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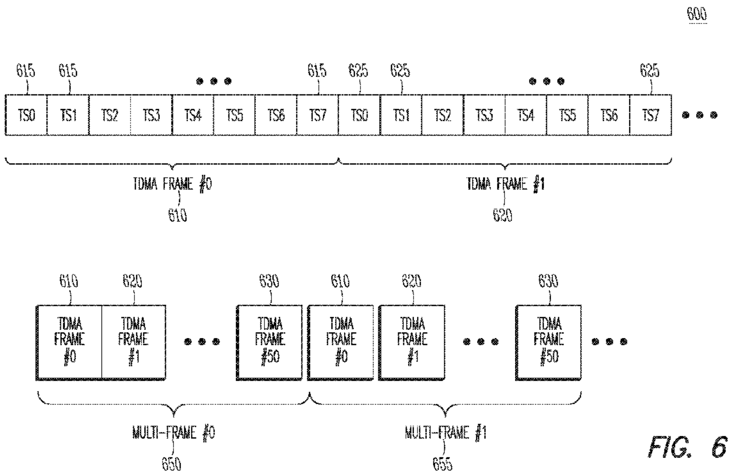

FIG. 6

(57) Abstract: Embodiments of an Evolved Node-B (eNB), User Equipment (UE) and methods for communication in accordance with enhance coverage (EC) global system for mobile (GSM) communication are generally described herein. In some embodiments, the eNB and/or UE may be configured to operate in accordance with enhanced coverage GSM internet-of-things (EC-GSM-IoT) operation. The eNB may transmit a bitmap of enhanced coverage paging channel (EC-PCH) indicators that indicate whether a group of EC-PCHs are allocated during a multi-frame for paging of one or more UEs. The multi-frame may include a control portion and an EC-PCH portion that includes multiple time-division multiple-access (TDMA) frames. Different portions of the EC-PCH indicators may be mapped to EC-PCHs that span different numbers of TDMA frames.

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EVOLVED NODE-B (ENB), USER EQUIPMENT (UE) AND METHODS FOR PAGING IN ENHANCED COVERAGE PAGING CHANNELS

TECHNICAL FIELD

[0001] This application claims priority under 35 U.S.C. 120 to International Application Serial No. PCT/CN2016/076993, filed March 22, 2016, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] Embodiments pertain to wireless communications. Some embodiments relate to wireless networks including 3GPP (Third Generation Partnership Project) networks, 3GPP GPRS (General Packet Radio Service) networks, 3GPP GSM (Global System for Mobile) networks, 3GPP LTE (Long Term Evolution) networks and/or 3GPP LTE-A (LTE Advanced) networks, although the scope of the embodiments is not limited in this respect. Some embodiments related to enhanced coverage (EC) operation. Some embodiments relate to internet-of-things (IoT) operation, including EC-GSM-IoT operation. Some embodiments relate to paging channels and/or paging messages.

BACKGROUND

[0003] Base stations and mobile devices operating in a cellular network may exchange data and related control messages. In an example scenario, the network may support operation according to Internet of Things (IoT) protocols or techniques. In some embodiments, mobile devices that support IoT operation may operate in accordance with reduced processing power, memory, size, complexity and/or other factors. Some operations may be challenging, including paging, synchronization, exchanging of data and/or others. Accordingly, there is a general need for methods and systems for performing these and other operations as part of IoT techniques and/or other techniques.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. 1 is a functional diagram of a 3GPP network in accordance with some embodiments;

[0005] FIG. 2 illustrates a block diagram of an example machine in accordance with some embodiments;

[0006] FIG. 3 is a block diagram of an Evolved Node-B (eNB) in accordance with some embodiments;

[0007] FIG. 4 is a block diagram of a User Equipment (UE) in accordance with some embodiments;

[0008] FIG. 5 illustrates a coverage enhancement scenario in accordance with some embodiments;

[0009] FIG. 6 illustrates an example of time-division multiple-access (TDMA) operation in accordance with some embodiments;

[0010] FIG. 7 illustrates the operation of a method of communication in accordance with some embodiments;

[0011] FIG. 8 illustrates examples of enhanced coverage paging channels (EC-PCHs) in accordance with some embodiments;

[0012] FIG. 9 illustrates additional examples of EC-PCHs in accordance with some embodiments;

[0013] FIG. 10 illustrates additional examples of EC-PCHs in accordance with some embodiments;

[0014] FIG. 11 illustrates additional examples of EC-PCHs in accordance with some embodiments;

[0015] FIG. 12 illustrates an example of an enhanced coverage paging information channel (EC-PICH) in accordance with some embodiments;

[0016] FIG. 13 illustrates the operation of another method of communication in accordance with some embodiments; and

[0017] FIG. 14 illustrates the operation of another method of communication in accordance with 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 is a functional diagram of a 3GPP network in accordance with some embodiments. It should be noted that embodiments are not limited to the example 3GPP network shown in FIG. 1, as other networks may be used in some embodiments. In some embodiments, a network that supports one or more technologies, such as Global System for Mobile (GSM), General Packet Radio Service (GPRS), Enhanced Data Rates for GSM Evolution (EDGE), Wideband Code-Division Multiple Access (W-CDMA), Long Term Evolution (LTE), Fifth Generation (5G) and/or others may be used. The network may support a combination of one or more such technologies, in some embodiments, although a stand-alone network that supports one such technology may also be used. As an example, a network may support an updated or newer technology and may continue to support (and/or be backward compatible with) a previously implemented technology (which may be a legacy technology). As an example, an LTE network may support legacy GPRS operation, in some cases. Embodiments are not limited to these example networks, however, as other networks may be used in some embodiments. In addition, in some embodiments, one or more networks, including these example networks and/or other networks, may be used in combination. As an example, the UE 102 may be configured to communicate with an LTE network 110 and a GPRS network 120 in some cases. Such networks may or may not include some or all of the components shown in FIG. 1, and may include additional components and/or alternative components in some cases.

