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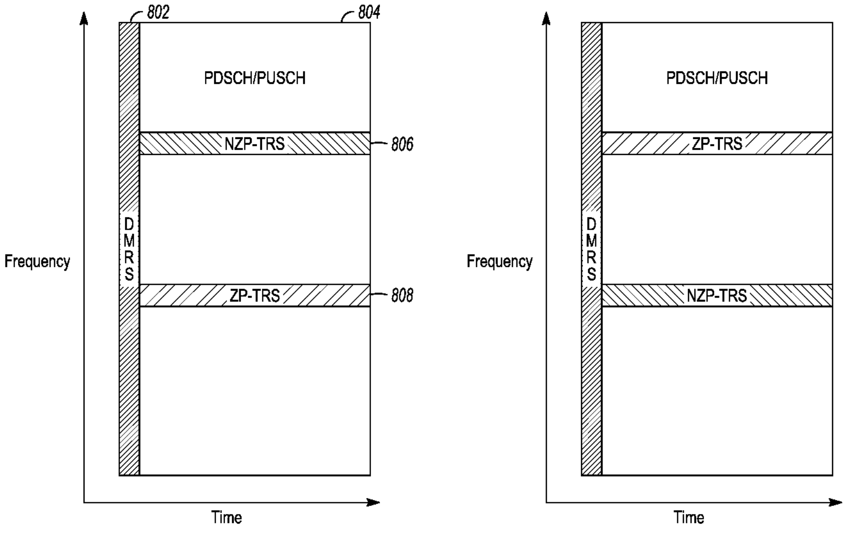

810 —Frame structure in victim cell

820 —Frame structure in interference cell

FIG. 8

(57) **Abstract:** Systems and methods of compensating for interference in a 5G system are generally described. An Interference Measurement Resource (IMR) is present in multiple resource elements of a subframe or a combination of a ZP and NZP Tracking Reference Signal (PT-RS) are used. An IMR covariance matrix is applied to compensate for the interference. The number of IMR subcarriers and symbols between adjacent IMRs is dependent on the numerologies and synchronization within the UE network. When the IMR is in multiple subcarriers in the first symbol of the second slot, and the matrix is determined using the IMR rather than a DMRS. The DCI comprises a flag that denotes whether IMR is enabled for a current PDCH, and indicates the manner to use the IMR. The subcarrier index for the NZP PT-RS overlaps the subcarrier index for the ZP PT-RS of another UE or gNB.

[Continued on next page]

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SYSTEM AND METHOD FOR IMR ASSOCIATED WITH DATA TRANSMISSION

PRIORITY CLAIM

[0001] This application claims the benefit of priority to United States Provisional Patent Application Serial No. 62/423,035, filed November 16, 2016, entitled "INTERFERENCE SUPPRESSION FOR PHASE TRACKING," and International Application No. PCT/CN2016/097336, filed August 30, 2016, entitled "IMR ASSOCIATED WITH DATA TRANSMISSION," each of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] Embodiments pertain to radio access networks. Some embodiments relate to interference between networks with different numerology including 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. Some embodiments relate to Interference Measurement Resource (IMR) mapping associated with a data transmission.

BACKGROUND

[0003] The use of 3GPP LTE systems (including both LTE and LTE-A systems) has increased due to both an increase in the types of devices user equipment (UEs) using network resources as well as the amount of data and bandwidth being used by various applications, such as video streaming, operating on these UEs. The advent of the latest generation (5G) may increase the flexibility of the numerology (e.g., subframe duration and timing) of the various uplink and downlink communications. Different cells may have different numerologies, which may lead to misalignment of interference between the cells and consequently impacting the interference covariance matrix.

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 of limitation, various embodiments discussed in the present document.

[0005] FIG. 1 illustrates an architecture of a system of a network in accordance with some embodiments.

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

[0007] FIG. 3 illustrates example interfaces of baseband circuitry in accordance with some embodiments.

[0008] FIG. 4 is an illustration of a control plane protocol stack in accordance with some embodiments.

[0009] FIG. 5 is an illustration of a user plane protocol stack in accordance with some embodiments.

[0010] FIG. 6 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein.

[0011] FIG. 7 illustrates a self-contained frame structure in accordance with some embodiments.

[0012] FIG. 8 illustrates frame structures containing Phase Tracking Reference Signals (PT-RS) in accordance with some embodiments.

[0013] FIG. 9 illustrates generation of a frame structure in accordance with some embodiments.

[0014] FIG. 10 illustrates PT-RS patterns for different bandwidth allocation in accordance with some embodiments.

[0015] FIG. 11 illustrates cells with different numerologies in accordance with some embodiments.

[0016] FIG. 12 illustrates IMR resource mapping according to some embodiments.

[0017] FIG. 13 illustrates IMR resource mapping according to some embodiments.

DETAILED DESCRIPTION

[0018] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other 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.

[0019] FIG. 1 illustrates an architecture of a system 100 of a network in accordance with some embodiments. The system 100 is shown to include a user equipment (UE) 101 and a UE 102. The UEs 101 and 102 are illustrated as smartphones (e.g., handheld touchscreen mobile computing devices connectable to one or more cellular networks), but may also comprise any mobile or non-mobile computing device, such as Personal Data Assistants (PDAs), pagers, laptop computers, desktop computers, wireless handsets, or any computing device including a wireless communications interface.

[0020] In some embodiments, any of the UEs 101 and 102 can comprise an Internet of Things (IoT) UE, which can comprise a network access layer designed for low-power IoT applications utilizing short-lived UE connections. An IoT UE can utilize technologies such as machine-to-machine (M2M) or machine-type communications (MTC) for exchanging data with an MTC server or device via a public land mobile network (PLMN), Proximity-Based Service (ProSe) or device-to-device (D2D) communication, sensor networks, or IoT networks. The M2M or MTC exchange of data may be a machine-initiated exchange of data. An IoT network describes interconnecting IoT UEs, which may include uniquely identifiable embedded computing devices (within the Internet infrastructure), with short-lived connections. The IoT UEs may execute background applications (e.g., keep-alive messages, status updates, etc.) to facilitate the connections of the IoT network.

[0021] The UEs 101 and 102 may be configured to connect, e.g., communicatively couple, with a radio access network (RAN) 110 - the RAN 110 may be, for example, an Evolved Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access Network (E-UTRAN), a NextGen RAN (NG RAN), or some other type of RAN. The UEs 101 and 102 utilize connections 103 and 104, respectively, each of which comprises a physical communications interface or layer (discussed in further detail below); in this example, the connections 103 and 104 are illustrated as an air interface to enable communicative coupling, and can be consistent with cellular communications protocols, such as a Global System for Mobile Communications (GSM) protocol, a code-division multiple access (CDMA) network protocol, a Push-to-Talk (PTT) protocol, a PTT over Cellular (POC) protocol, a Universal Mobile Telecommunications System (UMTS) protocol, a 3GPP Long Term Evolution (LTE) protocol, a fifth generation (5G) protocol, a New Radio (NR) protocol, and the like.

[0022] In this embodiment, the UEs 101 and 102 may further directly exchange communication data via a ProSe interface 105. The ProSe interface 105 may alternatively be referred to as a sidelink interface comprising one or more logical channels, including but not limited to a Physical Sidelink Control Channel (PSCCH), a Physical Sidelink Shared Channel (PSSCH), a Physical Sidelink Discovery Channel (PSDCH), and a Physical Sidelink Broadcast Channel (PSBCH).

[0023] The UE 102 is shown to be configured to access an access point (AP) 106 via connection 107. The connection 107 can comprise a local wireless connection, such as a connection consistent with any IEEE 802.11 protocol, wherein the AP 106 would comprise a wireless fidelity (WiFi®) router. In this example, the AP 106 is shown to be connected to the Internet without connecting to the core network of the wireless system (described in further detail below).

[0024] The RAN 110 can include one or more access nodes that enable the connections 103 and 104. These access nodes (ANs) can be referred to as base stations (BSs), NodeBs, evolved NodeBs (eNBs), next Generation NodeBs (gNB), RAN nodes, and so forth, and can comprise ground stations (e.g., terrestrial access points) or satellite stations providing coverage within a geographic area (e.g., a cell). The RAN 110 may include one or more RAN nodes for providing macrocells, e.g., macro RAN node 111, and one or more RAN nodes for providing femtocells or picocells (e.g., cells having smaller coverage areas, smaller user capacity, or higher bandwidth compared to macrocells), e.g., low power (LP) RAN node 112.

[0025] Any of the RAN nodes 111 and 112 can terminate the air interface protocol and can be the first point of contact for the UEs 101 and 102. In some embodiments, any of the RAN nodes 111 and 112 can fulfill various logical functions for the RAN 110 including, but not limited to, radio network controller (RNC) functions such as radio bearer management, uplink and downlink dynamic radio resource management and data packet scheduling, and mobility management.

[0026] In accordance with some embodiments, the UEs 101 and 102 can be configured to communicate using Orthogonal Frequency-Division Multiplexing (OFDM) communication signals with each other or with any of the RAN nodes 111 and 112 over a multicarrier communication channel in accordance various communication techniques, such as, but not limited to, an Orthogonal Frequency-Division Multiple Access (OFDMA) communication technique (e.g., for downlink communications) or a Single Carrier Frequency Division Multiple Access (SC-FDMA) communication technique (e.g., for uplink and ProSe or sidelink communications), although the scope of the embodiments is not limited in this respect. The OFDM signals can comprise a plurality of orthogonal subcarriers.

[0027] In some embodiments, a downlink resource grid can be used for downlink transmissions from any of the RAN nodes 111 and 112 to the UEs 101 and 102, while uplink transmissions can utilize similar techniques. The grid can be a time-frequency grid, called a resource grid or time-frequency resource grid, which is the physical resource in the downlink in each slot. Such a time-frequency plane representation is a common practice for OFDM systems, which makes it intuitive for radio resource allocation. Each column and each row of the resource grid corresponds to one OFDM symbol and one OFDM subcarrier, respectively. The duration of the resource grid in the time domain corresponds to one slot in a radio frame. The smallest time-frequency unit in a resource grid is denoted as a resource element. Each resource grid comprises a number of resource blocks, which describe the mapping of certain physical channels to resource elements. Each resource block comprises a collection of resource elements; in the frequency domain, this may represent the smallest quantity of resources that currently can be allocated. There are several different physical downlink channels that are conveyed using such resource blocks.

[0028] The physical downlink shared channel (PDSCH) may carry user data and higher-layer signaling to the UEs 101 and 102. The physical downlink control channel (PDCCH) may carry information about the transport format and resource allocations related to the PDSCH channel, among other things. It may also inform the UEs 101 and 102 about the transport format, resource allocation, and H-ARQ (Hybrid Automatic Repeat Request) information related to the uplink shared channel. Typically, downlink scheduling (assigning control and shared channel resource blocks to the UE 102 within a cell) may be performed at any of the RAN nodes 111 and 112 based on channel quality information fed back from any of the UEs 101 and 102. The downlink resource assignment information may be sent on the PDCCH used for (e.g., assigned to) each of the UEs 101 and 102.

[0029] The PDCCH may use control channel elements (CCEs) to convey the control information. Before being mapped to resource elements, the PDCCH complex-valued symbols may first be organized into quadruplets, which may then be permuted using a sub-block interleaver for rate matching. Each PDCCH may be transmitted using one or more of these CCEs, where each CCE may correspond to nine sets of four physical resource elements known as resource element groups (REGs). Four Quadrature Phase Shift Keying (QPSK) symbols may be mapped to each REG. The PDCCH can be transmitted using one or more CCEs, depending on the size of the downlink control information (DCI) and the channel condition. There can be four or more different PDCCH formats defined in LTE with different numbers of CCEs (e.g., aggregation level, L=1, 2, 4, or 8).

[0030] Some embodiments may use concepts for resource allocation for control channel information that are an extension of the above-described concepts. For example, some embodiments may utilize an enhanced physical downlink control channel (EPDCCH) that uses PDSCH resources for control information transmission. The EPDCCH may be transmitted using one or more enhanced the control channel elements (ECCEs). Similar to above, each ECCE may correspond to nine sets of four physical resource elements known as an enhanced resource element groups (EREGs). An ECCE may have other numbers of EREGs in some situations.

[0031] The RAN 110 is shown to be communicatively coupled to a core network (CN) 120 —via an S1 interface 113. In embodiments, the CN 120 may be an evolved packet core (EPC) network, a NextGen Packet Core (NPC) network, or some other type of CN. In this embodiment, the S1 interface 113 is split into two parts: the S1-U interface 114, which carries traffic data between the RAN nodes 111 and 112 and the serving gateway (S-GW) 122, and the S1-mobility management entity (MME) interface 115, which is a signaling interface between the RAN nodes 111 and 112 and MMEs 121.

[0032] In this embodiment, the CN 120 comprises the MMEs 121, the S-GW 122, the Packet Data Network (PDN) Gateway (P-GW) 123, and a home subscriber server (HSS) 124. The MMEs 121 may be similar in function to the control plane of legacy Serving General Packet Radio Service (GPRS) Support Nodes (SGSN). The MMEs 121 may manage mobility aspects in access such as gateway selection and tracking area list management. The HSS 124 may comprise a database for network users, including subscription-related information to support the network entities’ handling of communication sessions. The CN 120 may comprise one or several HSSs 124, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS 124 can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc.

[0033] The S-GW 122 may terminate the S1 interface 113 towards the RAN 110, and routes data packets between the RAN 110 and the CN 120. In addition, the S-GW 122 may be a local mobility anchor point for inter-RAN node handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement.

[0034] The P-GW 123 may terminate an SGi interface toward a PDN. The P-GW 123 may route data packets between the EPC network 123 and external networks such as a network including the application server 130 (alternatively referred to as application function (AF)) via an Internet Protocol (IP) interface 125. Generally, the application server 130 may be an element offering applications that use IP bearer resources with the core network (e.g., UMTS Packet Services (PS) domain, LTE PS data services, etc.). In this embodiment, the P-GW 123 is shown to be communicatively coupled to an application server 130 via an IP communications interface 125. The application server 130 can also be configured to support one or more communication services (e.g., Voice-over-Internet Protocol (VoIP) sessions, PTT sessions, group communication sessions, social networking services, etc.) for the UEs 101 and 102 via the CN 120.

[0035] The P-GW 123 may further be a node for policy enforcement and charging data collection. Policy and Charging Enforcement Function (PCRF) 126 is the policy and charging control element of the CN 120. In a non-roaming scenario, there may be a single PCRF in the Home Public Land Mobile Network (HPLMN) associated with a UE’s Internet Protocol Connectivity Access Network (IP-CAN) session. In a roaming scenario with local breakout of traffic, there may be two PCRFs associated with a UE’s IP-CAN session: a Home PCRF

(H-PCRF) within a HPLMN and a Visited PCRF (V-PCRF) within a Visited Public Land Mobile Network (VPLMN). The PCRF 126 may be communicatively coupled to the application server 130 via the P-GW 123. The application server 130 may signal the PCRF 126 to indicate a new service flow and select the appropriate Quality of Service (QoS) and charging parameters. The PCRF 126 may provision this rule into a Policy and Charging Enforcement Function (PCEF) (not shown) with the appropriate traffic flow template (TFT) and QoS class of identifier (QCI), which commences the QoS and charging as specified by the application server 130.

