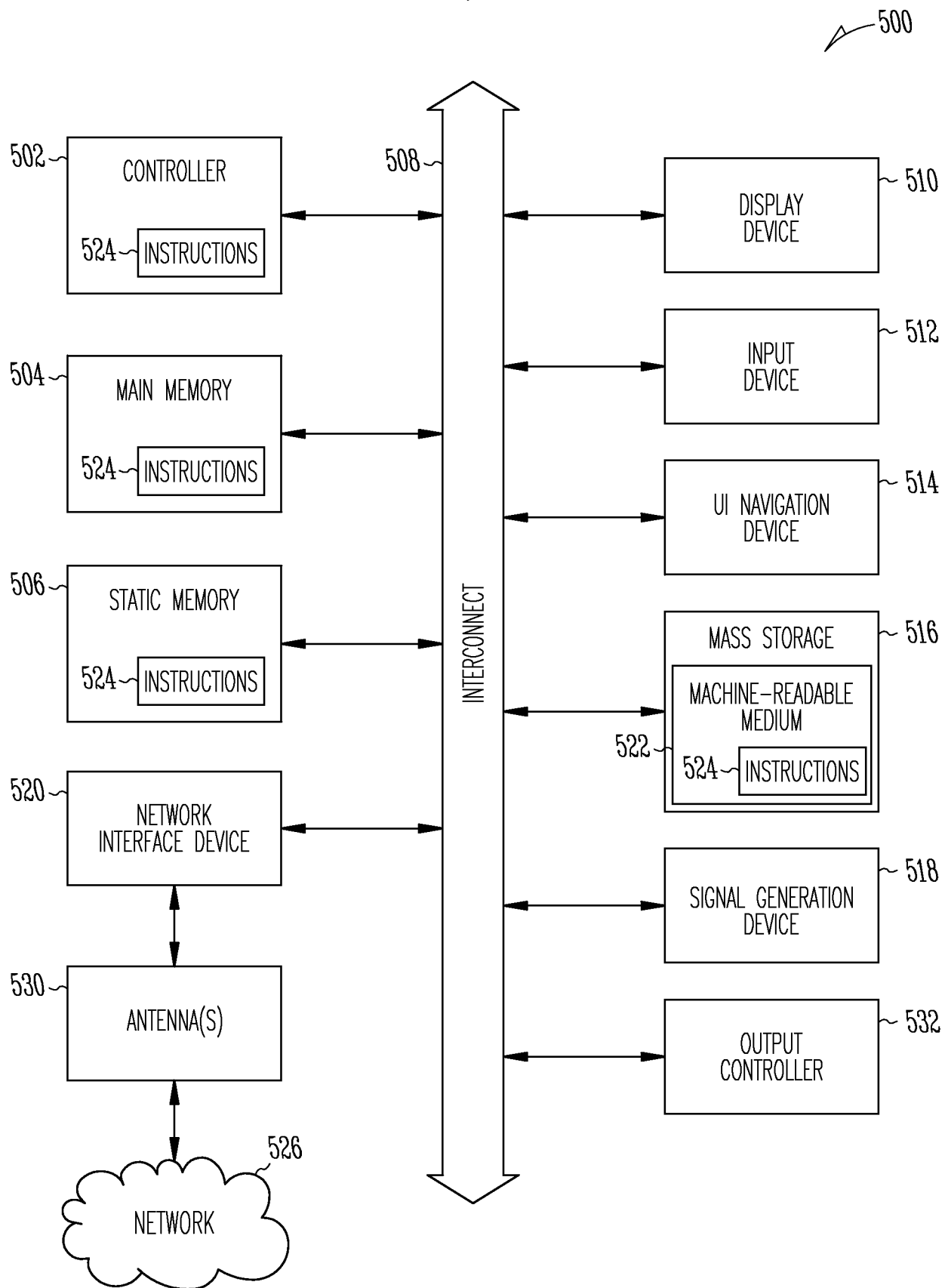


Fig. 17

*Fig. 18*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/035276**A. CLASSIFICATION OF SUBJECT MATTER****H04L 5/00(2006.01)I, H04W 76/04(2009.01)I**

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

B. FIELDS SEARCHEDMinimum documentation searched (classification system followed by classification symbols)
H04L 5/00; H04W 74/00; H04W 74/08; H04J 11/00; H04B 7/04; H04W 24/08; H04W 76/04Documentation 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 modelsElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: beamforming reference signals (BRSSs), antenna ports, MIB, PBCH, map, REs, RRC, DM-RS, PSS, SSS, ESS, interleave, frequency-division multiplexed, same OFDM symbol**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CMCC, 'Comparison on Port-based and Beam-based UE specific CSI-RS', R1-157004, 3GPP TSG RAN WG1 Meeting #83, Anaheim, USA, 7 November 2015 See page 3; and figure 3.	1-25
A	US 2015-0245378 A1 (SAMSUNG ELECTRONICS CO., LTD.) 27 August 2015 See paragraphs [0106]-[0118]; claims 1, 2; and figure 8.	1-25
A	NEC, 'Discussion on beamformed CSI-RS based scheme', R1-155279, 3GPP TSG RAN WG1 Meeting #82bis, Malmo, Sweden, 25 September 2015 See pages 1-4.	1-25
A	WO 2015-115776 A1 (SAMSUNG ELECTRONICS CO., LTD.) 6 August 2015 See paragraphs [132]-[142]; and figures 10, 11.	1-25
A	US 2016-0006549 A1 (LG ELECTRONICS INC.) 7 January 2016 See paragraphs [0159]-[0209]; claim 15; and figures 10, 11.	1-25



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

12 September 2016 (12.09.2016)

Date of mailing of the international search report

12 September 2016 (12.09.2016)

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

Facsimile No. +82-42-481-8578

Authorized officer

LEE, EUN KYU

Telephone No. +82-42-481-3580



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/035276

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2015-0245378 A1	27/08/2015	EP 2759076 A1 EP 2759076 A4 KR 10-2013-0032548 A US 2013-0077582 A1 US 9031019 B2 WO 2013-043006 A1	30/07/2014 10/06/2015 02/04/2013 28/03/2013 12/05/2015 28/03/2013
WO 2015-115776 A1	06/08/2015	US 2015-0124688 A1	07/05/2015
US 2016-0006549 A1	07/01/2016	KR 10-2015-0134328 A WO 2014-157867 A1	01/12/2015 02/10/2014