[0020] FIG. 1 shows a portion of an end-to-end network architecture of a 3GPP network with various components of the network in accordance with some embodiments. The network 100 may include one or more radio access networks (RAN) such as the E-UTRAN 110 and the GERAN/UTRAN 120, which may provide air interfaces for the UE 102 to communicate with the network 100 over the links 115 and 125, respectively. It should be noted that although GERAN and UTRAN are two different radio access networks standardized by 3GPP, the GERAN/UTRAN 120 is shown as a single block in FIG. 1 for convenience. In addition, the term "GERAN/UTRAN" may also be used for convenience, and may refer to a "GERAN or UTRAN." The E-UTRAN 110 may include the eNB 104 and additional eNBs not shown, while the GERAN/UTRAN 120 may include the base transceiver system (BTS) 122 and/or Node-B 122 and additional BTSs/Node-Bs not shown. In addition, other components may be included in the E-UTRAN 110 and the GERAN/UTRAN 120, although such components may not be shown in FIG. 1 for ease of illustration. In some embodiments, the E-UTRAN 110 may provide an air interface to the UE 102 for 4G services while the GERAN/UTRAN 120 may provide an air interface to the UE 102 for 3G and/or 2G services. In accordance with some embodiments, the eNB 104 may transmit paging messages in one or more enhanced coverage paging channels (EC-PCHs). The paging messages may indicate that one or more UEs 102 are to be paged. In some embodiments, the paging messages may indicate that one or more paging groups (which may include one or more UEs 102) are to be paged. The UE 102 and eNB 104 may exchange control messages and/or data messages. It should also be noted that in some embodiments, the BTS 122 and/or Node-B 122 may transmit paging messages in one or more EC-PCHs. In addition, the UE 102 may exchange control messages and/or data messages with the BTS 122 and/or Node-B 122, in some embodiments. These embodiments will be described in more detail below.

[0021] The network 100 may also include a Mobile Switching Center / Visitor Location Register (MSC / VLR) 150, which may provide, manage or facilitate delivery of circuit-switched (CS) services for the UE 102. The network

100 may also include the Mobility Management Entity (MME) 130, which may provide, manage or facilitate delivery of packet-switched (PS) services for the UE 102 through the E-UTRAN 110. The network 100 may also include the Serving GPRS Support Node (SGSN) 140, which may provide, manage or facilitate delivery of packet-switched (PS) services for the UE 102 through the GERAN/UTRAN 120. The MME 130 and/or the SGSN 140 may manage mobility aspects in access such as gateway selection and tracking area list management.

[0022] The MME 130 may be communicatively coupled to the MSC/VLR 150 through the SGs interface 164 and to the E-UTRAN 110 through the S1 interface 160. The SGSN 140 may be communicatively coupled to the MSC/VLR 150 through the Gs interface 165 and to the GERAN 120 through the Gb interface 161 or to the UTRAN 120 through the Iu-ps interface 161. The MSC/VLR 150 may be communicatively coupled to the GERAN 120 through the A interface 163 or to the UTRAN 120 through the Iu-cs interface 163. In addition, the SGSN 140 and MME 130 may be communicatively coupled through the S3 interface 162. It should be noted that the interfaces 161, 163 as shown in FIG. 1 include multiple labels for convenience of illustration only.

[0023] In some embodiments, the UE 102 may receive 4G services through a path that includes the E-UTRAN 110 and the MME 130. In some embodiments, the UE 102 may receive 3G services through a path that includes the UTRAN 120 and the SGSN 140, or through a path that includes the UTRAN 120 and the MSC/VLR 150. In some embodiments, the UE 102 may receive 2G services through a path that includes the GERAN 120 and the SGSN 140, or through a path that includes the GERAN 120 and the MSC/VLR 150. These embodiments are not limiting, however, as the components in the network 100 may provide all or some of those or other services in any suitable manner.

[0024] In some embodiments, one or more of the UEs 102 may be configured to operate in accordance with an internet-of-things (IoT) protocol and/or IoT techniques. As an example, enhanced coverage GSM internet-of-things (EC-GSM-IoT) protocols and/or techniques may be used in some cases. Accordingly, references herein to a UE, IoT UE and/or EC-GSM-IoT UE as part of descriptions herein are not limiting. For instance, references to one of the UE, IoT UE or EC-GSM-IoT UE as part of descriptions of various operations and/or techniques may be applicable to the others in some embodiments (and may be applicable to other devices, in some embodiments). In some embodiments, the eNB 104 may be configured to operate in accordance with an internet-of-things (IoT) protocol, IoT techniques, an EC-GSM-IoT protocol and/or EC-GSM-IoT techniques. In some embodiments, the UE 102 and/or eNB 104 may be configured to operate in accordance with a machine type communication (MTC) protocol and/or MTC techniques.

[0025] In accordance with some embodiments, UEs 102 may be configured to communicate Gaussian minimum shift-keying (GMSK) communication signals with the eNB 104 (or other base station component). The eNBs 104 may be configured to communicate GMSK signals with the UEs 102 (or other devices and/or mobile devices) in some embodiments. The GMSK signals may be communicated in accordance with a GSM protocol, in some embodiments. In some embodiments, the GMSK signals may be further communicated in accordance with an EC-GSM-IoT protocol. In addition, the GMSK signals may be communicated in accordance with time-division multiple-access (TDMA) techniques, frequency-division multiple-access (FDMA) techniques and/or a combination thereof, in some embodiments.

[0026] As used herein, the term "circuitry" may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable hardware components that provide the described functionality. In some embodiments, the circuitry may be implemented in, or functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware. Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software.

[0027] FIG. 2 illustrates a block diagram of an example machine in accordance with some embodiments. The machine 200 is an example machine upon which any one or more of the techniques and/or methodologies discussed herein may be performed. In alternative embodiments, the machine 200 may operate as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine 200 may operate in the capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine 200 may act as a peer machine in peer-to-peer (P2P) (or other distributed) network environment. The machine 200 may be a UE 102, eNB 104, access point (AP), station (STA), mobile device, base station, personal computer (PC), a tablet PC, a set-top box (STB), a personal digital assistant (PDA), a mobile telephone, a smart phone, a web appliance, a network router, switch or bridge, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine. Further, while only a single machine is illustrated, the term "machine" shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein, such as cloud computing, software as a service (SaaS), other computer cluster configurations.

[0028] Examples as described herein, may include, or may operate on, logic or a number of components, modules, or mechanisms. Modules are tangible entities (e.g., hardware) capable of performing specified operations and may be configured or arranged in a certain manner. In an example, circuits may be arranged (e.g., internally or with respect to external entities such as other circuits) in a specified manner as a module. In an example, the whole or part of one or more computer systems (e.g., a standalone, client or server computer system) or one or more hardware processors may be configured by firmware or software (e.g., instructions, an application portion, or an application) as a module that operates to perform specified operations. In an example, the software may reside on a machine readable medium. In an example, the software, when executed by the underlying hardware of the module, causes the hardware to perform the specified operations.