[0036] FIG. 2 illustrates example components of a device 200 in accordance with some embodiments. In some embodiments, the device 200 may include application circuitry 202, baseband circuitry 204, Radio Frequency (RF) circuitry 206, front-end module (FEM) circuitry 208, one or more antennas 210, and power management circuitry (PMC) 212 coupled together at least as shown. The components of the illustrated device 200 may be included in a UE or a RAN node. In some embodiments, the device 200 may include less elements (e.g., a RAN node may not utilize application circuitry 202, and instead include a processor/controller to process IP data received from an EPC). In some embodiments, the device 200 may include additional elements such as, for example, memory/storage, display, camera, sensor, or input/output (I/O) interface. In other embodiments, the components described below may be included in more than one device (e.g., said circuitries may be separately included in more than one device for Cloud-RAN (C-RAN) implementations).

[0037] The application 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 or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications or operating systems to run on the device 200. In some embodiments, processors of application circuitry 202 may process IP data packets received from an EPC.

[0038] 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 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 circuity 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 third generation (3G) baseband processor 204A, a fourth generation (4G) baseband processor 204B, a fifth generation (5G) baseband processor 204C, or other baseband processor(s) 204D for other existing generations, generations in development or to be developed in the future (e.g., second generation (2G), sixth generation (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. In other embodiments, some or all of the functionality of baseband processors 204A-D may be included in modules stored in the memory 204G and executed via a Central Processing Unit (CPU) 204E. 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 Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 204 may include convolution, tail-biting convolution, turbo, Viterbi, 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.

[0039] In some embodiments, the baseband circuitry 204 may include one or more audio digital signal processor(s) (DSP) 204F. The audio DSP(s) 204F may be 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).

[0040] 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 (EUTRAN) 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.

[0041] 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. 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 signals to the FEM circuitry 208 for transmission.

[0042] In some embodiments, the receive signal path of the RF circuitry 206 may include mixer circuitry 206A, amplifier circuitry 206B and filter circuitry 206C. In some embodiments, the transmit signal path of the RF circuitry 206 may include 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 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 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.

[0043] 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.

[0044] 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 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 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.

[0045] 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.

[0046] 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.

[0047] 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.

[0048] 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.

[0049] 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.

[0050] 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 Nd equal packets of phase, where Nd is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

[0051] 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 (fLO). In some embodiments, the RF circuitry 206 may include an IQ/polar converter.

[0052] 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. In various embodiments, the amplification through the transmit or receive signal paths may be done solely in the RF circuitry 206, solely in the FEM 208, or in both the RF circuitry 206 and the FEM 208.

[0053] 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 an 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).

[0054] In some embodiments, the PMC 212 may manage power provided to the baseband circuitry 204. In particular, the PMC 212 may control power-source selection, voltage scaling, battery charging, or DC-to-DC conversion. The PMC 212 may often be included when the device 200 is capable of being powered by a battery, for example, when the device is included in a UE. The PMC 212 may increase the power conversion efficiency while providing desirable implementation size and heat dissipation characteristics.

[0055] While FIG. 2 shows the PMC 212 coupled only with the baseband circuitry 204. However, in other embodiments, the PMC 2 12 may be additionally or alternatively coupled with, and perform similar power management operations for, other components such as, but not limited to, application circuitry 202, RF circuitry 206, or FEM 208.

[0056] In some embodiments, the PMC 212 may control, or otherwise be part of, various power saving mechanisms of the device 200. For example, if the device 200 is in an RRC_Connected state, where it is still connected to the RAN node as it expects to receive traffic shortly, then it may enter a state known as Discontinuous Reception Mode (DRX) after a period of inactivity. During this state, the device 200 may power down for brief intervals of time and thus save power.

[0057] If there is no data traffic activity for an extended period of time, then the device 200 may transition off to an RRC_Idle state, where it disconnects from the network and does not perform operations such as channel quality feedback, handover, etc. The device 200 goes into a very low power state and it performs paging where again it periodically wakes up to listen to the network and then powers down again. The device 200 may not receive data in this state, in order to receive data, it must transition back to RRC_Connected state.

[0058] An additional power saving mode may allow a device to be unavailable to the network for periods longer than a paging interval (ranging from seconds to a few hours). During this time, the device is totally unreachable to the network and may power down completely. Any data sent during this time incurs a large delay and it is assumed the delay is acceptable.

[0059] Processors of the application circuitry 202 and processors of the baseband circuitry 204 may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry 204, alone or in combination, may be used execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry 204 may utilize data (e.g., packet data) received from these layers and further execute Layer 4 functionality (e.g., transmission communication protocol (TCP) and user datagram protocol (UDP) layers). As referred to herein, Layer 3 may comprise a radio resource control (RRC) layer, described in further detail below. As referred to herein, Layer 2 may comprise a medium access control (MAC) layer, a radio link control (RLC) layer, and a packet data convergence protocol (PDCP) layer, described in further detail below. As referred to herein, Layer 1 may comprise a physical (PHY) layer of a UE/RAN node, described in further detail below.

[0060] FIG. 3 illustrates example interfaces of baseband circuitry in accordance with some embodiments. As discussed above, the baseband circuitry 204 of FIG. 2 may comprise processors 204A-XT04E and a memory 204G utilized by said processors. Each of the processors 204A-XT04E may include a memory interface, 304A-XU04E, respectively, to send/receive data to/from the memory 204G.

[0061] The baseband circuitry 204 may further include one or more interfaces to communicatively couple to other circuitries/devices, such as a memory interface 312 (e.g., an interface to send/receive data to/from memory external to the baseband circuitry 204), an application circuitry interface 314 (e.g., an interface to send/receive data to/from the application circuitry 202 of FIG. 2), an RF circuitry interface 316 (e.g., an interface to send/receive data to/from RF circuitry 206 of FIG. 2), a wireless hardware connectivity interface 318 (e.g., an interface to send/receive data to/from Near Field Communication (NFC) components, Bluetooth® components (e.g., Bluetooth® Low Energy), Wi-Fi® components, and other communication components), and a power management interface 320 (e.g., an interface to send/receive power or control signals to/from the PMC 212).

[0062] FIG. 4 is an illustration of a control plane protocol stack in accordance with some embodiments. In this embodiment, a control plane 400 is shown as a communications protocol stack between the UE 101 (or alternatively, the UE 102), the RAN node 111 (or alternatively, the RAN node 112), and the MME 121.

[0063] The PHY layer 401 may transmit or receive information used by the MAC layer 402 over one or more air interfaces. The PHY layer 401 may further perform link adaptation or adaptive modulation and coding (AMC), power control, cell search (e.g., for initial synchronization and handover purposes), and other measurements used by higher layers, such as the RRC layer 405. The PHY layer 401 may still further perform error detection on the transport channels, forward error correction (FEC) coding/decoding of the transport channels, modulation/demodulation of physical channels, interleaving, rate matching, mapping onto physical channels, and Multiple Input Multiple Output (MIMO) antenna processing.

[0064] The MAC layer 402 may perform mapping between logical channels and transport channels, multiplexing of MAC service data units (SDUs) from one or more logical channels onto transport blocks (TB) to be delivered to PHY via transport channels, de-multiplexing MAC SDUs to one or more logical channels from transport blocks (TB) delivered from the PHY via transport channels, multiplexing MAC SDUs onto TBs, scheduling information reporting, error correction through hybrid automatic repeat request (HARQ), and logical channel prioritization.

[0065] The RLC layer 403 may operate in a plurality of modes of operation, including: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM). The RLC layer 403 may execute transfer of upper layer protocol data units (PDUs), error correction through automatic repeat request (ARQ) for AM data transfers, and concatenation, segmentation and reassembly of RLC SDUs for UM and AM data transfers. The RLC layer 403 may also execute re-segmentation of RLC data PDUs for AM data transfers, reorder RLC data PDUs for UM and AM data transfers, detect duplicate data for UM and AM data transfers, discard RLC SDUs for UM and AM data transfers, detect protocol errors for AM data transfers, and perform RLC re-establishment.

[0066] The PDCP layer 404 may execute header compression and decompression of IP data, maintain PDCP Sequence Numbers (SNs), perform in-sequence delivery of upper layer PDUs at re-establishment of lower layers, eliminate duplicates of lower layer SDUs at re-establishment of lower layers for radio bearers mapped on RLC AM, cipher and decipher control plane data, perform integrity protection and integrity verification of control plane data, control timer-based discard of data, and perform security operations (e.g., ciphering, deciphering, integrity protection, integrity verification, etc.).

[0067] The main services and functions of the RRC layer 405 may include broadcast of system information (e.g., included in Master Information Blocks (MIBs) or System Information Blocks (SIBs) related to the non-access stratum (NAS)), broadcast of system information related to the access stratum (AS), paging, establishment, maintenance and release of an RRC connection between the UE and E-UTRAN (e.g., RRC connection paging, RRC connection establishment, RRC connection modification, and RRC connection release), establishment, configuration, maintenance and release of point to point Radio Bearers, security functions including key management, inter radio access technology (RAT) mobility, and measurement configuration for UE measurement reporting. Said MIBs and SIBs may comprise one or more information elements (IEs), which may each comprise individual data fields or data structures.

[0068] The UE 101 and the RAN node 111 may utilize a Uu interface (e.g., an LTE-Uu interface) to exchange control plane data via a protocol stack comprising the PHY layer 401, the MAC layer 402, the RLC layer 403, the PDCP layer 404, and the RRC layer 405.

[0069] The non-access stratum (NAS) protocols 406 form the highest stratum of the control plane between the UE 101 and the MME 121. The NAS protocols 406 support the mobility of the UE 101 and the session management procedures to establish and maintain IP connectivity between the UE 101 and the P-GW 123.

[0070] The S1 Application Protocol (S1-AP) layer 415 may support the functions of the S1 interface and comprise Elementary Procedures (EPs). An EP is a unit of interaction between the RAN node 111 and the CN 120. The S1-AP layer services may comprise two groups: UE-associated services and non UE-associated services. These services perform functions including, but not limited to: E-UTRAN Radio Access Bearer (E-RAB) management, UE capability indication, mobility, NAS signaling transport, RAN Information Management (RIM), and configuration transfer.

[0071] The Stream Control Transmission Protocol (SCTP) layer (alternatively referred to as the SCTP/IP layer) 414 may ensure reliable delivery of signaling messages between the RAN node 111 and the MME 121 based, in part, on the IP protocol, supported by the IP layer 413. The L2 layer 412 and the L1 layer 411 may refer to communication links (e.g., wired or wireless) used by the RAN node and the MME to exchange information.

[0072] The RAN node 111 and the MME 121 may utilize an S1-MME interface to exchange control plane data via a protocol stack comprising the L1 layer 411, the L2 layer 412, the IP layer 413, the SCTP layer 414, and the S1-AP layer 415.

[0073] FIG. 5 is an illustration of a user plane protocol stack in accordance with some embodiments. In this embodiment, a user plane 500 is shown as a communications protocol stack between the UE 101 (or alternatively, the UE 102), the RAN node 111 (or alternatively, the RAN node 112), the S-GW

122, and the P-GW 123. The user plane 500 may utilize at least some of the same protocol layers as the control plane 400. For example, the UE 101 and the RAN node 111 may utilize a Uu interface (e.g., an LTE-Uu interface) to exchange user plane data via a protocol stack comprising the PHY layer 401, the MAC layer 402, the RLC layer 403, the PDCP layer 404.

[0074] The General Packet Radio Service (GPRS) Tunneling Protocol for the user plane (GTP-U) layer 504 may be used for carrying user data within the GPRS core network and between the radio access network and the core network. The user data transported can be packets in any of IPv4, IPv6, or PPP formats, for example. The UDP and IP security (UDP/IP) layer 503 may provide checksums for data integrity, port numbers for addressing different functions at the source and destination, and encryption and authentication on the selected data flows. The RAN node 111 and the S-GW 122 may utilize an S1-U interface to exchange user plane data via a protocol stack comprising the L1 layer 411, the L2 layer 412, the UDP/IP layer 503, and the GTP-U layer 504. The S-GW 122 and the P-GW 123 may utilize an S5/S8a interface to exchange user plane data via a protocol stack comprising the L1 layer 411, the L2 layer 412, the UDP/IP layer 503, and the GTP-U layer 504. As discussed above with respect to FIG. 4, NAS protocols support the mobility of the UE 101 and the session management procedures to establish and maintain IP connectivity between the UE 101 and the P-GW 123.

[0075] FIG. 6 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, FIG. 6 shows a diagrammatic representation of hardware resources 600 including one or more processors (or processor cores) 610, one or more memory/storage devices 620, and one or more communication resources 630, each of which may be communicatively coupled via a bus 640. For embodiments where node virtualization (e.g., NFV) is utilized, a hypervisor 602 may be executed to provide an execution environment for one or more network slices/sub-slices to utilize the hardware resources 600

[0076] The processors 610 (e.g., a central processing unit (CPU), a reduced instruction set computing (RISC) processor, a complex instruction set computing (CISC) processor, a graphics processing unit (GPU), a digital signal processor (DSP) such as a baseband processor, an application specific integrated circuit (ASIC), a radio-frequency integrated circuit (RFIC), another processor, or any suitable combination thereof) may include, for example, a processor 612 and a processor 614.

[0077] The memory/storage devices 620 may include main memory, disk storage, or any suitable combination thereof. The memory/storage devices 620 may include, but are not limited to any type of volatile or non-volatile memory such as dynamic random access memory (DRAM), static random-access memory (SRAM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), Flash memory, solid-state storage, etc.

[0078] The communication resources 630 may include interconnection or network interface components or other suitable devices to communicate with one or more peripheral devices 604 or one or more databases 606 via a network 608. For example, the communication resources 630 may include wired communication components (e.g., for coupling via a Universal Serial Bus (USB)), cellular communication components, NFC components, Bluetooth® components (e.g., Bluetooth® Low Energy), Wi-Fi® components, and other communication components.

[0079] Instructions 650 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 610 to perform any one or more of the methodologies discussed herein. The instructions 650 may reside, completely or partially, within at least one of the processors 610 (e.g., within the processor’s cache memory), the memory/storage devices 620, or any suitable combination thereof. In some embodiments, the instructions 650 may reside on a tangible, non-volatile communication device readable medium, which may include a single medium or multiple media. Furthermore, any portion of the instructions 650 may be transferred to the hardware resources 600 from any combination of the peripheral devices 604 or the databases 606. Accordingly, the memory of processors 610, the memory/storage devices 620, the peripheral devices 604, and the databases 606 are examples of computer-readable and machine-readable media.

[0080] FIG. 7 illustrates a self-contained frame structure in accordance with some embodiments. The self-contained TDD frame structure 700 includes a downlink (DL) transmission 710 and an uplink (UL) transmission 720, each of which may contain control information (e.g., Physical Downlink Control Channel (PDCCH) 702 or Physical Uplink Control Channel (PUCCH) 712) and data (e.g., Physical Data Channel (PDCH) which may be the Physical Downlink Shared Channel (PDSCH) 706 or Physical Uplink Shared Channel (PUSCH) 714) as well as feedback (e.g., Demodulation Reference Signal (DMRS) 704) multiplexed in the same subframe. A gap period 708 may be used between the downlink and uplink transmissions to permit the transceiver to switch from the transmitter chain to the receiver chain.