[0029] Accordingly, the term "module" is understood to encompass a tangible entity, be that an entity that is physically constructed, specifically configured (e.g., hardwired), or temporarily (e.g., transitorily) configured (e.g., programmed) to operate in a specified manner or to perform part or all of any operation described herein. Considering examples in which modules are temporarily configured, each of the modules need not be instantiated at any one moment in time. For example, where the modules comprise a general-purpose hardware processor configured using software, the general-purpose hardware processor may be configured as respective different modules at different times. Software may accordingly configure a hardware processor, for example, to constitute a particular module at one instance of time and to constitute a different module at a different instance of time.

[0030] The machine (e.g., computer system) 200 may include a hardware processor 202 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 204 and a static memory 206, some or all of which may communicate with each other via an interlink (e.g., bus) 208. The machine 200 may further include a display unit 210, an alphanumeric input device 212 (e.g., a keyboard), and a user interface (UI) navigation device 214 (e.g., a mouse). In an example, the display unit 210, input device 212 and UI navigation device 214 may be a touch screen display. The machine 200 may additionally include a storage device (e.g., drive unit) 216, a signal generation device 218 (e.g., a speaker), a network interface device 220, and one or more sensors 221, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The machine 200 may include an output controller 228, such as a serial (e.g., universal serial bus (USB), parallel, or other wired or wireless (e.g., infrared (IR), near field communication (NFC), etc.) connection to communicate or control one or more peripheral devices (e.g., a printer, card reader, etc.).

[0031] The storage device 216 may include a machine readable medium 222 on which is stored one or more sets of data structures or instructions 224 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 224 may also reside, completely or at least partially, within the main memory 204, within static memory 206, or within the hardware processor 202 during execution thereof by the machine 200. In an example, one or any combination of the hardware processor 202, the main memory 204, the static memory 206, or the storage device 216 may constitute machine readable media. In some embodiments, the machine readable medium may be or may include a non-transitory computer-readable storage medium.

[0032] While the machine readable medium 222 is illustrated as a single medium, the term "machine readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) configured to store the one or more instructions 224. The term "machine readable medium" may include any medium that is capable of storing, encoding, or carrying instructions for execution by the machine 200 and that cause the machine 200 to perform any one or more of the techniques of the present disclosure, or that is capable of storing, encoding or carrying data structures used by or associated with such instructions. Non-limiting machine readable medium examples may include solid-state memories, and optical and magnetic media. Specific examples of machine readable media may include: non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; Random Access Memory (RAM); and CD-ROM and DVD-ROM disks. In some examples, machine readable media may include non-transitory machine readable media. In some examples, machine readable media may include machine readable media that is not a transitory propagating signal.

[0033] The instructions 224 may further be transmitted or received over a communications network 226 using a transmission medium via the network interface device 220 utilizing any one of a number of transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communication networks may include a local area network (LAN), a wide area network (WAN), a packet data network (e.g., the Internet), mobile telephone networks (e.g., cellular networks), Plain Old Telephone (POTS) networks, and wireless data networks (e.g., Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards known as Wi-Fi®, IEEE 802.16 family of standards known as WiMax®), IEEE 802.15.4 family of standards, a Long Term Evolution (LTE) family of standards, a Universal Mobile Telecommunications

System (UMTS) family of standards, peer-to-peer (P2P) networks, among others. In an example, the network interface device 220 may include one or more physical jacks (e.g., Ethernet, coaxial, or phone jacks) or one or more antennas to connect to the communications network 226. In an example, the network interface device 220 may include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), multiple-input multiple-output (MIMO), or multiple-input single-output (MISO) techniques. In some examples, the network interface device 220 may wirelessly communicate using Multiple User MIMO techniques. The term "transmission medium" shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution by the machine 200, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

[0034] FIG. 3 is a block diagram of an Evolved Node-B (eNB) in accordance with some embodiments. It should be noted that in some embodiments, the eNB 300 may be a stationary non-mobile device. The eNB 300 may be suitable for use as an eNB 104 as depicted in FIG. 1. It should be noted that embodiments are not limited by references herein to an eNB 104, such as in descriptions herein of methods, operations and/or techniques. In some embodiments, such methods, operations and/or techniques may be applicable to embodiments in which another base station component (such as a BTS, Node-B or other) are included.

[0035] The eNB 300 may include physical layer circuitry 302 and a transceiver 305, one or both of which may enable transmission and reception of signals to and from the UE 200, other eNBs, other UEs or other devices using one or more antennas 301. As an example, the physical layer circuitry 302 may perform various encoding and decoding functions that may include formation of baseband signals for transmission and decoding of received signals. As another example, the transceiver 305 may perform various transmission and reception functions such as conversion of signals between a baseband range and a Radio Frequency (RF) range. Accordingly, the physical layer circuitry 302 and the transceiver 305 may be separate components or may be part of a combined component. In addition, some of the described functionality related to transmission and reception of signals may be performed by a combination that may include one, any or all of the physical layer circuitry 302, the transceiver 305, and other components or layers. The eNB 300 may also include medium access control layer (MAC) circuitry 304 for controlling access to the wireless medium. The eNB 300 may also include processing circuitry 306 and memory 308 arranged to perform the operations described herein. The eNB 300 may also include one or more interfaces 310, which may enable communication with other components, including other eNBs 104 (FIG. 1), components in the network 100 (FIG. 1) or other network components. In addition, the interfaces 310 may enable communication with other components that may not be shown in FIG. 1, including components external to the network. The interfaces 310 may be wired or wireless or a combination thereof. It should be noted that in some embodiments, an eNB or other base station may include some or all of the components shown in either FIG. 2 or FIG. 3 or both.

[0036] FIG. 4 is a block diagram of a User Equipment (UE) in accordance with some embodiments. The UE 400 may be suitable for use as a UE 102 as depicted in FIG. 1. It should be noted that embodiments are not limited by references herein to a UE 102, such as in descriptions herein of methods, operations and/or techniques. In some embodiments, such methods, operations and/or techniques may be applicable to embodiments in which another mobile device (such as an MS or other) are included.

[0037] In some embodiments, the UE 400 may include application circuitry 402, baseband circuitry 404, Radio Frequency (RF) circuitry 406, front-end module (FEM) circuitry 408 and one or more antennas 410, coupled together at least as shown. In some embodiments, other circuitry or arrangements may include one or more elements and/or components of the application circuitry 402, the baseband circuitry 404, the RF circuitry 406 and/or the FEM circuitry 408, and may also include other elements and/or components in some cases. As an example, "processing circuitry" may include one or more elements and/or components, some or all of which may be included in the application circuitry 402 and/or the baseband circuitry 404. As another example, a "transceiver" and/or "transceiver circuitry" may include one or more elements and/or components, some or all of which may be included in the RF circuitry 406 and/or the FEM circuitry 408. These examples are not limiting, however, as the processing circuitry, transceiver and/or the transceiver circuitry may also include other elements and/or components in some cases. It should be noted that in some embodiments, a UE or other mobile device may include some or all of the components shown in either FIG. 2 or FIG. 4 or both.

[0038] The application circuitry 402 may include one or more application processors. For example, the application circuitry 402 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with and/or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications and/or operating systems to run on the system.

[0039] The baseband circuitry 404 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 404 may include one or more baseband processors and/or control logic to process baseband signals received from a receive signal path of the RF circuitry 406 and to generate baseband signals for a transmit signal path of the RF circuitry 406. Baseband processing circuitry 404 may interface with the application circuitry 402 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 406. For example, in some embodiments, the baseband circuitry 404 may include a second generation (2G) baseband processor 404a, third generation (3G) baseband processor 404b, fourth generation (4G) baseband processor 404c, and/or other baseband processor(s) 404d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 404 (e.g., one or more of baseband processors 404a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 406. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 404 may include

Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 404 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

[0040] In some embodiments, the baseband circuitry 404 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (EUTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), and/or radio resource control (RRC) elements. A central processing unit (CPU) 404e of the baseband circuitry 404 may be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP and/or RRC layers. In some embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (DSP) 404f. The audio DSP(s) 404f may 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 404 and the application circuitry 402 may be implemented together such as, for example, on a system on a chip (SOC).

[0041] In some embodiments, the baseband circuitry 404 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 404 may support communication with an evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 404 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[0042] RF circuitry 406 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 406 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 406 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 408 and provide baseband signals to the baseband circuitry 404. RF circuitry 406 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 404 and provide RF output signals to the FEM circuitry 408 for transmission.

[0043] In some embodiments, the RF circuitry 406 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 406 may include mixer circuitry 406a, amplifier circuitry 406b and filter circuitry 406c. The transmit signal path of the RF circuitry 406 may include filter circuitry 406c and mixer circuitry 406a. RF circuitry 406 may also include synthesizer circuitry 406d for synthesizing a frequency for use by the mixer circuitry 406a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 406a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 408 based on the synthesized frequency provided by synthesizer circuitry 406d. The amplifier circuitry 406b may be configured to amplify the down-converted signals and the filter circuitry 406c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be provided to the baseband circuitry 404 for further processing. In some embodiments, the output baseband signals may be zero-frequency baseband signals, although this is not a requirement. In some embodiments, mixer circuitry 406a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect. In some embodiments, the mixer circuitry 406a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 406d to generate RF output signals for the FEM circuitry 408. The baseband signals may be provided by the baseband circuitry 404 and may be filtered by filter circuitry 406c. The filter circuitry 406c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

[0044] In some embodiments, the mixer circuitry 406a of the receive signal path and the mixer circuitry 406a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and/or upconversion respectively. In some embodiments, the mixer circuitry 406a of the receive signal path and the mixer circuitry 406a of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 406a of the receive signal path and the mixer circuitry 406a may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 406a of the receive signal path and the mixer circuitry 406a of the transmit signal path may be configured for super-heterodyne operation.

[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 406 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 404 may include a digital baseband interface to communicate with the RF circuitry 406. In some dual-mode embodiments, a separate radio IC circuitry may be provided for processing signals for each spectrum, although the scope of the embodiments is not limited in this respect.

[0046] In some embodiments, the synthesizer circuitry 406d may be a fractional-N synthesizer or a fractional N/N+1 synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 406d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider. The synthesizer circuitry 406d may be configured to synthesize an output frequency for use by the mixer circuitry 406a of the RF circuitry 406 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 406d may be a fractional

N/N+1 synthesizer. In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry 404 or the applications processor 402 depending on the desired output frequency. In some embodiments, a divider control input (e.g., N) may be determined from a look-up table based on a channel indicated by the applications processor 402.

[0047] Synthesizer circuitry 406d of the RF circuitry 406 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or N+1 (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up 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.

[0048] In some embodiments, synthesizer circuitry 406d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency may be a LO frequency (f_{LO}). In some embodiments, the RF circuitry 406 may include an IQ/polar converter.

[0049] FEM circuitry 408 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 410, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 406 for further processing. FEM circuitry 408 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 406 for transmission by one or more of the one or more antennas 410.

[0050] In some embodiments, the FEM circuitry 408 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 406). The transmit signal path of the FEM circuitry 408 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 406), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 410. In some embodiments, the UE 400 may include additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface.

[0051] The antennas 230, 301, 410 may comprise one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, patch antennas, loop antennas, microstrip antennas or other types of antennas suitable for transmission of RF signals. In some multiple-input multiple-output (MIMO) embodiments, the antennas 230, 301, 410 may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result.

[0052] In some embodiments, the UE 400 and/or the eNB 300 may be a mobile device and may be a portable wireless communication device, such as a personal digital assistant (PDA), a laptop or portable computer with wireless communication capability, a web tablet, a wireless telephone, a smartphone, a wireless headset, a pager, an instant messaging device, a digital camera, an access point, a television, a wearable device such as a medical device (e.g., a heart rate monitor, a blood pressure monitor, etc.), or other device that may receive and/or transmit information wirelessly. In some embodiments, the UE 400 or eNB 300 may be configured to operate in accordance with 3GPP standards, although the scope of the embodiments is not limited in this respect. Mobile devices or other devices in some embodiments may be configured to operate according to other protocols or standards, including IEEE 802.11 or other IEEE standards. In some embodiments, the UE 400, eNB 300 or other device may include one or more of a keyboard, a display, a non-volatile memory port, multiple antennas, a graphics processor, an application processor, speakers, and other mobile device elements. The display may be an LCD screen including a touch screen.

[0053] Although the UE 400 and the eNB 300 are each illustrated as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For example, some elements may comprise one or more microprocessors, DSPs, field-programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), radio-frequency integrated circuits (RFICs) and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements may refer to one or more processes operating on one or more processing elements.

[0054] Embodiments may be implemented in one or a combination of hardware, firmware and software. Embodiments may also be implemented as instructions stored on a computer-readable storage device, which may be read and executed by at least one processor to perform the operations described herein. A computer-readable storage device may include any non-transitory mechanism for storing information in a form readable by a machine (e.g., a computer). For example, a computer-readable storage device may include read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and other storage devices and media. Some embodiments may include one or more processors and may be configured with instructions stored on a computer-readable storage device.