[0081] Decoding some or all of the subframe may take a finite amount of time, thereby creating a latency between reception and processing of the subframe. The decoding latency can be reduced, however, based on the frame structure 700. To support low decoding latency, the DMRS 704 may be provided in the symbol ahead of the PDCH. A Phase Tracking Reference Signals (PT-RS) also may be used to compensate for the phase noise impact for symbols allocated to PDCH. Note that in 5G systems, unlike LTE systems, the DMRS may be constrained to be located in only the first slot of a subframe.

[0082] One or more factors may cause phase shifts for different symbols. These factors include the Doppler effect, Carrier Frequency Offset (CFO) and phase noise. Phase noise may cause a Common Phase Error (CPE) and Inter Carrier Interference (ICI). The CPE is phase rotation of all subcarriers by an equal amount; ICI is an additive noise. For Doppler, an additional DMRS could be utilized to track the phase shift as well as the amplitude change. For CFO and phase noise, the low density PT-RS can help to compensate the phase shift. However, as the density of PT-RS is relatively low (compared with, e.g., the DMRS), the channel estimation may not be accurate enough through the use of PT-RS alone, leading to the potential for additional phase error being present. Reduction of interference for the PT-RS may be desirable.

[0083] In a dynamic TDD frame structure, for example, the interference may originate from a neighbor gNB or UE. In particular, interference may arise from various communication interactions. The types of interference may include interference from a neighbor gNB to a victim UE (Case DL-1 (or D-1)), interference from a neighbor UE to a victim UE (Case D-2), interference from a neighbor UE to a victim gNB (Case UL-1 (or U-1)) and interference from a neighbor gNB to a victim gNB (Case U-2). Due to the transmission power levels, cases D-1 and U-2 are generally more problematic. The PT-RS may be used to support interference suppression, which may help to increase the phase compensation accuracy for various types of waveforms. The waveforms may include both cyclic prefix OFDM (CP-OFDM) and discrete Fourier transform spread OFDM (DFT-S-OFDM) waveforms.

[0084] With the use of different waveforms, the interference types can be further classified into sub-cases. In particular, interference from a neighbor UE to a victim gNB (Case U-1)) may be classified into: a DFT-S-OFDM waveform in the neighbor cell and a CP-OFDM waveform in the victim cell (case U-1a); a DFT-S-OFDM waveform in the neighbor cell and a DFT-S-OFDM waveform in the victim cell (case U-1b); a CP-OFDM waveform in the neighbor cell and a CP-OFDM waveform in the victim cell (case U-1c); and a CP-OFDM waveform in the neighbor cell and a DFT-S-OFDM waveform in the victim cell (case U-1d). Similarly, interference from a neighbor gNB to a victim gNB (Case U-2)) may be classified into: a CP-OFDM waveform in the neighbor cell and a CP-OFDM waveform in the victim cell (case U-2a); and a CP-OFDM waveform in the neighbor cell and a DFT-S-OFDM waveform in the victim cell (case U-2b).

[0085] FIG. 8 illustrates frame structures containing Tracking Reference Signals (PT-RS) in accordance with some embodiments. The frame structure, like that shown in FIG. 7, may be generated and encoded by the baseband processing circuitry (e.g., UE or gNB) before being transmitted via an interface to another device (e.g., gNB or UE), where the frame structure is received and decoded. The frame structure of a subframe as a function of frequency is shown for different cells; in particular the subframe of the victim cell 810 and the subframe of the interference cell 820 are shown in FIG. 8. The frame structure of each of the victim cell 810 and the interference cell 820 may share similar regions.

[0086] The regions in common may include a DMRS 802. The DMRS 802 may be provided in the first symbol across the entire frequency spectrum. The remaining symbols of the subframe 810, 820 may include data regions 804 separated by tracking regions 806, 808. Specifically, the data regions 804 may include a PDSCH (for a DL subframe) or a PUSCH (for a UL subframe). The tracking regions 806, 808 may include zero power (ZP) PT-RS symbols 806 transmitted on a first predetermined (e.g., 1 or 2) number of subcarriers over the entire subframe and non-zero power (NZP) PT-RS symbols 808 transmitted on a second predetermined (e.g., 1 or 2) number of subcarriers over the entire subframe. The number of subcarriers for transmission of the ZP and NZP PT-RS symbols 806, 808 may generally be the same, although in other embodiments they may differ. As shown in the embodiment of FIG. 8, the ZP PT-RS symbols 806 of each of the victim cell 810 and the interference cell 820 may overlap in time and frequency with the NZP PT-RS 808 of the other of the victim cell 810 and the interference cell 820 (i.e., the subcarrier index may be the same).

[0087] The use of the ZP and NZP PT-RS 806, 808 may reduce the interference for the PT-RS in the system. The NZP PT-RS 808 may be generated at the desired subcarrier index by the interfering UE and the ZP PT-RS 806 may be generated by the victim UE at the same subcarrier index. The mutual interference for the PT-RS subcarriers can be suppressed with the help of a frequency offset and the ZP PT-RS 806. The subcarriers where the PT-RS are added may be the same in all cells. In some embodiments, the subcarrier index of the NZP and ZP PT-RS can be different in different cells. The subcarrier index can be determined dependent on one or more of the cell ID, the virtual cell ID, the subframe index or slot index or configured by higher layer signaling or via the DCI. In some embodiments, while the NZP PT-RS may always be transmitted, whether or not the ZP PT-RS are to be transmitted may be configured by higher layer signaling or the DCI. The subcarrier index may thus be programmed and stored in memory of the UEs or provided to the UEs from an gNB to which the UE is connected. Although only one subcarrier index appears to contain each of the NZP PT-RS and ZP PT-RS, one or both PT-RSs may be carried by multiple consecutive or non-consecutive subcarrier indexes.

[0088] FIG. 9 illustrates generation of a frame structure in accordance with some embodiments. The frame structure 800 may be similar to the frame structure shown in FIG. 8 and may be generated, encoded and transmitted and received and decoded similar to the above. To generate the UL frame structure 800, the baseband circuitry 900 may use a discrete Fourier transform (DFT) 904 and a PT-RS generator 902. The DFT 904 may receive data and encode the data on the subcarriers indicated by the cell ID, the virtual cell ID, the subframe index and/or slot index or as configured by higher layer signaling or via the DCI. The PT-RS generator 902 may similarly generate and encode the NZP PT-RS signals in the appropriate subcarriers. The PT-RS generator 902 may or may not generate and encode ZP PT-RS signals in the other subcarriers, as indicated. If not, these NZP PT-RS subcarriers may be used for data. As seen, the NZP PT-RS signals may be generated by the PT-RS generator 902 and added to the data generated by the DFT 904. At the subcarriers used for PT-RS, the corresponding data channel symbols after DFT may be punctured.

[0089] As different uplink waveforms may be used, to reduce the mutual interference, the frequency position of possible PT-RS may be the same for both waveforms. In some embodiments, these positions may be predefined. In this case, the PT-RS can be provided in the same subcarriers for the DFT-S-OFDM waveform as for the CP-OFDM waveform. The PT-RS pattern can be the same for both uplink and downlink.

[0090] In some embodiments, the PT-RS may be UE-specific. In this case, the frequency density of the PT-RS may be sensitive to the scheduled bandwidth used for the particular UE. FIG. 10 illustrates PT-RS patterns for different bandwidth allocation in accordance with some embodiments. In particular, FIG. 10 illustrates PT-RS patterns for a UE with a smaller bandwidth allocation and a UE with a larger bandwidth allocation, as determined by the gNB.

[0091] To enable interference suppression, at least some of subcarriers used for PT-RS of the larger bandwidth allocation UE and that of smaller bandwidth allocation UE may overlap. The overlapping PT-RS can be used by the UE generating the interference for NZP PT-RS generation. Similarly, an interference cancellation-based receiver can be used by the victim UE to suppress the interference measured from ZP PT-RS positions aligned with the NZP PT-RS generation of the interfering UE. As indicated in relation to FIG. 8, the PT-RS allocation may differ between the UEs; as shown in FIG. 10 the smaller bandwidth allocation UE may have more subcarrier indexes to which PT-RS are allocated than the larger bandwidth allocation UE. Thus, although multiple NZP PT-RS of the smaller bandwidth allocation UE overlap with bandwidth of the larger bandwidth allocation UE, a minimum of a single NZP PT-RS of the smaller bandwidth allocation UE overlaps with a ZP PT-RS of the larger bandwidth allocation UE. The remaining NZP PT-RSs of the smaller bandwidth allocation UE may overlap the data region of the larger bandwidth allocation UE, which may be UL or DL. Adjacent sets of NZP PT-RSs of the smaller bandwidth allocation UE, which may each contain one or more consecutive subcarriers, may be separated by one or more subcarriers. Similarly, as shown in the embodiment of FIG. 10 a minimum of a single NZP PT-RS of the larger bandwidth allocation UE overlaps with the ZP PT-RS of the smaller bandwidth allocation UE.

[0092] The ZP PT-RS pattern, as above, can be configured for each UE by higher layer signaling and/or DCI. In each subframe, the UE may then be able to determine which subcarriers should be muted. If several ZP PT-RS patterns are predefined or configured by higher layer signaling, a ZP PT-RS pattern index can be added in the DCI to indicate the exact ZP PT-RS pattern. In this case, a particular index, e.g. 0, may indicate that there is no ZP PT-RS.

[0093] The above may be viable in 4G and some 5G networks. However, in other 5G networks, the numerology of neighboring cells (gNB) may be different. In some embodiments, numerology refers to waveform parametrization, e.g., cyclic prefix and subcarrier spacing in OFDM. In some embodiments, dynamic numerology may be allowed, leading to differing subframe duration, dependent on the numerology and the scheduling granularity. Selecting the numerology used may require care as the use of a smaller subcarrier spacing may result in high Error Vector Magnitude (EVM) due to phase noise, for example. The subcarrier spacing may have an upper limit set by the cyclic prefix overhead. The channel bandwidth may in turn be determined by the maximum FFT size of the OFDM modulator in the UE. The numerologies used by the different gNBs may be unrelated to each other or may be related, e.g., by scaling a particular base numerology by an integer value. The use of different numerologies by the neighbor gNBs may result in the interference observed in a particular subframe not only being misaligned, but changing from subframe to subframe.

[0094] FIG. 11 illustrates cells with different numerologies in accordance with some embodiments. The network 1100 contains multiple gNBs 1104 that each serve one or more UEs 1102. As shown, the numerology of the gNBs 1104 is different, with the TDD subframe being twice as long in gNB 1 as in gNB 2. The interference observed in two slots of UE 1 may be different as the two slots may be allocated to different UEs in the neighbor cells (the subcarrier spacing can be as twice as that in gNB 1). This may be problematic as the DMRS signal may not be enabled in the second slot. The baseband processing circuitry of the UE 1102 may contain a minimum mean square error-interference rejection combining (MMSE-IRC) receiver. The MMSE-IRC may be used for spatial domain interference handling. The MMSE-IRC receiver can suppress inter-cell interference as well as intra-cell interference. If the MMSE-IRC receiver is utilized in UE 1 1102, the interference misalignment between two slots may have a significant impact on the accuracy of interference covariance matrix in the second slot where the DMRS is not enabled. Further, if the network is unsynchronized, the interference observed in two slots may also be different. This is merely an example, as FDD communications may be used in addition to or instead of TDD communications in the network. It would be desirable to reduce the interference misalignment.

[0095] As the interference may be misaligned among different symbols for the PDCH, in some embodiments the interference for at least some of the symbols in the PDCH may be estimated. The PT-RS may be used in each PDCH symbol may be used to compensate the phase noise with low frequency domain density. However, certain issues may arise in the use of the PT-RS for interference estimation. For example, the channel estimation accuracy may suffer due to the low frequency domain density, thereby increasing the difficultly in distinguishing between the channel and interference. In addition, to use the PT-RS, the gNBs generating the DMRS and PT-RS may be assumed to be quasi-co-located; however, the quasi-co-location assumption between the DMRS and PT-RS should be defined.

[0096] In some embodiments, an Interference Measurement Resource (IMR) associated with PDCH transmission may be used when the interference is not aligned in each symbol. The IMR can be one or more empty resource elements (unallocated to a UE) for one or more Antenna Ports (APs) and are different from other reference signals (e.g., DMRS). The UE may obtain an interference covariance matrix based on a signal received in these resource elements. In one example, the interference covariance matrix can be calculated by:

$$R = \frac{1}{N}\sum_{k\in S} Y_k Y_k^H$$

Where S denotes the subcarriers for the IMR in one or more symbols; N denotes the number of resource elements in S; Y_k refers to the received signal at IMR resource k. The dimensions of the interference covariance matrix is NR x 1, where NR is the number of receiving antenna ports. To maintain the self-contained structure, averaging can be done symbol by symbol in some embodiments. In other embodiments, averaging may be performed over multiple symbols. The interference covariance matrix may be valid for the symbols between l_1 to l_{2-1}, where l_1 denotes the symbol where the IMR is applied and l_2 denotes the symbol where the next IMR is applied. The interference covariance matrix may be used to correct for the interference misalignment caused by the different cell numerology.

[0097] In some embodiments, the IMR can be mapped to x subcarriers in each resource block (RB) or resource block grant (RBG), where x can be predefined (and stored in the UE) or configured via higher layer signaling (e.g., RRC signaling) or in Downlink Control Information (DCI). The IMR can be mapped to y symbols, where y as above can be predefined or configured via higher layer signaling or DCI. The symbol index can be pre-defined by the system or configured by higher layer signaling or DCI. Thus, the gNB may inform the UE when the resource elements containing the different interference may occur. The number of symbols used for the IMR may be determined by the gNB and dependent on, for example, the amount of misalignment or predicted amount of interference (e.g., based on the number of microcells or UEs in the geographical area served by the gNB) or on a per-UE basis. The UE may subsequently use the IMRs to estimate the changed interference covariance matrix. In addition, the IMR for different UEs may be able to use different subcarriers (and different numbers of subcarriers) so that the mutual interference from co-scheduled UEs with overlapping bandwidth can be measured. In some embodiments, the subcarriers used for the IMR for each UE are unique to that UE.

[0098] In some embodiments, the IMR can be mapped to *N*, e.g. N=2 subcarriers in each RB. A subcarrier index offset for the IMR can be determined by the antenna port index or indicated by DCI. The UE may then estimate the interference of one RBG by averaging the interference observed for all the IMR tones.

[0099] FIG. 12 illustrates IMR resource mapping according to some embodiments. The IMR may be provided on 2 subcarriers at the first symbol of the second slot (Slot 1). As shown, the IMR may be provided in different subcarriers for different UEs. The number of subcarriers used for the IMR, as well as which subcarriers are used, may be different between the UEs. The subcarriers may be adjacent, as shown, or non-adjacent in other embodiments. The interference covariance matrix for the second slot can be estimated by the IMR instead of a calculation based on the DMRS in the third symbol of the first slot (Slot 0). Multiple (e.g., two) IMRs can be used to calculate the interference from when a different numerology is used, such as in which the subcarrier spacing used by the interfering gNB (or UE) is twice that of the UE.