[0055] It should be noted that in some embodiments, an apparatus used by the UE 400 and/or eNB 300 and/or machine 200 may include various components of the UE 400 and/or the eNB 300 and/or the machine 200 as shown in FIGs. 2-4. Accordingly, techniques and operations described herein that refer to the UE 400 (or 102) may be applicable to an apparatus for a UE. In addition, techniques and operations described herein that refer to the eNB 300 (or 104) may be applicable to an apparatus for an eNB.

[0056] In accordance with some embodiments, the eNB 104 may transmit a bitmap of enhanced coverage paging channel (EC-PCH) indicators that indicate whether a group of EC-PCHs are allocated during a multi-frame for paging of one or more User Equipments (UEs). In some embodiments, the bitmap of EC-PCH indicators may indicate whether the group of EC-PCHs are allocated during the multi-frame for paging of one or more paging groups (which may include one or more UEs 102). The multi-frame may include a control portion and an EC-PCH portion that includes multiple time-division multiple-access (TDMA) frames. Different portions of the EC-PCH indicators may be mapped to EC-PCHs that span different numbers of TDMA frames. These embodiments are described in more detail below.

[0057] FIG. 5 illustrates a coverage enhancement scenario in accordance with some embodiments. In some embodiments, coverage enhancement techniques may be used to improve range, signal quality, capacity and/or other performance metric. Although embodiments are not limited to IoT operation, coverage enhancement techniques may be used for IoT devices (including but not limited to EC-GSM-IoT devices) that exchange relatively small amounts of data at relatively infrequent rates. In such cases, the data rate may not be as important as range. Coverage enhancement may be in accordance with a group of coverage classes (CCs). Any suitable number of CCs may be used. The CCs may be temporary in some cases, and may be based on a level of additional resources for performance at or above a performance threshold. Examples of such may include an additional link margin, a number of repetitions of a message, a diversity gain, an allocated number of time slots and/or other factors. As a non-limiting example, a number of TDMA frames in which a downlink message is repeated may be based on the CC. For instance, a higher number of repetitions may be used for a first CC in which a relatively high amount of coverage enhancement is used. A lower number of repetitions may be used for a second CC in which a relatively low amount of coverage enhancement is used. These embodiments are described in more detail below.

[0058] In some scenarios, the UE 102 operating in a cellular communication network (such as 100) may lose connectivity to the network or may have difficulty in receiving messages (such as paging messages and/or other) from the network for various reasons. As an example, the UE 102 may move toward an area with reduced coverage, such as the edge of a sector or cell. As another example, the UE 102 may operate in an area that is essentially out of the normal coverage of the network, such as in a basement of a building. As another example, the UE 102 or other device may support EC-GSM-IoT operation, IoT operation and/or Machine Type Communication (MTC). EC-GSM-IoT devices, IoT devices, devices operating in an EC-GSM-IoT mode, devices operating in an IoT mode, MTC devices and/or devices operating in an MTC mode may be expected to operate in highly challenging link budget scenarios while exchanging small quantities of data at an infrequent rate.

[0059] Referring to FIG. 5, an example of a scenario 500 is shown, in which a tower eNB 104 and three UEs 510, 515, 520 (which may be suitable for use as a UE 102) located at various distances from the eNB 104 are operating, or attempting to operate, as part of a 3GPP or other network. It should be noted that the eNB 104 is not limited to the tower configuration and that scenarios described herein are not limited to the number or distribution of eNBs 104 or UEs 510, 515, 520 as shown in FIG. 5. Embodiments are also not limited to the number of coverage ranges shown and/or a number of CCs illustrated.

[0060] The first UE 510 is in communication with the eNB 104 over the link 530, and is comfortably located within the coverage area 550 of the eNB 104. The second UE 515 is located outside of the coverage area 550 in a demarcated zone 560, and may be attempting to receive messages over the link 535. Similarly, the third UE 520 is also located outside of the coverage area 550 in another demarcated zone 570 that is further away from the eNB 104 than the first demarcated zone 560. The third UE 520 may also be attempting to receive messages over the link 540.

[0061] The second UE 515 and third UE 520 may use "coverage enhancement" or may operate in a "coverage enhancement mode," as they are out of the coverage area 550. Additionally, while both UEs 515, 520 are outside of the coverage area 550, the third UE 520 may have more trouble or challenges in receiving messages than would the second UE 515, as the third UE 520 is further away from the eNB 104. Accordingly, it may be possible to formulate different coverage classes (CCs) for UEs depending on how far out of coverage they are located or other factors. In some embodiments, descriptions may be used in the CCs. For instance, the third UE 520 may be considered in a "high" CC while the second UE 515 may be considered in a "low" CC. In some embodiments, the CCs may be numerical or may represent numerical parameters, such as a number of diversity repetitions to be used, a number of TDMA frames of an EC-PCH and/or other. Such numerical parameters may represent additional resources that may be used for communication with the UEs 515, 520 in order to realize a "normal operation." As another example of numerical categories, an additional amount of link budget that may be added to the UEs 515, 520 in order to realize the normal operation may be used. The normal operation may be characterized by any suitable criteria such as a target packet error rate, acquisition time, data throughput or the like.

[0062] It should be pointed out that the above discussion focuses on path loss due to distance only, for purposes of illustration, but this is not limiting. It is understood that path loss, signal loss, coverage holes or the like may result from effects other than distance, such as obstacles or indoor location. For instance, a device located in a basement of a building close to the eNB 104 may actually be in need of a coverage enhancement while another device located much further away, but outdoors, may have a stronger connection to the eNB 104 and may be in need of less or no coverage enhancement.

[0063] FIG. 6 illustrates an example of time-division multiple-access (TDMA) operation in accordance with some embodiments. It should be noted that embodiments are not limited by the number, type, ordering and/or arrangement of frames, slots, multi-frames and/or other elements shown in the example 600. A first TDMA frame 610 may include 8 TDMA slots 615, labeled as TS0-TS7. A second TDMA frame 620 may include 8 TDMA slots 625, also labeled as TS0-TS7. The first and second TDMA frames 610, 620 and additional TDMA frames are included in a first multi-frame 650. A second multi-frame 655 may also include the same configuration of TDMA frames 610, 620 of the first multi-frame 655, although embodiments are not limited as such. Additional multi-frames may also be included.

[0064] In some embodiments, one of the TDMA slots (such as TS1, as will be used in examples below) may be allocated for transmission of EC-PCHs by the eNB 104. In addition, other TDMA slots may be used for other purposes, such as transmission of data to UEs 102. Embodiments are not limited to usage of a single TDMA slot (of TS0-TS7) for the transmission of the EC-PCHs. In some embodiments, at least some of the multi-frames may include a control portion and an EC-PCH portion (and perhaps other portions and/or additional portions in some cases).