[00100] FIG. 13 illustrates IMR resource mapping according to some embodiments. As indicated above, multiple types of numerologies may exist in the network or the network may be unsynchronized, either of which may cause the interference to vary fairly quickly among each symbol. In this case, more than 2 IMRs may be used. In some embodiments, the IMR can be mapped to n subcarriers every m symbols, where n and m can be predefined or configured by higher layer signaling or DCI. As shown in FIG. 13, $n=2$ subcarriers and $m=2$ symbols, although placement of the IMR may differ between slots and/or UEs as above. In the embodiment shown in FIG. 13, the interference covariance matrix can be estimated based on interference averaging among the IMRs every m symbols. In some embodiments, frequency hopping can be enabled between IMR transmissions, sets of IMR transmissions, or slots to achieve diversity gain. The subcarrier index for each IMR within one RB may be different.

[00101] In some embodiments, an IMR flag can be added in the DCI to configure whether IMR is enabled for the current PDCH. In some embodiments, the IMR flag may be 1 bit (single bit), in which a value of 0 may denote that the IMR is disabled and a value of 1 may denote that the IMR is enabled. When IMR is enabled, resource mapping for the PDSCH transmission may be performed by puncturing or rate matching around the REs used for the IMR transmission.

[00102] In other embodiments, multiple use cases may be used for a DMRS-based channel state information (CSI) measurement framework, if the IMR is used. In this case, the IMR flag may use multiple bits (e.g., 2-4) to indicate the use case. In a first case, the IMR may be used for decoding an interference measurement only. In a second case, the IMR may be used for a CSI measurement only. In a third case, the IMR may be used for both decoding and CSI measurement. Table 1 illustrates one example for the IMR flag indication.

IMR flag	Indication
0	No IMR
1	IMR for decoding only
2	IMR for CSI measurement only
3	IMR for decoding and CSI measurement

Table 1: IMR flag indication

[00103] If the IMR is used for decoding only, the DMRS-based CSI measurement may only take the interference measured from the DMRS into account. If the IMR is used for the CSI measurement only, the interference measured from the DMRS can be used for decoding of all the symbols and the DMRS-based CSI measurement may average the interference observed from the DMRS and the IMR. If the IMR is used for decoding and CSI measurement, the interference measurement may be taken into account in decoding the symbols where the IMR is enabled and the CSI measurement using interference averaging in the DMRS symbol and the IMR.

[00104] Examples

[00105] Example 1 is an apparatus of a user equipment (UE), the apparatus comprising: an interface to communicate with a gigabit NodeB (gNB); and processing circuitry in communication with the interface and arranged to: determine whether interference misalignment associated with the gNB and due to different cell numerology is present; decode, in response to a determination that the different cell numerology is present, an Interference Measurement Resource (IMR) received via the interface in multiple resource elements; determine an interference covariance matrix based on the IMR; and apply the interference covariance matrix to correct for the interference misalignment.

[00106] In Example 2, the subject matter of Example 1 includes, wherein: the interference covariance matrix is:

$R = \frac{1}{N}\sum_{k\in S} Y_k Y_k^H$ where S denotes subcarriers used for the IMR, N denotes a number of resource elements in S and Yk refers to a received signal at IMR resource k.

[00107] In Example 3, the subject matter of Examples 1–2 includes, wherein: the interference covariance matrix is valid for symbols between l1 to l2-1, where l1 denotes a symbol where the IMR is applied and l2 denotes a symbol where a next IMR is applied.

[00108] In Example 4, the subject matter of Examples 1–3 includes, wherein: subcarriers used for the IMR are unique to the UE such that the subcarriers are different from subcarriers used for a different IMR from the gNB used for a different UE.

[00109] In Example 5, the subject matter of Examples 1–4 includes, wherein: a subcarrier index offset of the IMR is determined by an antenna port index associated with the IMR.

[00110] In Example 6, the subject matter of Examples 1–5 includes, wherein: the IMR is located in multiple subcarriers in a first symbol of a second slot of a subframe, and the processing circuitry is further configured to determine the interference covariance matrix for the second slot through the use of the IMR rather than through a Demodulation Reference Signal (DMRS).

[00111] In Example 7, the subject matter of Examples 1–6 includes, wherein: a number of subcarriers used for the IMR and a number of symbols between adjacent IMRs is dependent on a number of numerologies and synchronization within a network in which the UE is disposed.

[00112] In Example 8, the subject matter of Example 7 includes, wherein: the number of subcarriers and the number of symbols are configured via one of higher layer signaling or Downlink Control Signaling (DCI).

[00113] In Example 9, the subject matter of Examples 1–8 includes, wherein: the processing circuitry is further configured to use frequency hopping in reception of adjacent IMRs by the UE.

[00114] In Example 10, the subject matter of Examples 1–9 includes, wherein: the processing circuitry is configured to determine the presence of interference misalignment based on Downlink Control Signaling (DCI) that comprises an IMR flag that denotes whether IMR is enabled for a current Physical Data Channel (PDCH).

[00115] In Example 11, the subject matter of Example 10 includes, wherein: when the IMR is enabled, resource elements used for the IMR transmission are punctured or rate matched around to provide resource mapping for a Physical Downlink Shared Channel (PDSCH).

[00116] In Example 12, the subject matter of Example 11 includes, wherein: the IMR flag further indicates one of a plurality of use cases for the IMR, the use cases comprising: use of the IMR for decoding free from use of the IMR for channel state information (CSI) measurement, in which a Demodulation Reference Signal (DMRS)-based CSI measurement takes interference measured from the DMRS into account free from the IMR being taken into account, use of the IMR for CSI measurement free from use of the IMR for decoding, in which the DMRS is used for decoding free from use of the IMR and the DMRS-based CSI measurement is averaged with interference observed from the DMRS and the IMR, and use of the IMR for decoding and CSI measurement.

[00117] In Example 13, the subject matter of Examples 1–12 includes, wherein: the processing circuitry comprises a baseband processor configured to compensate for interference indicated by the interference covariance matrix.

[00118] Example 14 is an apparatus of a user equipment (UE), the apparatus comprising: at least one interface to communicate with at least one of a next Generation NodeB (gNB) or another UE; and processing circuitry in communication with the at least one interface and arranged to: determine a subcarrier index for a non-zero power (NZP) Tracking Reference Signal (PT-RS) and a zero power (ZP) PT-RS in a Physical Data Channel (PDCH) of a subframe, the subcarrier index for the NZP PT-RS being different from the subcarrier index for the ZP PT-RS; encode the NZP PT-RS for transmission using the subcarrier index for the NZP PT-RS; and provide phase compensation to PDCH signals based on interference from the one of the gNB and other UE in the subcarrier index for the ZP PT-RS.

[00119] In Example 15, the subject matter of Example 14 includes, wherein: at least one of the subcarrier index for the NZP PT-RS or the ZP PT-RS is dependent on which of a cyclic prefix Orthogonal Frequency-Division Multiplexing (CP-OFDM) or discrete Fourier transform spread OFDM (DFT-S-OFDM) waveform is used.

[00120] In Example 16, the subject matter of Examples 14–15 includes, wherein: the at least one of the subcarrier index for the NZP PT-RS or the ZP PT-RS is dependent on at least one of a cell ID, a virtual cell ID or a subframe or slot index of the PDCH.

[00121] In Example 17, the subject matter of Examples 14–16 includes, wherein: transmission of the ZP PT-RS is provided via one of higher layer signaling or Downlink Control Signaling (DCI) prior to the processing circuitry making a determination of the subcarrier index for the ZP PT-RS.

[00122] In Example 18, the subject matter of Examples 14–17 includes, wherein the processing circuitry comprises: a Discrete Fourier Transform configured to generate data of a Physical Uplink Shared Channel (PUSCH) of the PDCH, and a PT-RS generator configured to add the NZP PT-RS after generation of the data prior to transmission of the data and the NZP PT-RS in appropriate subcarriers by the UE.

[00123] In Example 19, the subject matter of Examples 14–18 includes, wherein: at least one of the subcarrier index for the NZP PT-RS or the ZP PT-RS is UE-specific.

[00124] In Example 20, the subject matter of Example 19 includes, wherein: the subcarrier index for the NZP PT-RS and the ZP PT-RS overlap with a subcarrier index for a NZP PT-RS and ZP PT-RS of the other UE such that the NZP PT-RS of the UE overlaps the ZP PT-RS of the other UE and the ZP PT-RS of the UE overlaps the NZP PT-RS of the other UE, and a bandwidth allocation of the UE is different from that of the other UE.

[00125] In Example 21, the subject matter of Example 20 includes, wherein: a density of at least one of the NZP PT-RS or the ZP PT-RS is dependent on the bandwidth allocation, and at least one of the NZP PT-RS or the ZP PT-RS of a first of the UE or the other UE overlaps with data of a second of the UE or the other UE.

[00126] In Example 22, the subject matter of Examples 14–21 includes, wherein: an indication of which of a plurality of ZP PT-RS patterns is provided to the UE via a ZP PT-RS pattern index in Downlink Control Signaling (DCI).

[00127] In Example 23, the subject matter of Examples 14–22 includes, wherein: the NZP PT-RS are inserted after use of a discrete Fourier transform and at subcarriers used for PT-RS, a data channel is punctured.

[00128] Example 24 is a computer-readable storage medium that stores instructions for execution by one or more processors of a user equipment (UE), the one or more processors to configure the UE to: receive an indication of whether an Interference Measurement Resource (IMR) is present in multiple resource elements of a subframe; determine an interference covariance matrix based on the IMR; and apply the interference covariance matrix to compensate for the interference in data of the subframe, wherein a number of subcarriers used for the IMR and a number of symbols between adjacent IMRs is dependent on a number of numerologies and synchronization within a network in which the UE is disposed.

[00129] In Example 25, the subject matter of Example 24 includes, wherein: subcarriers used for the IMR are unique to the UE such that the subcarriers are different from subcarriers used for a different IMR used for a different UE.

[00130] In Example 26, the subject matter of Examples 24–25 includes, wherein: the IMR is located in multiple subcarriers in a first symbol of a second slot of the subframe, and the interference covariance matrix for the second slot is determined through the use of the IMR rather than through a Demodulation Reference Signal (DMRS).

[00131] In Example 27, the subject matter of Examples 24–26 includes, wherein: Downlink Control Signaling (DCI) comprises an IMR flag that denotes whether IMR is enabled for a current Physical Data Channel (PDCH).

[00132] In Example 28, the subject matter of Example 27 includes, wherein: the IMR flag further indicates one of a plurality of use cases for the IMR, the use cases comprising: use of the IMR for decoding free from use of the IMR for channel state information (CSI) measurement, in which a Demodulation Reference Signal (DMRS)-based CSI measurement takes interference measured from the DMRS into account free from the IMR being taken into account, use of the IMR for CSI measurement free from use of the IMR for decoding, in which the DMRS is used for decoding free from use of the IMR and the DMRS-based CSI measurement is averaged with interference observed from the DMRS and the IMR, and use of the IMR for decoding and CSI measurement.

[00133] Example 29 is an apparatus of a user equipment (UE), the apparatus comprising: means for receiving an indication of whether an Interference Measurement Resource (IMR) is present in multiple resource elements of a subframe; means for determining an interference covariance matrix based on the IMR; and means for applying the interference covariance matrix to compensate for the interference in data of the subframe, wherein a number of subcarriers used for the IMR and a number of symbols between adjacent IMRs is dependent on a number of numerologies and synchronization within a network in which the UE is disposed.

[00134] In Example 30, the subject matter of Example 29 includes, wherein: subcarriers used for the IMR are unique to the UE such that the subcarriers are different from subcarriers used for a different IMR used for a different UE.

[00135] In Example 31, the subject matter of Examples 29–30 includes, wherein: the IMR is located in multiple subcarriers in a first symbol of a second slot of the subframe, and the interference covariance matrix for the second slot is determined through the use of the IMR rather than through a Demodulation Reference Signal (DMRS).

[00136] In Example 32, the subject matter of Examples 29–31 includes, wherein: Downlink Control Signaling (DCI) comprises an IMR flag that denotes whether IMR is enabled for a current Physical Data Channel (PDCH).

[00137] In Example 33, the subject matter of Example 32 includes, wherein: the IMR flag further indicates one of a plurality of use cases for the IMR, the use cases comprising: use of the IMR for decoding free from use of the IMR for channel state information (CSI) measurement, in which a Demodulation Reference Signal (DMRS)-based CSI measurement takes interference measured from the DMRS into account free from the IMR being taken into account, use of the IMR for CSI measurement free from use of the IMR for decoding, in which the DMRS is used for decoding free from use of the IMR and the DMRS-based CSI measurement is averaged with interference observed from the DMRS and the IMR, and use of the IMR for decoding and CSI measurement.

[00138] Example 34 is a method of compensating for interference in a user equipment (UE), the method comprising: receiving an indication of whether an Interference Measurement Resource (IMR) is present in multiple resource elements of a subframe; determining an interference covariance matrix based on the IMR; and applying the interference covariance matrix to compensate for the interference in data of the subframe, wherein a number of subcarriers used for the IMR and a number of symbols between adjacent IMRs is dependent on a number of numerologies and synchronization within a network in which the UE is disposed.

[00139] In Example 35, the subject matter of Example 34 includes, wherein: subcarriers used for the IMR are unique to the UE such that the subcarriers are different from subcarriers used for a different IMR used for a different UE.

[00140] In Example 36, the subject matter of Examples 34–35 includes, wherein: the IMR is located in multiple subcarriers in a first symbol of a second slot of the subframe, and the interference covariance matrix for the second slot is determined through the use of the IMR rather than through a Demodulation Reference Signal (DMRS).

[00141] In Example 37, the subject matter of Examples 34–36 includes, wherein: Downlink Control Signaling (DCI) comprises an IMR flag that denotes whether IMR is enabled for a current Physical Data Channel (PDCH).

[00142] In Example 38, the subject matter of Example 37 includes, wherein: the IMR flag further indicates one of a plurality of use cases for the IMR, the use cases comprising: use of the IMR for decoding free from use of the IMR for channel state information (CSI) measurement, in which a Demodulation Reference Signal (DMRS)-based CSI measurement takes interference measured from the DMRS into account free from the IMR being taken into account, use of the IMR for CSI measurement free from use of the IMR for decoding, in which the DMRS is used for decoding free from use of the IMR and the DMRS-based CSI measurement is averaged with interference observed from the DMRS and the IMR, and use of the IMR for decoding and CSI measurement.

[00143] Example 39 is at least one machine-readable medium including instructions that, when executed by processing circuitry, cause the processing circuitry to perform operations to implement of any of Examples 1–38.

[00144] Example 40 is an apparatus comprising means to implement of any of Examples 1–38.

[00145] Example 41 is a system to implement of any of Examples 1–38.

[00146] Example 42 is a method to implement of any of Examples 1–38.

[00147] Although an embodiment has been described with reference to specific example embodiments, it will be evident that various modifications and changes may be made to these embodiments without departing from the broader 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 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 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.