[0065] FIG. 7 illustrates the operation of a method of communication in accordance with some embodiments. It is important to note that embodiments of the method 700 may include additional or even fewer operations or processes in comparison to what is illustrated in FIG. 7. In addition, embodiments of the method 700 are not necessarily limited to the chronological order that is shown in FIG. 7. In describing the method 700, reference may be made to FIGs. 1-6 and 8-14, although it is understood that the method 700 may be practiced with any other suitable systems, interfaces and components.

[0066] In addition, while the methods 700, 1400 and/or other methods described herein may refer to eNBs 104 or UEs 102 operating in accordance with 3GPP GSM/GPRS standards, embodiments of those methods are not limited to just those eNBs 104 or UEs 102 and may also be practiced on other devices, such as a base transceiver system (BTS), Node-B, mobile station (MS), Wi-Fi access point (AP) or user station (STA). In some embodiments, the eNB 104 and UE 102 of the methods 700, 1400 and/or other methods may be arranged to operate in accordance with a GSM protocol and further in accordance with an enhanced coverage GSM internet-of-things (EC-GSM-IoT) protocol, although the scope of embodiments is not limited in this respect.

[0067] In addition, the method 700, 1400 and/or other methods described herein may be practiced by wireless devices configured to operate in other suitable types of wireless communication systems, including systems configured to operate according to various IEEE standards such as IEEE 802.11. The methods 700 and/or 1400 may also refer to an apparatus for a UE 102 and/or eNB 104 and/or other device described above, in some embodiments.

[0068] It should also be noted that embodiments are not limited by references herein (such as in descriptions of the methods 700 and 1400 and/or other descriptions herein) to transmission, reception and/or exchanging of elements such as frames, messages, requests, indicators, signals or other elements. In some embodiments, such an element may be generated, encoded or otherwise processed by processing circuitry (such as by a baseband processor included in the processing circuitry) for transmission. The transmission may be performed by a transceiver or other component, in some cases. In some embodiments, such an element may be decoded, detected or otherwise processed by the processing circuitry (such as by the baseband processor). The element may be received by a transceiver or other component, in some cases. In some embodiments, the processing circuitry and the transceiver may be included in a same apparatus. The scope of embodiments is not limited in this respect, however, as the transceiver may be separate from the apparatus that comprises the processing circuitry, in some embodiments.

[0069] In some embodiments, an EC-GSM-IoT protocol may enable performance gains in comparison to legacy GPRS protocols. As an example, EC-GSM-IoT protocols may support a Maximum Coupling Loss (MCL) of 164 dB, which may be 20dB larger than the legacy GPRS solution, in some cases. In some cases, the EC-GSM-IoT protocol may provide improvements, such as reduced device complexity, reduced energy consumption, increased battery life and/or others in comparison to previous solutions like legacy GPRS, legacy GSM or other.

[0070] At operation 705 of the method 700, the eNB 104 may determine an allocation of a group of enhanced coverage paging channels (EC-PCHs) for transmission of paging messages to one or more UEs 102 during a multi-frame. In some embodiments, an EC-PCH may be allocated for the multi-frame when the eNB 104 intends to transmit one or more paging messages in the EC-PCH during the multi-frame. In some embodiments, the EC-PCHs may be allocated in time resources of an EC-PCH portion of the multi-frame, as will be described below.

[0071] At operation 710, the eNB 104 may transmit an enhanced coverage paging information channel (EC-PICH) message that indicates the allocation of the EC-PCHs. In some embodiments, the EC-PICH may be transmitted during a control portion of the multi-frame, as will be described below. In some embodiments, the EC-PICH may include a bitmap of EC-PCH indicators that indicate whether EC-PCHs of the group are allocated during the multi-frame for the paging of one or more UEs 102. In some embodiments, the bitmap of EC-PCH indicators may indicate whether EC-PCHs of the group are allocated during the multi-frame for the paging of one or more paging groups (which may include one or more UEs 102). As an example, an EC-PCH of the group may be shared by UEs 102 of a paging group. For instance, the UEs 102 may be mapped to the paging group based on factors such as international mobile subscriber identities (IMSIs) of the UEs 102, other identifiers of the UEs 102 and/or other factors. In addition, different EC-PCHs of the group may be shared by different paging groups of UEs 102, in some embodiments.

[0072] A predetermined mapping between EC-PCH indicators and EC-PCHs may be used in the bitmap, in some embodiments. As a non-limiting example, each bit position may be mapped to one of the EC-PCHs in the group. A value of the bitmap at a particular bit position may indicate whether or not a corresponding EC-PCH (for instance, the EC-PCH mapped to that bit position) is allocated during the multi-frame. It should also be noted that embodiments are not limited to usage of the EC-PICH for transmission of the bitmap of EC-PCH indicators. In some embodiments, the bitmap may be included in another control message, which may or may not be part of a standard. In some embodiments, the bitmap may not necessarily be included in a message.

[0073] At operation 715, the eNB 104 may transmit one or more paging messages to one or more UEs 102. In some embodiments, the eNB 104 may transmit one or more paging messages to one or more paging groups (which may include one or more UEs 102). In some embodiments, the UEs 102 may be EC-GSM-IoT UEs 102, enhanced coverage UEs 102 and/or UEs 102 operating in a coverage enhancement mode, although the scope of embodiments is not limited in this respect. The paging messages may be transmitted in accordance with the allocation of the EC-PCHs, in some embodiments. For instance, one or more paging messages may be transmitted in the allocated EC-PCH(s) during the multi-frame. In some embodiments, the paging message(s) may indicate to the one or more UEs 102 that the eNB 104 intends to initiate communication with the UE 102 for data communication, voice communication and/or other operations. In some embodiments, the paging message(s) may indicate to one or more paging groups that the eNB 104 intends to initiate communication with at least a portion of the UEs of the paging groups. Any suitable paging messages, identifiers of the UEs 102 and/or identifiers of the paging groups may be used. For instance, an international mobile subscriber identity (IMSI) that identifies a UE 102 may be included a paging message for the UE 102. The paging message may be allocated for a single UE 102 in some cases, although embodiments are not limited as such. Multiple UEs 102 and/or paging group(s) of one or more UEs 102 may be paged by a paging message, in some cases. In some embodiments, the paging messages may be included in one or more standards, including but not limited to a 3GPP standard such as LTE, GPRS, GSM and/or other. The scope of embodiments is not limited in this respect, however. In some embodiments, other control messages that may be included in other standards may be used. In addition, control messages that may not necessarily be part of a standard may also be used, in some embodiments.