[00148] The subject matter may be referred to herein, individually and/or collectively, by the term “embodiment” merely for convenience and without intending to voluntarily limit the scope of this application to any single 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 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.

[00149] 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 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 terms "first," "second," and "third," etc. are used merely as labels, and are not intended to impose numerical requirements on their objects.

[00150] 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 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 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.

CLAIMS

What is claimed is:

1. An apparatus of a user equipment (UE), the apparatus comprising:

an interface to communicate with a gigabit NodeB (gNB); and

processing circuitry in communication with the interface and arranged to:

determine whether interference misalignment associated with the gNB and due to different cell numerology is present;

decode, in response to a determination that the different cell numerology is present, an Interference Measurement Resource (IMR) received via the interface in multiple resource elements;

determine an interference covariance matrix based on the IMR; and

apply the interference covariance matrix to correct for the interference misalignment.

2. The apparatus of claim 1, wherein:

the interference covariance matrix is:

$$R = \frac{1}{N}\sum_{k \in S} Y_k Y_k^H$$

where S denotes subcarriers used for the IMR, N denotes a number of resource elements in S and Y_k refers to a received signal at IMR resource k.

3. The apparatus of claim 1 or 2, wherein:

the interference covariance matrix is valid for symbols between l_1 to $l_{2\text{-}1}$, where l_1 denotes a symbol where the IMR is applied and l_2 denotes a symbol where a next IMR is applied.

4. The apparatus of claim 1 or 2, wherein:

subcarriers used for the IMR are unique to the UE such that the subcarriers are different from subcarriers used for a different IMR from the gNB used for a different UE.

5. The apparatus of claim 1 or 2, wherein:

a subcarrier index offset of the IMR is determined by an antenna port index associated with the IMR.

6. The apparatus of claim 1 or 2, wherein:

the IMR is located in multiple subcarriers in a first symbol of a second slot of a subframe, and

the processing circuitry is further configured to determine the interference covariance matrix for the second slot through the use of the IMR rather than through a Demodulation Reference Signal (DMRS).

7. The apparatus of claim 1 or 2, wherein:

a number of subcarriers used for the IMR and a number of symbols between adjacent IMRs is dependent on a number of numerologies and synchronization within a network in which the UE is disposed.

8. The apparatus of claim 7, wherein:

the number of subcarriers and the number of symbols are configured via one of higher layer signaling or Downlink Control Signaling (DCI).

9. The apparatus of claim 1 or 2, wherein:

the processing circuitry is further configured to use frequency hopping in reception of adjacent IMRs by the UE.

10. The apparatus of claim 1 or 2, wherein:

the processing circuitry is configured to determine the presence of interference misalignment based on Downlink Control Signaling (DCI) that comprises an IMR flag that denotes whether IMR is enabled for a current Physical Data Channel (PDCH).

11. The apparatus of claim 10, wherein:

when the IMR is enabled, resource elements used for the IMR transmission are punctured or rate matched around to provide resource mapping for a Physical Downlink Shared Channel (PDSCH).

12. The apparatus of claim 11, wherein:

the IMR flag further indicates one of a plurality of use cases for the IMR, the use cases comprising:

use of the IMR for decoding free from use of the IMR for channel state information (CSI) measurement, in which a Demodulation Reference Signal (DMRS)-based CSI measurement takes interference measured from the DMRS into account free from the IMR being taken into account,

use of the IMR for CSI measurement free from use of the IMR for decoding, in which the DMRS is used for decoding free from use of the IMR and the DMRS-based CSI measurement is averaged with interference observed from the DMRS and the IMR, and

use of the IMR for decoding and CSI measurement.

13. The apparatus of claim 1 or 2, wherein:

the processing circuitry comprises a baseband processor configured to compensate for interference indicated by the interference covariance matrix.

14. An apparatus of a user equipment (UE), the apparatus comprising:

at least one interface to communicate with at least one of a next Generation NodeB (gNB) or another UE; and

processing circuitry in communication with the at least one interface and arranged to:

determine a subcarrier index for a non-zero power (NZP) Tracking Reference Signal (PT-RS) and a zero power (ZP) PT-RS in a Physical Data Channel (PDCH) of a subframe, the subcarrier index for the NZP PT-RS being different from the subcarrier index for the ZP PT-RS;

encode the NZP PT-RS for transmission using the subcarrier index for the NZP PT-RS; and

provide phase compensation to PDCH signals based on interference from the one of the gNB and other UE in the subcarrier index for the ZP PT-RS.

15. The apparatus of claim 14, wherein:

at least one of the subcarrier index for the NZP PT-RS or the ZP PT-RS is dependent on which of a cyclic prefix Orthogonal Frequency-Division Multiplexing (CP-OFDM) or discrete Fourier transform spread OFDM (DFT-S-OFDM) waveform is used.

16. The apparatus of claim 14 or 15, wherein:

the at least one of the subcarrier index for the NZP PT-RS or the ZP PT-RS is dependent on at least one of a cell ID, a virtual cell ID or a subframe or slot index of the PDCH.

17. The apparatus of claim 14 or 15, wherein:

transmission of the ZP PT-RS is provided via one of higher layer signaling or Downlink Control Signaling (DCI) prior to the processing circuitry making a determination of the subcarrier index for the ZP PT-RS.

18. The apparatus of claim 14 or 15, wherein the processing circuitry comprises:

a Discrete Fourier Transform configured to generate data of a Physical Uplink Shared Channel (PUSCH) of the PDCH, and a PT-RS generator configured to add the NZP PT-RS after generation of the data prior to transmission of the data and the NZP PT-RS in appropriate subcarriers by the UE.

19. The apparatus of claim 14 or 15, wherein:

at least one of the subcarrier index for the NZP PT-RS or the ZP PT-RS is UE-specific.

20. The apparatus of claim 19, wherein:

the subcarrier index for the NZP PT-RS and the ZP PT-RS overlap with a subcarrier index for a NZP PT-RS and ZP PT-RS of the other UE such that the NZP PT-RS of the UE overlaps the ZP PT-RS of the other UE and the ZP PT-RS of the UE overlaps the NZP PT-RS of the other UE, and

a bandwidth allocation of the UE is different from that of the other UE.

21. The apparatus of claim 20, wherein:

a density of at least one of the NZP PT-RS or the ZP PT-RS is dependent on the bandwidth allocation, and

at least one of the NZP PT-RS or the ZP PT-RS of a first of the UE or the other UE overlaps with data of a second of the UE or the other UE.

22. The apparatus of claim 14 or 15, wherein:

an indication of which of a plurality of ZP PT-RS patterns is provided to the UE via a ZP PT-RS pattern index in Downlink Control Signaling (DCI).

23. The apparatus of claim 14 or 15, wherein:

the NZP PT-RS are inserted after use of a discrete Fourier transform and at subcarriers used for PT-RS, a data channel is punctured.

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

receive an indication of whether an Interference Measurement Resource (IMR) is present in multiple resource elements of a subframe;

determine an interference covariance matrix based on the IMR; and

apply the interference covariance matrix to compensate for the interference in data of the subframe,

wherein a number of subcarriers used for the IMR and a number of symbols between adjacent IMRs is dependent on a number of numerologies and synchronization within a network in which the UE is disposed.

25. The medium of claim 24, wherein:

subcarriers used for the IMR are unique to the UE such that the subcarriers are different from subcarriers used for a different IMR used for a different UE.

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

the IMR is located in multiple subcarriers in a first symbol of a second slot of the subframe, and

the interference covariance matrix for the second slot is determined through the use of the IMR rather than through a Demodulation Reference Signal (DMRS).

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

Downlink Control Signaling (DCI) comprises an IMR flag that denotes whether IMR is enabled for a current Physical Data Channel (PDCH).

28. The medium of claim 27, wherein:

the IMR flag further indicates one of a plurality of use cases for the IMR, the use cases comprising:

use of the IMR for decoding free from use of the IMR for channel state information (CSI) measurement, in which a Demodulation Reference Signal (DMRS)-based CSI measurement takes interference measured from the DMRS into account free from the IMR being taken into account,

use of the IMR for CSI measurement free from use of the IMR for decoding, in which the DMRS is used for decoding free from use of the IMR and the DMRS-based CSI measurement is averaged with interference observed from the DMRS and the IMR, and

use of the IMR for decoding and CSI measurement.

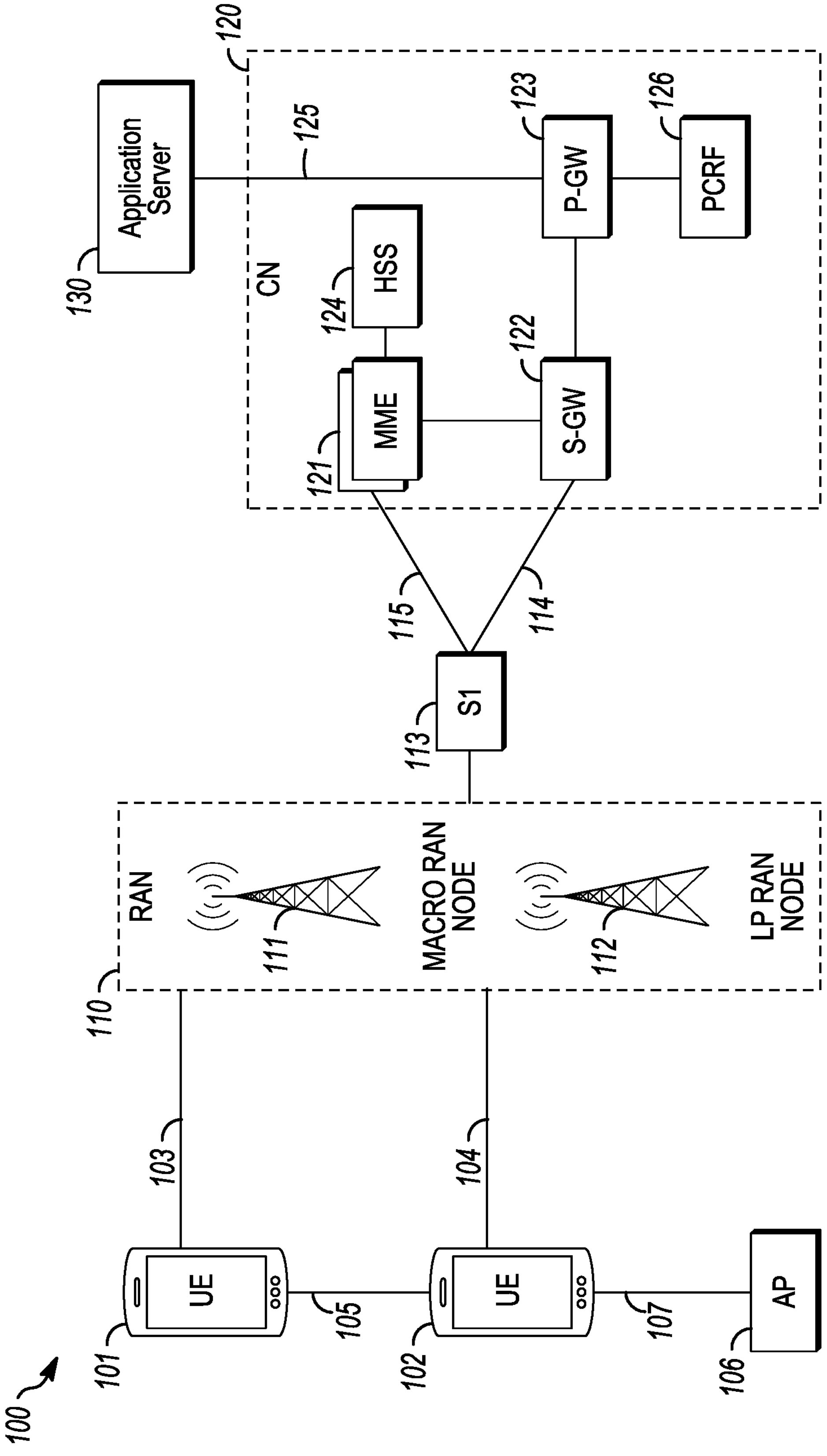
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FIG. 1