[0074] At operation 720, one or more paging messages may be transmitted to a group of legacy UEs 102. In some embodiments, the eNB 104 may communicate with a first group of UEs 102 that operate in accordance with an EC-GSM-IoT protocol and also with a second group of UEs 102 that operate in accordance with legacy operation, normal operation, non-IoT operation and/or non-EC-GSM-IoT operation. For instance, the UEs 102 in the second group may not necessarily be configured for IoT operation or EC-GSM-IoT operation, in some cases. Accordingly, one or more TDMA slots may be used for legacy communication, in some embodiments. In addition, methods of paging for legacy communication may also be used for the legacy UEs 102, although the scope of embodiments is not limited in this respect.

[0075] FIGs. 8-11 illustrate examples of enhanced coverage paging channels (EC-PCHs) in accordance with some embodiments. FIG. 12 illustrates an example of an enhanced coverage paging information channel (EC-PICH) in accordance with some embodiments. It should be noted that the examples shown in FIGs. 8-12 may illustrate some or all of the concepts and techniques described herein in some cases, but embodiments are not limited by the examples. For instance, embodiments are not limited by the name, number, type, size, ordering, arrangement and/or other aspects of the TDMA frames, TDMA slots, multi-frames, EC-PCHs, control portions, EC-PCH portions, fields and other elements as shown in FIGs. 8-12. Although some of the elements shown in the examples of FIGs. 8-12 may be included in a 3GPP GPRS standard, 3GPP GSM standard, 3GPP LTE standard and/or other standard, embodiments are not limited to usage of such elements that are included in standards.

[0076] Referring to FIG. 8, EC-PCHs for different CCs may be overlapped physically in time resources. Accordingly, it may be possible that collisions between some EC-PCHs may occur in some cases. It should be noted that descriptions herein may refer to embodiments in which 4 CCs are used, but embodiments are not limited as such. In some embodiments, any suitable number of CCs may be used, and it is understood that techniques and/or operations described herein may be extended to such embodiments, in some cases.

[0077] As a non-limiting example, the CCs 820, 830, 840, and 850 correspond to CC1, CC2, CC3, and CC4. As described herein, different levels of diversity gain, coverage enhancement, additional margin and/or other benefits may be provided to UEs 102 operating in the different CCs. UEs 102 operating in CC1 may be provided the least gain of the group CC1-CC4 while UEs 102 operating in CC4 may be provided the most gain of the group CC1-CC4.

[0078] Four multi-frames 805, 814, 816, 818 of 51 TDMA frames are shown. Additional detail is shown for the multi-frame 805, which may be divided into a control portion 807 of 19 TDMA frames and an EC-PCH portion 809 of 32 TDMA frames. The other multi-frames 814, 816, 818 may be divided in a similar manner. EC-PCHs of CC1 820 may span 2 TDMA frames of the multi-frame 805, EC-PCHs of CC2 830 may span 8 TDMA frames of the multi-frame 805, and EC-PCHs of CC3 840 may span

16 TDMA frames of the multi-frame 805. One of each type of EC-PCH is demarcated in FIG. 8, but the EC-PCHs of those types may be extended throughout the 32 TDMA frames of the EC-PCH portion 809 of the multi-frame 805. The other multi-frames 814, 816, 818 may also utilize the EC-PCH allocation for CC1 820, CC2 830, and CC3 840 as described for the multi-frame 805. Accordingly, the 32 TDMA frames of the multi-frame 805 may include 16 EC-PCHs of CC1, 4 EC-PCHs of CC2, and 2 EC-PCHs of CC3. In addition, EC-PCHs of a fourth CC (CC4) may span 64 TDMA frames comprising 16 TDMA frames in each of 4 multi-frames (805, 814, 816, and 818). For instance, 852, 854, 856, and 858 of multi-frames 805, 814, 816, and 818 may be allocated as an EC-PCH of CC4 850.

[0079] In some embodiments, when the EC-PCHs span overlapping time resources (such as TDMA frames) and UEs 102 of different CCs are paged, the EC-PCHs may block each other. For instance, one EC-PCH of CC4 850 may span 64 TDMA frames, which may overlap with TDMA frames of 32 EC-PCHs of CC1 820. Accordingly, a blocking probability may be high when an EC-PCH of CC4 850 is used. As another example of blocking, in FIG. 9, the CC1 EC-PCH channels 941, 942 may be blocked when the CC3 (or CC4) EC-PCH 943 is allocated. However, the CC1 EC-PCH 951 and the CC2 EC-PCH 952 as shown are not blocked and do not block each other. It may be beneficial for the eNB 104 to restrict allocations of EC-PCHs to combinations in which the TDMA frames spanned by the EC-PCHs are non-overlapping.

[0080] Referring to the example 1000 shown in FIG. 10, the control portion 1040 of the multi-frame 1000 may include 19 TDMA frames, in which 5 TDMA frames 1030 may be allocated for enhanced coverage synchronization channel (EC-SCH) messages and 2 TDMA frames 1031 may be allocated for EC-PICH. In some embodiments, the EC-PICH may be transmitted in accordance with a diversity repetition in multiple TDMA frames of the control portion, such as the 2 TDMA frames (as shown by 1031) or any suitable number of TDMA frames.

[0081] Continuing the example 1000 shown in FIG. 10, the EC-PCH portion 1045 may include 32 TDMA frames. In some embodiments, different divisions, partitions and/or allocations of the TDMA frames of the EC-PCH portion 1045 may include EC-PCHs of different sizes that may span different numbers of TDMA frames. In some embodiments, different divisions, partitions and/or allocations of the TDMA frames of the multi-frame 1000 may include EC-PCHs of different sizes that may span different numbers of TDMA frames.

[0082] In some embodiments, at least a portion of the EC-PCHs may span multiple TDMA frames to enable diversity repetition of paging messages within the EC-PCHs. In addition, the EC-PCHs of different CCs may span different numbers of TDMA frames to enable different diversity gains for the different CCs, in some embodiments. For instance, a paging message may be repeated in each TDMA frame of an EC-PCH. Accordingly, a paging message for a CC3 EC-PCH may be repeated more times than a paging message for a CC1 EC-PCH, and therefore more diversity may be provided to the CC3 EC-PCH in comparison to the CC1 EC-PCH. Similar differences in performance gains between CCs may also be realized using other techniques, in some embodiments, such as usage of stronger error correction coding (lower coding rate) for CC3 than for CC1.