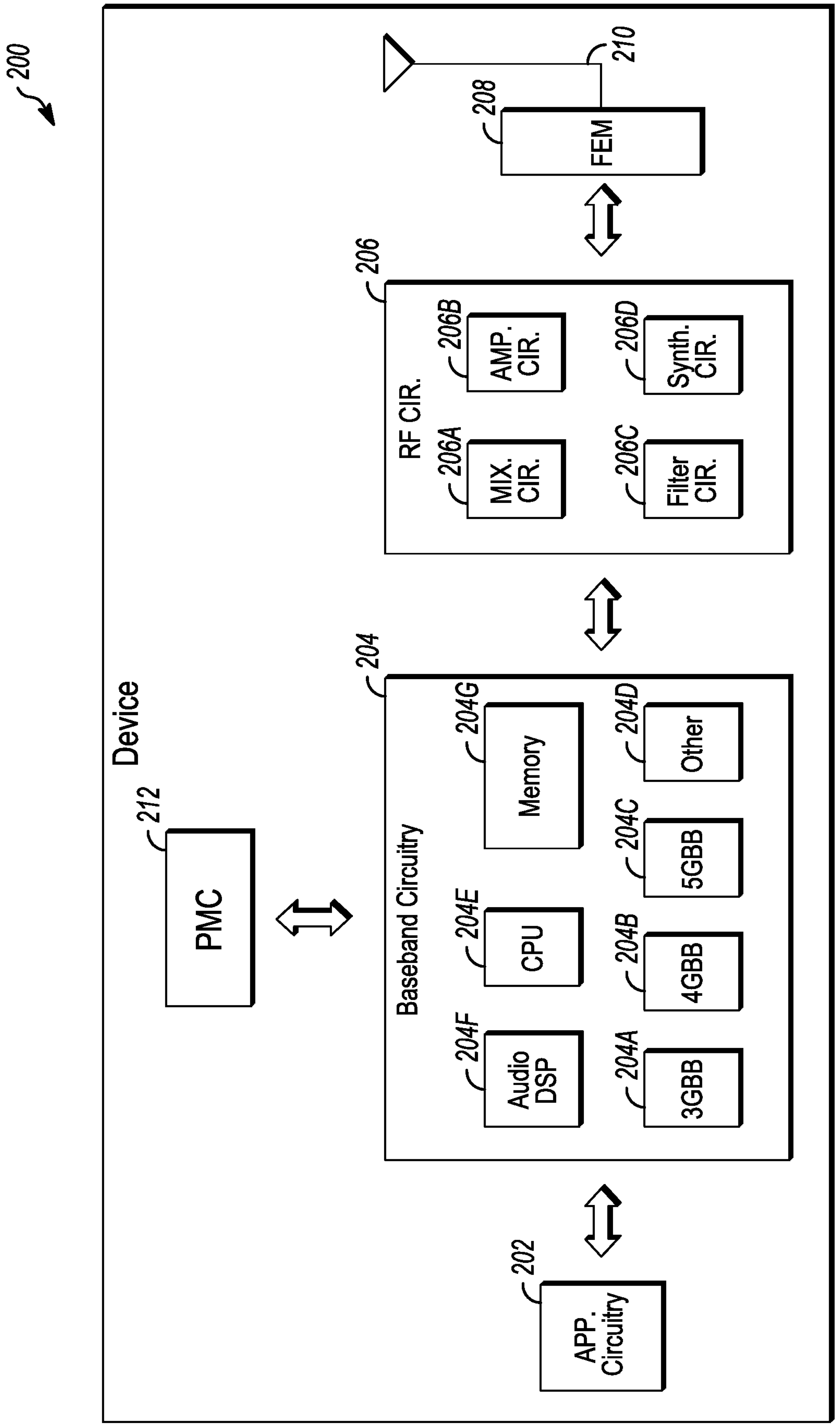
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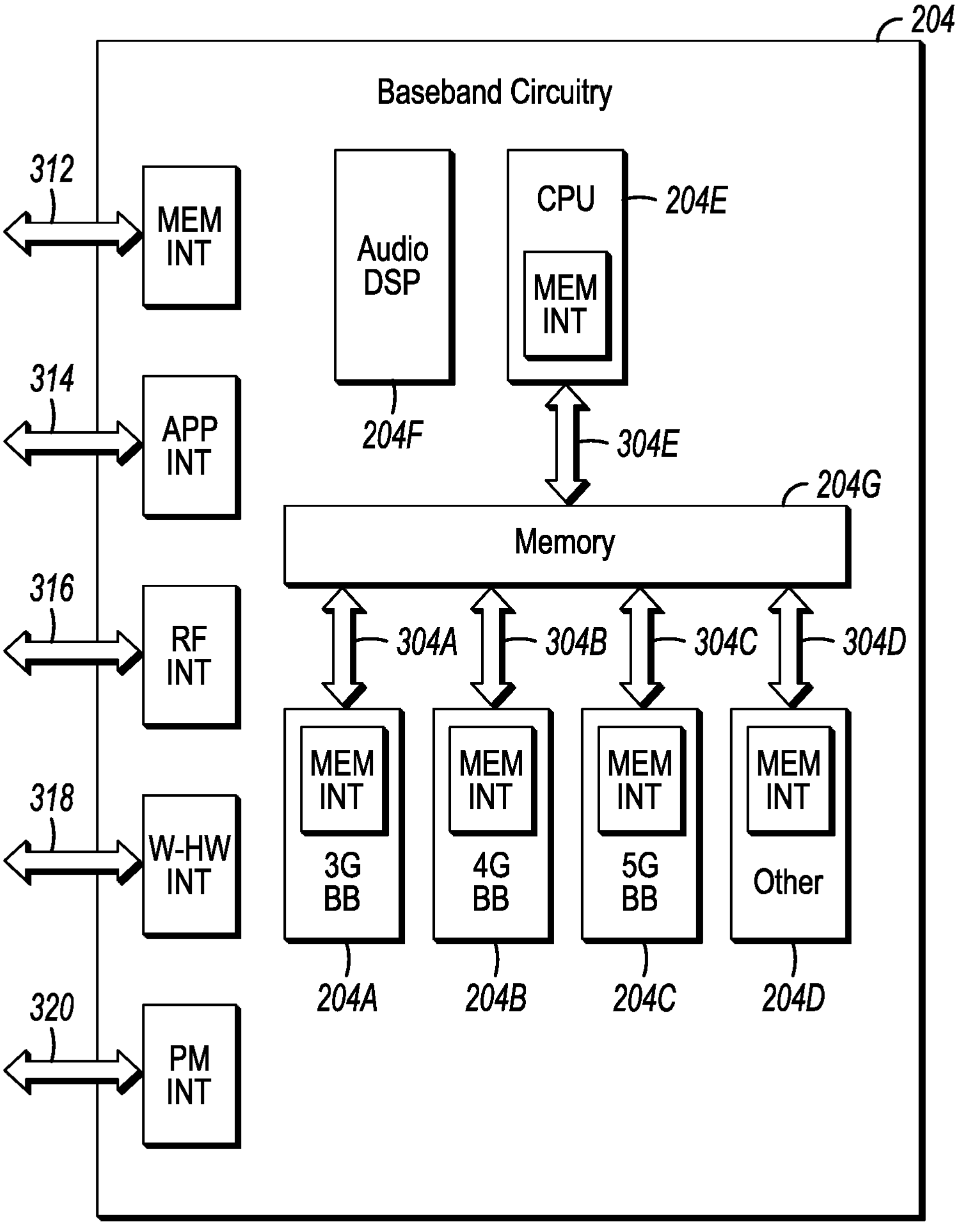
FIG. 2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304E
204G
Memory
304A
304B
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Other
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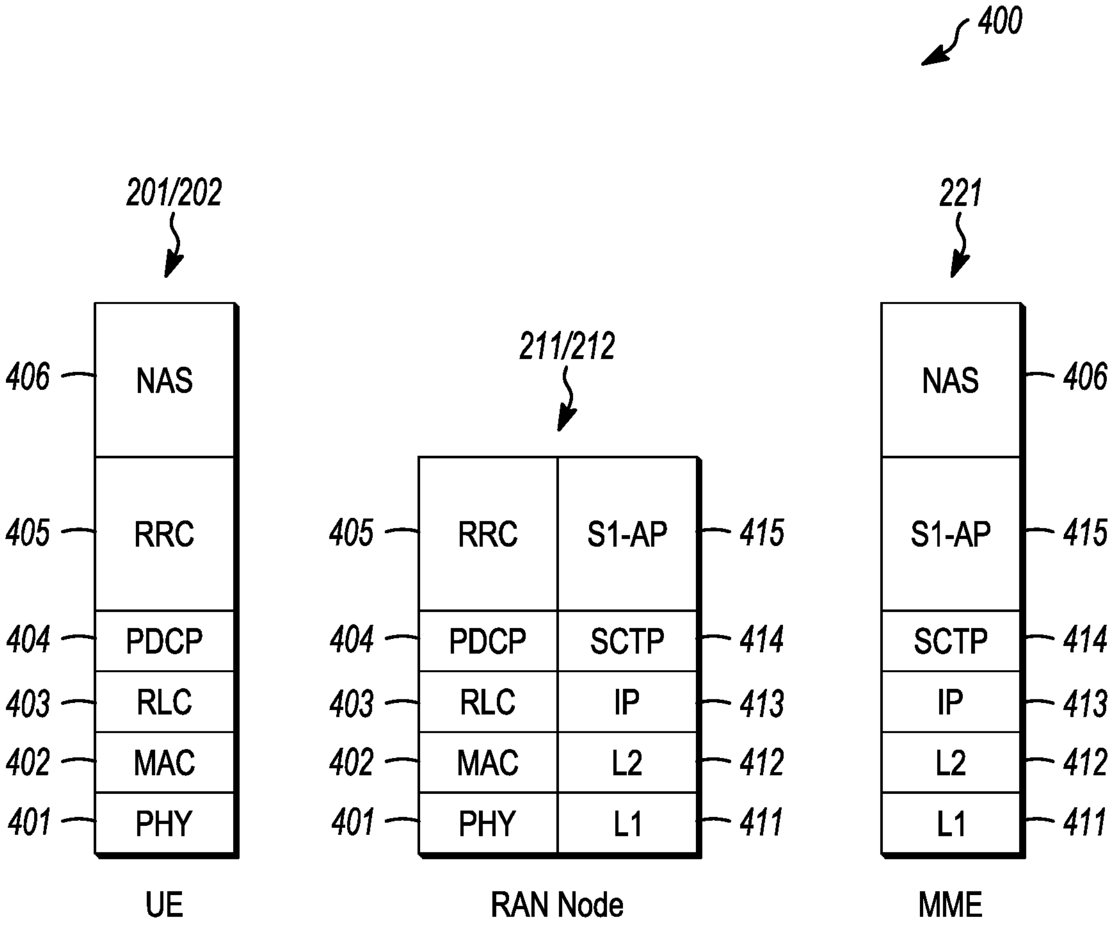
FIG. 3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401
PHY
L1
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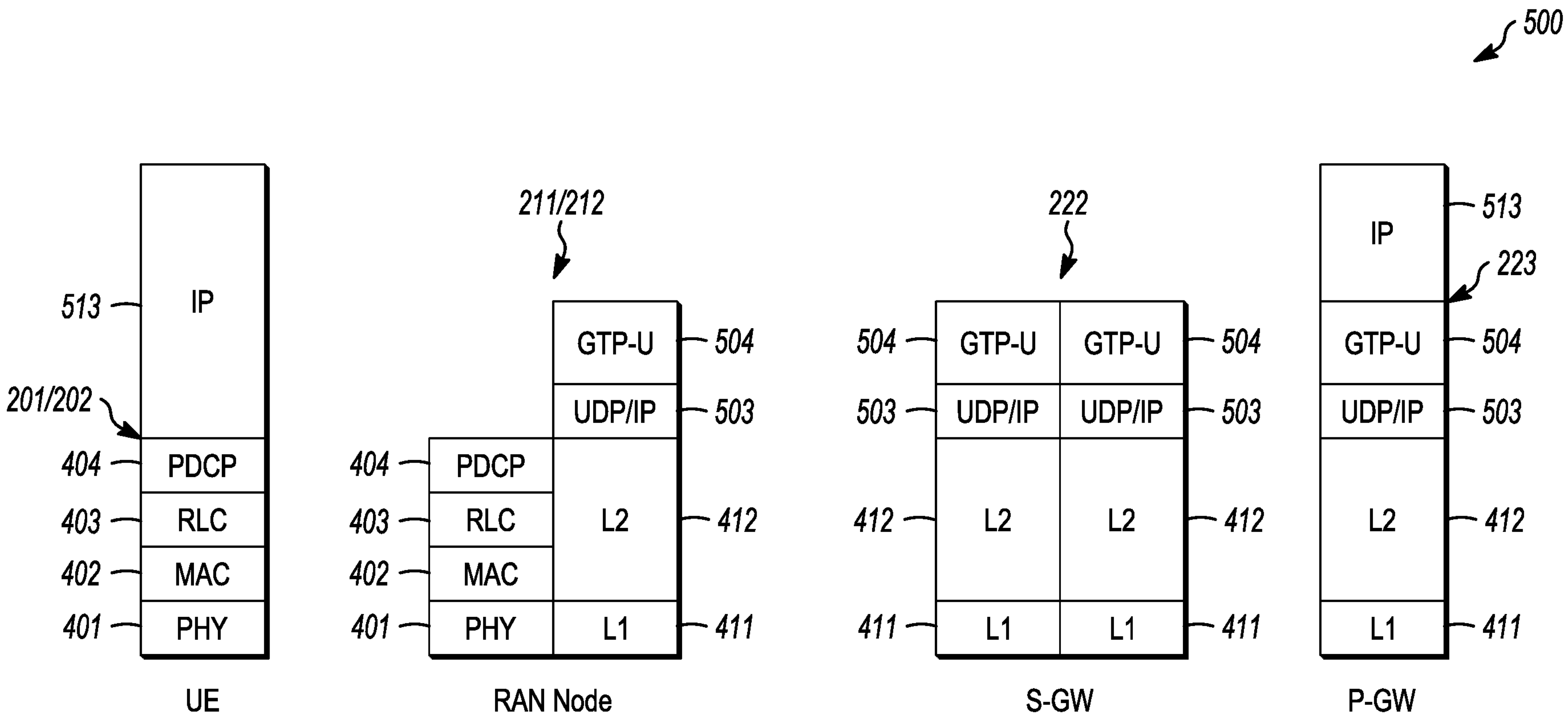
MME

FIG. 4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MAC
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L2
L1
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503
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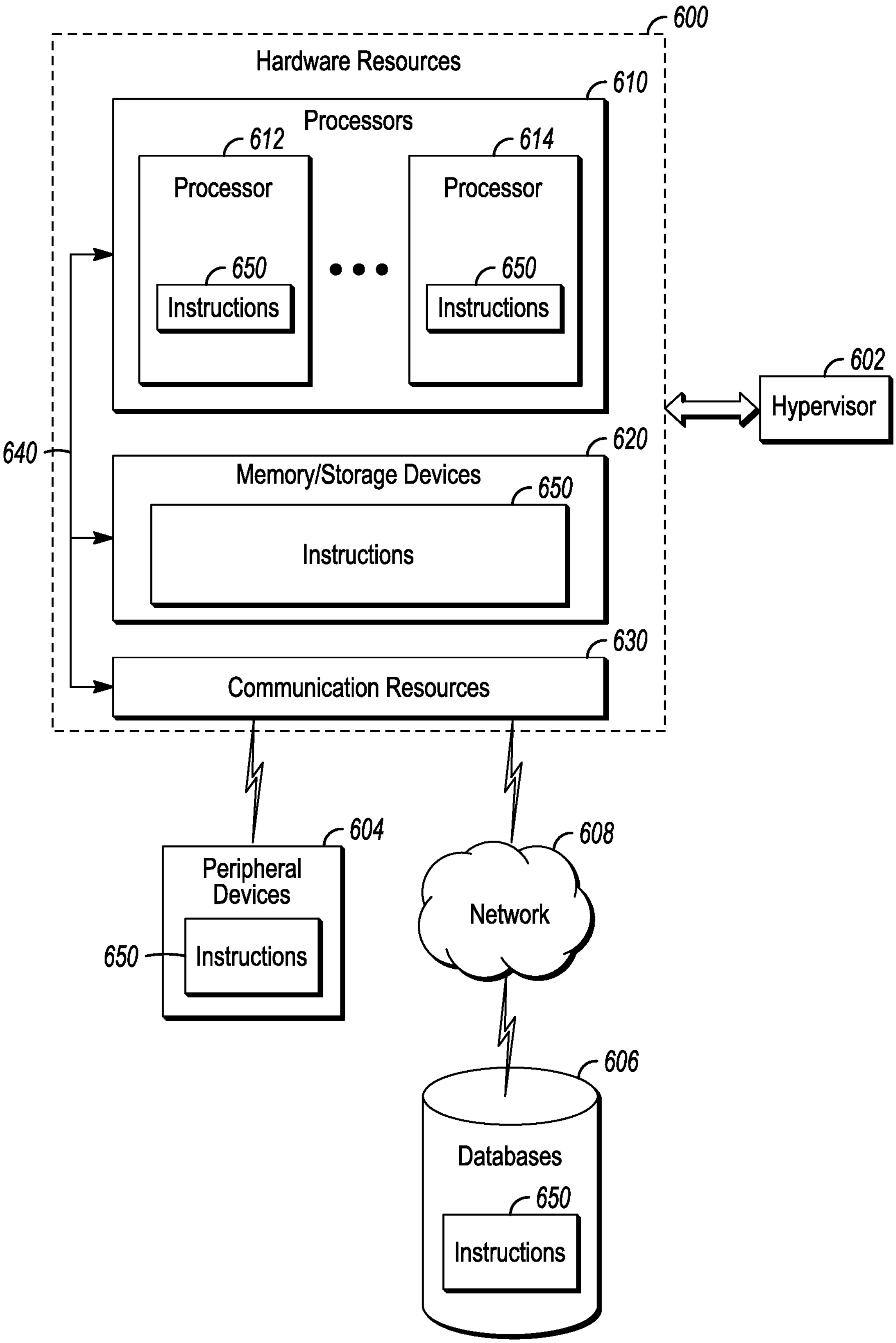
FIG. 5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Instructions
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Instructions
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Hypervisor
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620
Memory/Storage Devices
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Instructions
630
Communication Resources
604
Peripheral Devices
650
Instructions
608
Network
606
Databases
650
Instructions

FIG. 6

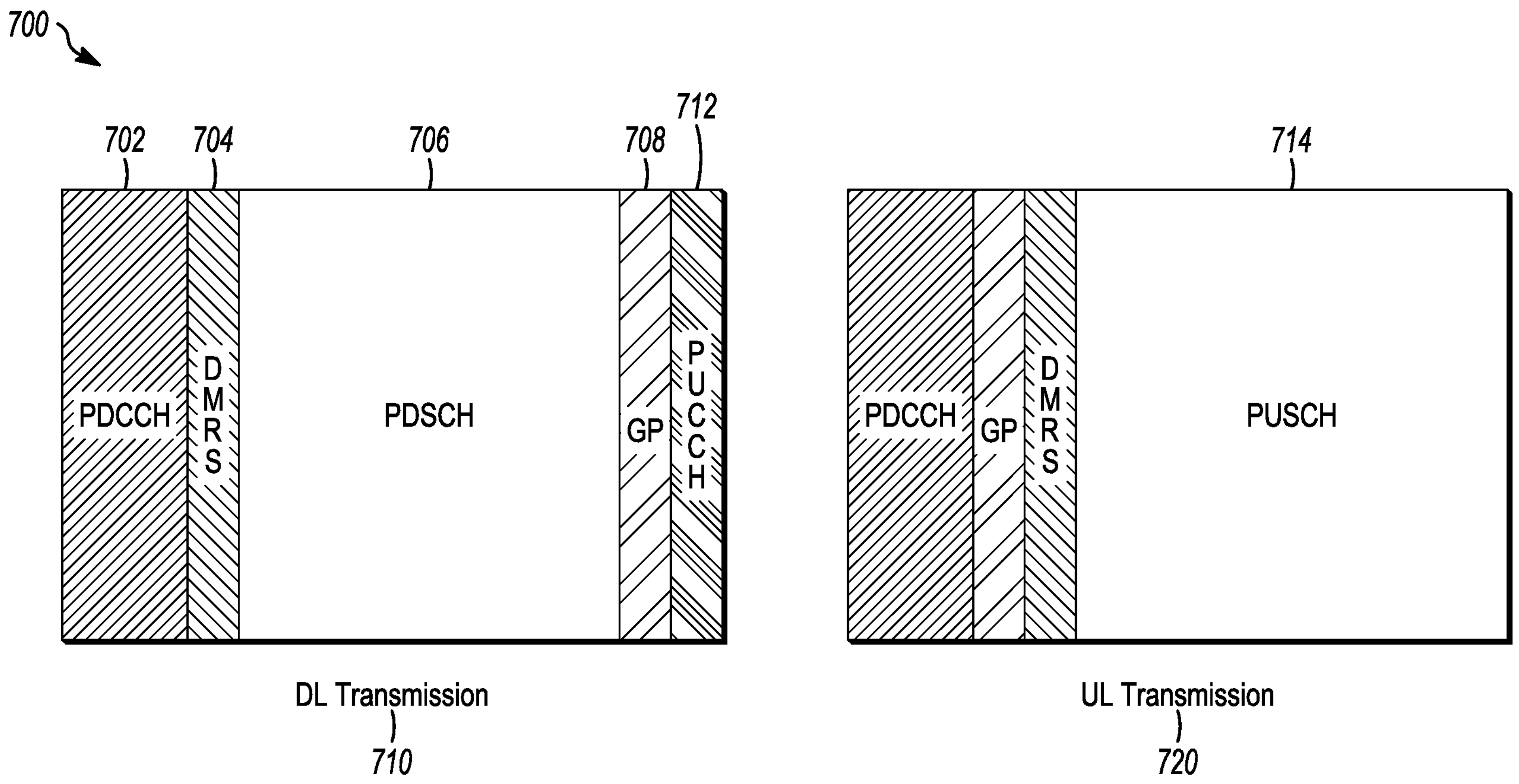
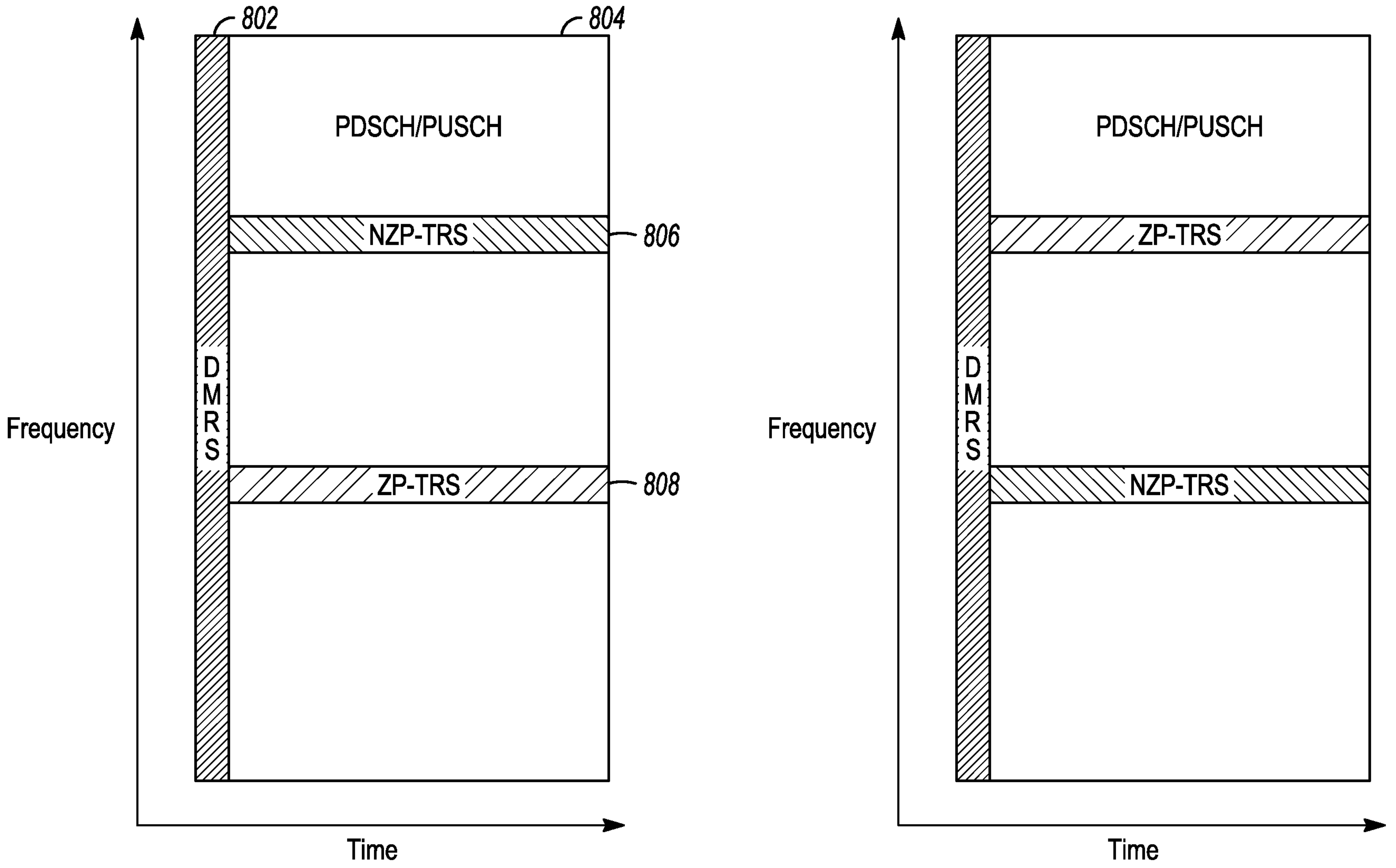

700
702
704
706
708
712
PDCCH
DMRS
PDSCH
GP
PUCCH
DL Transmission
710
714
PDCCH
GP
DMRS
PUSCH
UL Transmission
720

FIG. 7



810 — Frame structure in victim cell

820 — Frame structure in interference cell

FIG. 8

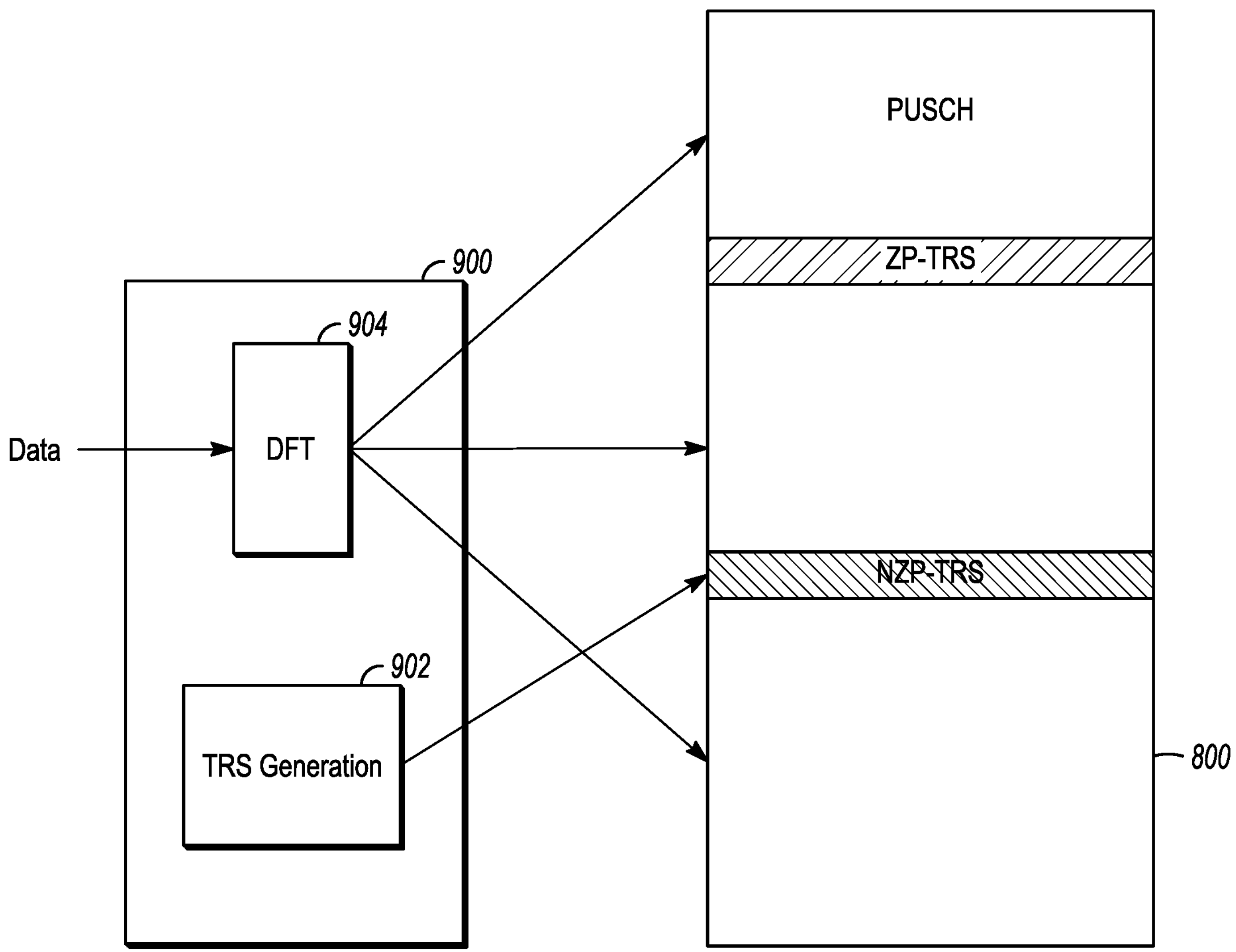


FIG. 9

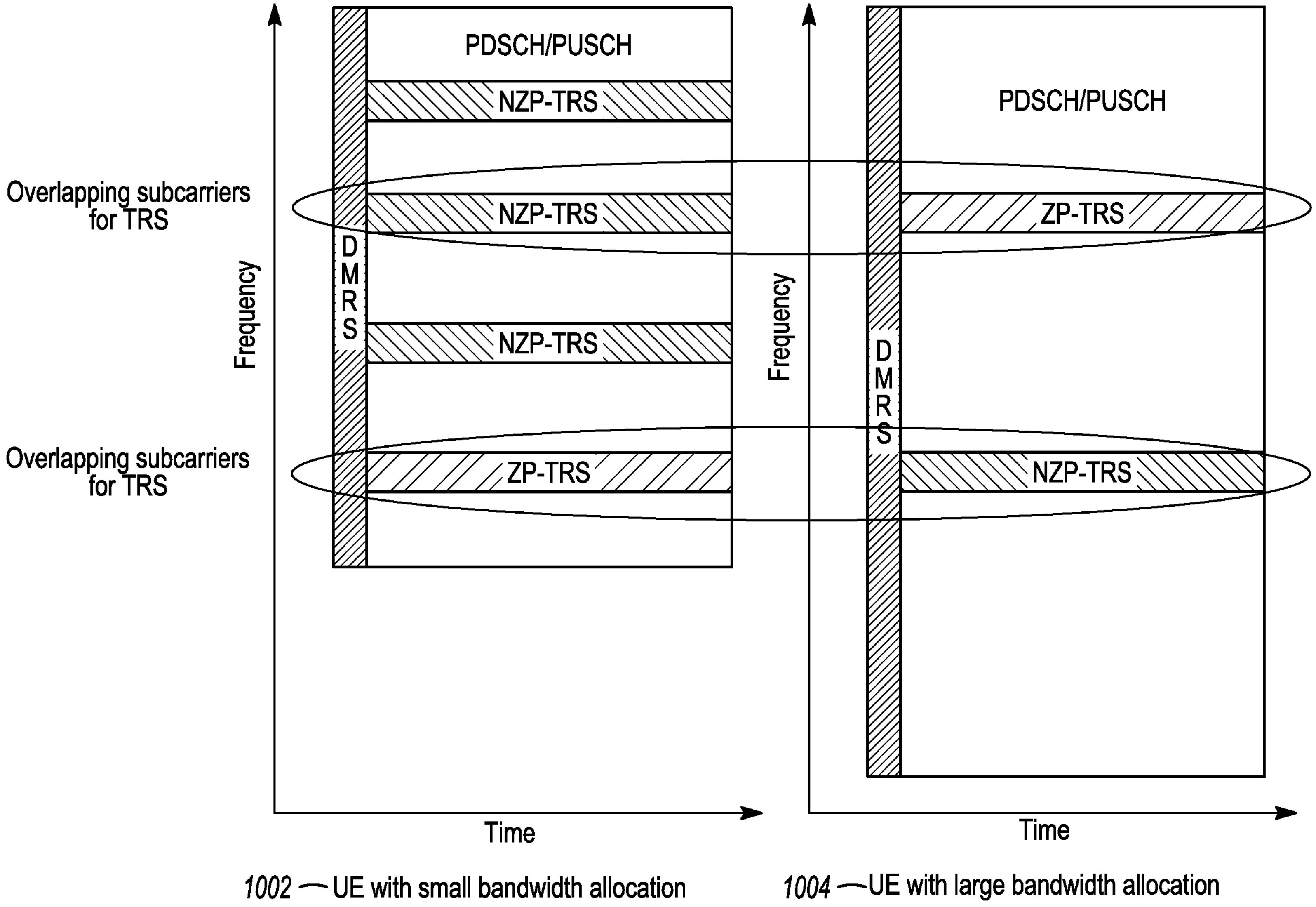

Overlapping subcarriers for TRS
Overlapping subcarriers for TRS
Frequency
PDSCH/PUSCH
NZP-TRS
NZP-TRS
NZP-TRS
ZP-TRS
DMRS
Time
1002 UE with small bandwidth allocation
Frequency
PDSCH/PUSCH
ZP-TRS
NZP-TRS
DMRS
Time
1004 UE with large bandwidth allocation

FIG. 10

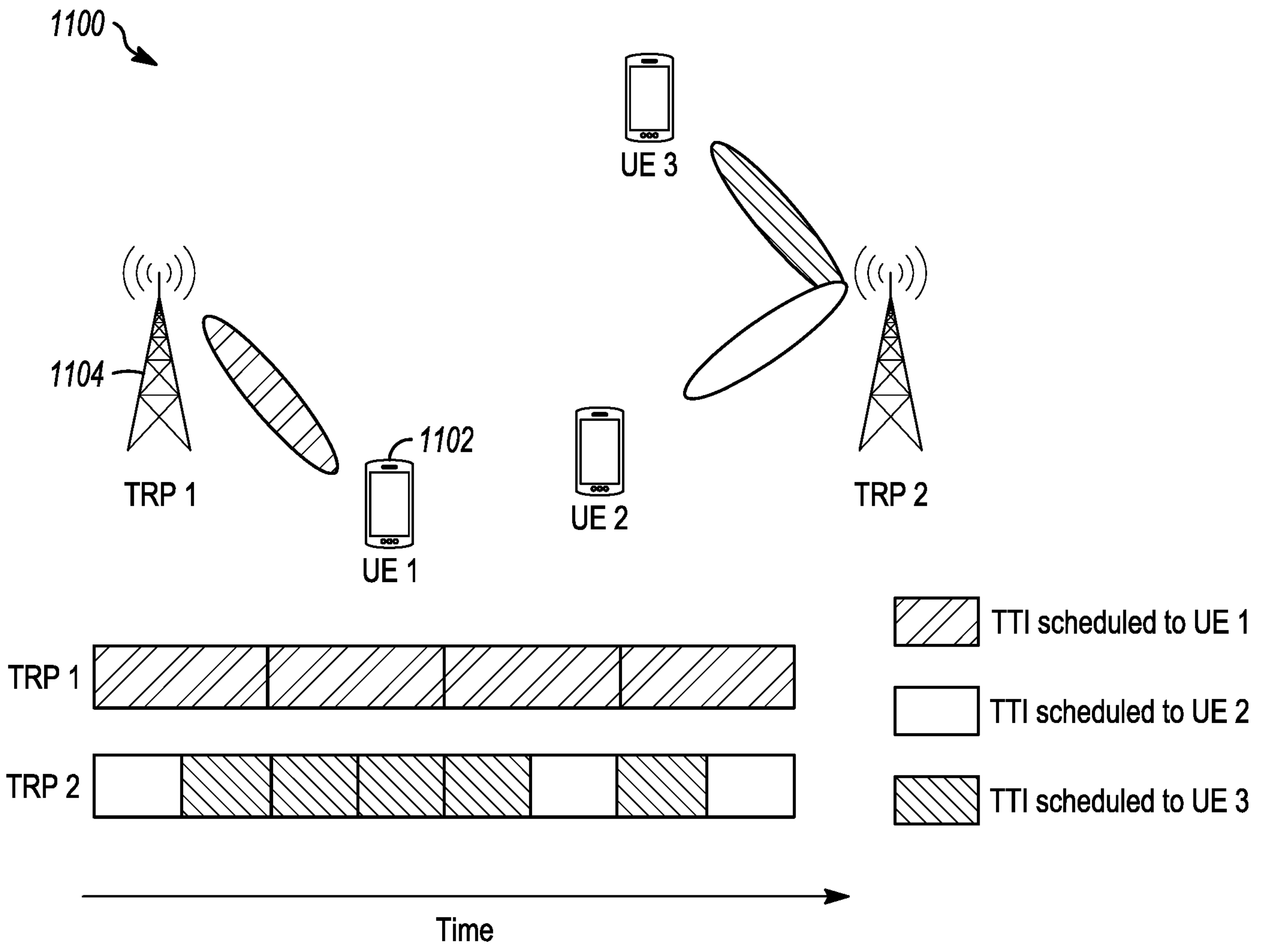
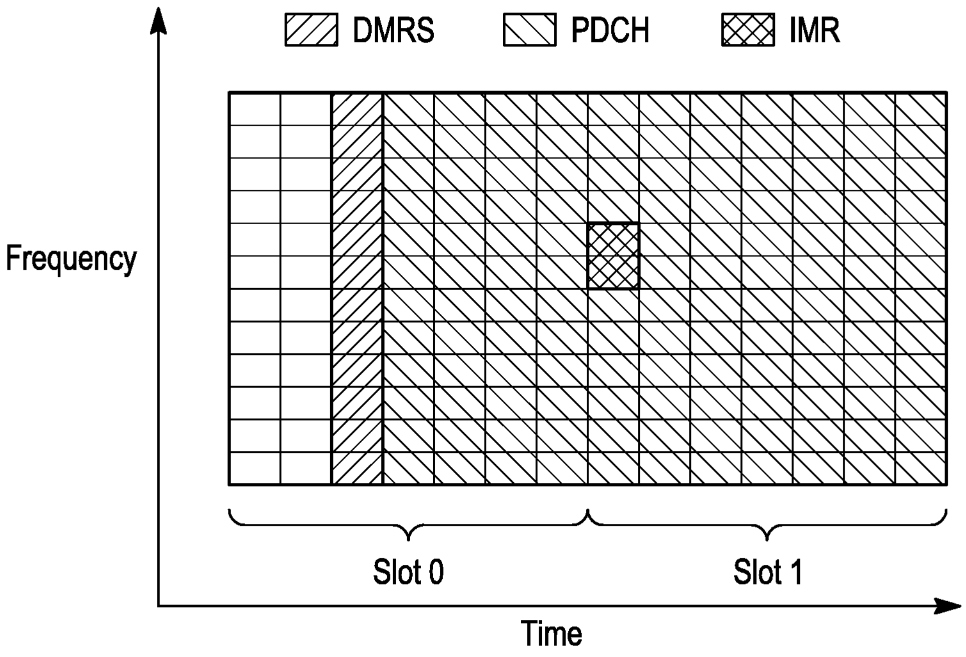
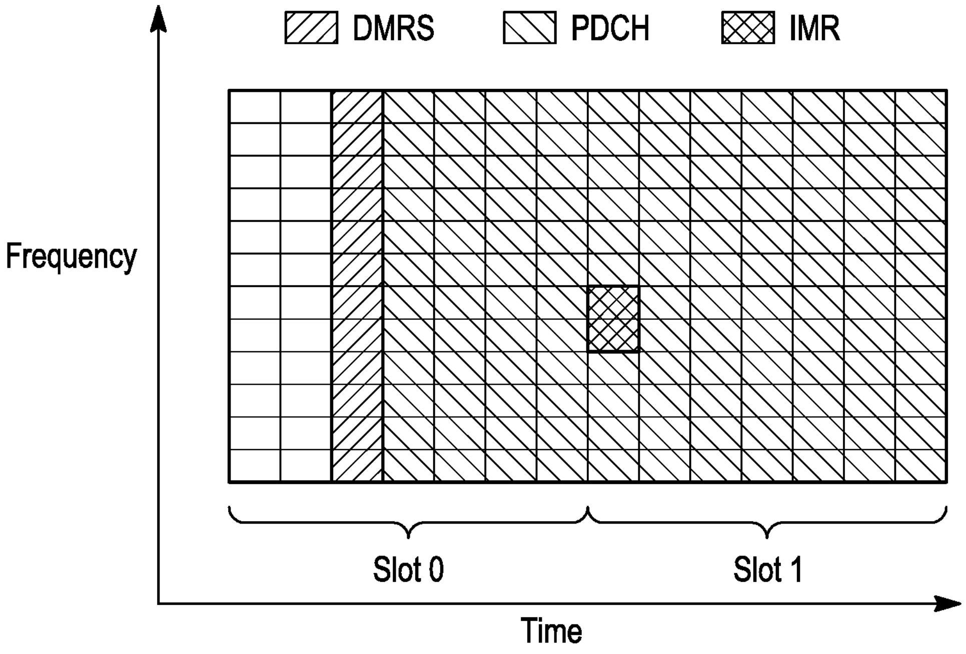

1100
1104
TRP 1
1102
UE 1
UE 2
UE 3
TRP 2
TRP 1
TRP 2
Time
TTI scheduled to UE 1
TTI scheduled to UE 2
TTI scheduled to UE 3

FIG. 11

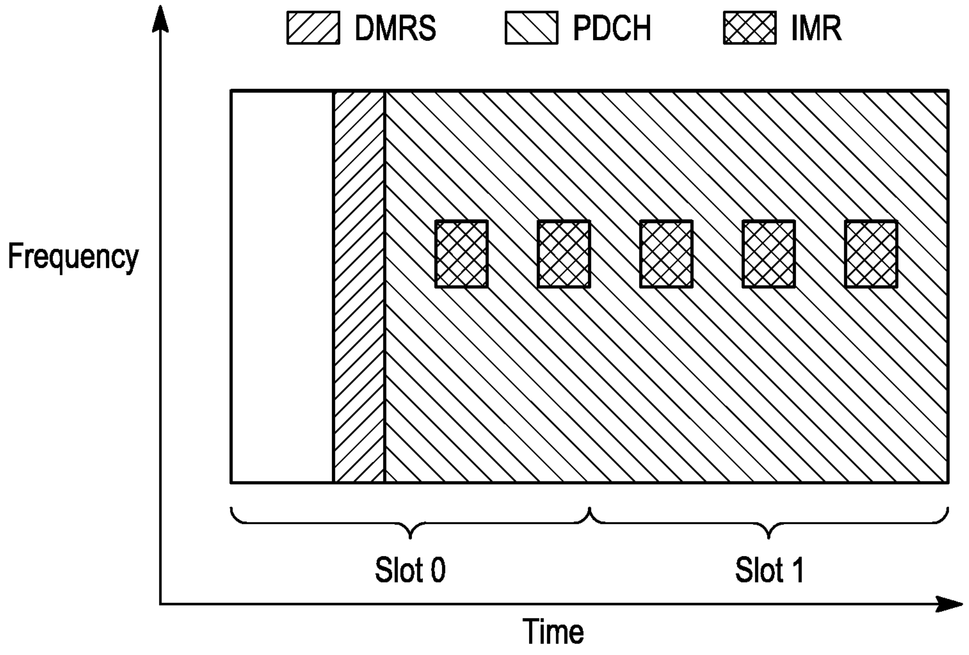


IMR for UE 1

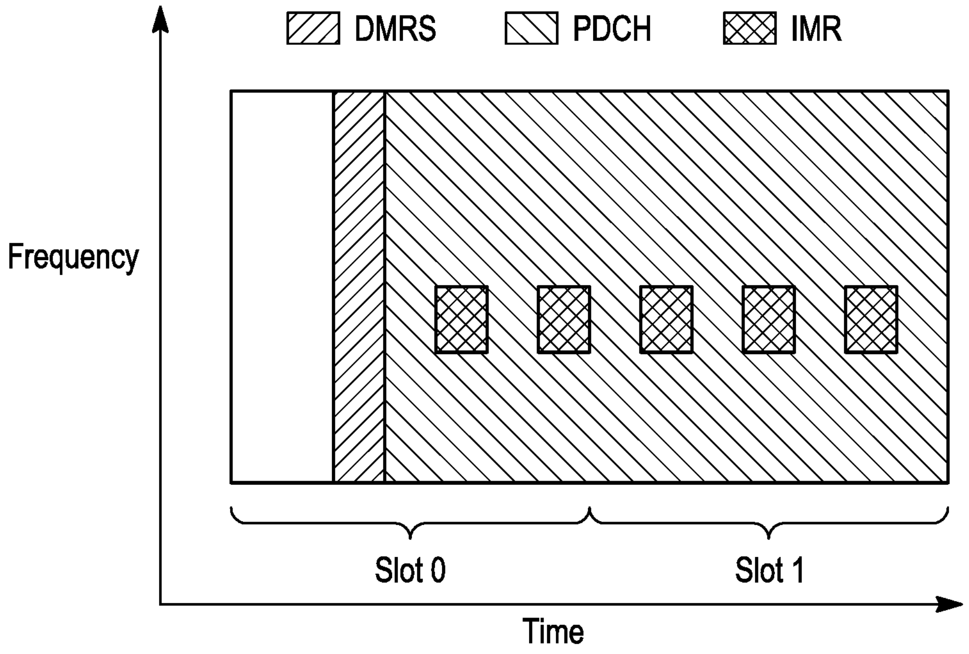


IMR for UE 2

FIG. 12



IMR for UE 1



IMR for UE 2

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/048614

A. CLASSIFICATION OF SUBJECT MATTER

H04L 5/00(2006.01)i, H04L 27/26(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04L 5/00; H04J 11/00; H04W 24/10; H04B 1/3827; H04W 72/08; H04W 24/08; H04L 27/26

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: interference measurement resource (IMR), interference covariance matrix, zero power (ZP) tracking reference signal (PT-RS), non-zero power (NZP)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2015-0098440 A1 (NOKIA SOLUTIONS AND NETWORKS OY) 09 April 2015 See paragraphs [0048]-[0093]; claims 1-2; and figures 1-2.	1,2,4,9-11,13
A		3,5-8,12,14-28
Y	US 2014-0233466 A1 (RESEARCH IN MOTION LIMITED) 21 August 2014 See paragraphs [0028]-[0059], [0103]-[0161]; and figures 3, 8, 15.	1,2,4,9-11,13
Y	US 2015-0264594 A1 (INTEL CORPORATION) 17 September 2015 See paragraphs [0040]-[0070]; and claim 26.	2
Y	US 2014-0092760 A1 (QUALCOMM INCORPORATED) 03 April 2014 See claims 1, 8.	9
Y	US 2014-0321313 A1 (LG ELECTRONICS INC.) 30 October 2014 See paragraphs [0148]-[0159]; and figure 7.	10-11

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

* Special categories of cited documents:	"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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"E" earlier application or patent but published on or after the international filing date	"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
"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)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
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Date of the actual completion of the international search 14 November 2017 (14.11.2017)	Date of mailing of the international search report **15 November 2017 (15.11.2017)**
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 KANG, Hee Gok Telephone No. +82-42-481-8264

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2017/048614

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