[0083] As a non-limiting example of EC-PCHs, a first division of the TDMA frames of the EC-PCH portion 1045 may include a first group of 16 CC1 EC-PCHs that span 2 TDMA frames each, as indicated by 1041. A second division of the TDMA frames of the EC-PCH portion 1045 may include a second group of 4 CC2 EC-PCHs that span 8 TDMA frames each, as indicated by 1042. A third division of the TDMA frames of the EC-PCH portion 1045 may include a third group of 2 CC3 EC-PCHs (and/or CC4 EC-PCHs) that span 16 TDMA frames each, as indicated by 1043.

[0084] In some embodiments, the TDMA frames spanned by the EC-PCHs of different groups may substantially overlap. As illustrated in the example of FIG. 10, the TDMA frames of the first four CC1 EC-PCHs (indexed by 19-20, 21-22, 23-24, and 25-26) are the same, in this case, as the TDMA frames of the first CC2 EC-PCH (indexed by 19-26). In addition, the time resources of the first CC3 EC-PCH (TDMA frames indexed by 19-34) substantially overlap the time resources of 8 CC1 EC-PCHs in those TDMA frames and 2 CC2 EC-PCHs in those TDMA frames.

[0085] In some embodiments, EC-PCHs of different sizes (number of TDMA frames spanned) may be allocated, although the scope of embodiments is not limited in this respect. In some embodiments, allocations of the EC-PCHs of the first, second, and third groups may be restricted to allocations in which the EC-PCHs are not overlapping in terms of time resources (such as TDMA frames spanned). Referring to FIG. 11, in the scenario on the left side of FIG. 11, the CC1 EC-PCHs indicated by 1120 and 1125 may be blocked by the CC3 EC-PCH indicated by 1130. However, in the scenario on the right side of FIG. 11, the EC-PCHs indicated by 1170, 1175, 1180, and 1190 are in TDMA frames that do not overlap. Accordingly, paging messages in those EC-PCHs would not block each other, in some cases.

[0086] Referring to FIG. 10, the EC-PICH 1050 may indicate which EC-PCH(s) are scheduled and their positions. In some cases, as only two EC-PICH bursts 1031 are included in the multi-frame 1000, the decoding probability of the EC-PICH message may be low for extended coverage users in CC2, CC3 and/or CC4, although CC1 users may be able to decode the EC-PICH message. In some embodiments, the CC1 EC-PCHs (indicated by 1041) may be dynamically allocated while the CC2 EC-PCHs (indicated by 1042) and the CC3/CC4 EC-PCHs (indicated by 1043) may be allocated according to a nominal paging group determination.

[0087] Referring to FIG. 11, in the scenario on the left side of FIG. 11, a CC3/CC4 EC-PCH (labeled #20, and indicated by 1130) may be allocated. In addition, a CC2 EC-PCH (labeled #18, and indicated by 1135) may be allocated. In order to page two CC1 users, the EC-PCHs labeled #1 and #6 (indicated by 1120 and 1125) may be allocated, but those EC-PCHs may be blocked by the EC-PCH #20 of CC3/CC4 (indicated by 1130).

[0088] In the scenario on the right side of FIG. 11, the EC-PICH 1165 may indicate which EC-PCH(s) are scheduled and their positions. The CC3/CC4 channel #20 (indicated by 1170) and the CC2 channel #18 (indicated by 1175) may be allocated in accordance with a nominal paging group determination. The CC1 channels #1 and #6 (indicated by 1180) may be dynamically allocated to residual EC-PCH blocks. In addition, as an overload of EC-PCH #1 and EC-PCH #2 may occur, two extended EC-

PCHs (#1E and #6E, indicated by 1190) may be scheduled in the residual EC-PCH blocks. In addition, the field "C" of the EC-PICH (which will be explained below regarding FIG. 12) may be set to a value of (0,1,0).

[0089] Referring to FIG. 12, an example EC-PICH 1200 includes a bitmap 1210 and a number of EC-PCHs 1220. As shown in 1250, the bitmap 1210 includes 22 bits in this example, of which 16 bits may be mapped to EC-PCHs of CC1 (spanning 2 TDMA frames each), 4 bits may be mapped to EC-PCHs of CC2 (spanning 8 TDMA frames each), and 2 bits may be mapped to EC-PCHs of CC3 or CC4 (spanning 16 TDMA frames each).

[0090] The number of EC-PCHs 1220 includes 3 bits in this example. Accordingly, the EC-PICH 1200 includes 25 bits in this example. Embodiments are not limited to these sizes for the EC-PICH 1200, bitmap 1210 or the number of EC-PCHs 1220, as any suitable sizes may be used. In some embodiments, other parameters or information may be included in the EC-PICH 1200. In addition, some embodiments may include the bitmap 1210 but may not necessarily include the number of EC-PCHs 1220.

[0091] A non-limiting example of the content of the EC-PICH is described below and shown in 1250 of FIG. 12. The 16 bits of the bitmap B0-B15 may indicate usage of the 16 CC1 EC-PCHs in the multi-frame. The CC1 EC-PCHs may be dynamically allocated in residual EC-PCH blocks after higher CC EC-PCHs are allocated. For instance, a bit value of 0 in B0-B15 may indicate that the EC-PCH channel is not scheduled, and a bit value of 1 may indicate that the EC-PCH is scheduled. This example assignment of bit values of 0 and 1 is not limiting, as any suitable assignment may be used. The 4 bits of the bitmap B16-B19 may indicate usage of the 4 CC2 EC-PCHs in the multi-frame. The CC2 EC-PCHs may be allocated in a fixed manner in accordance with a nominal paging group determination, in some embodiments. As previously described for the EC-PCHs of CC1, bit values of 0 and 1 may indicate whether the EC-PCHs of CC2 are scheduled in the multi-frame. The 2 bits of the bitmap B20 and B21 may indicate usage of the 2 CC3/4 EC-PCHs of CC3/CC4 in the multi-frame. The CC3/CC4 EC-PCHs may be allocated in a fixed manner in accordance with a nominal paging group determination, in some embodiments. As previously described for the EC-PCHs of CC1 and CC2, bit values of 0 and 1 may indicate whether the EC-PCHs of CC3/CC4 are scheduled in the multi-frame.

[0092] The number of EC-PCHs 1220 (labeled as "C" in 1250 of FIG. 12) may indicate a number of extended CC1 EC-PCHs. As an example, values of "C" in the range [0,6] may indicate a number of extended CC1 EC-PCHs in the multi-frame. A value of 7 for "C"" may indicate that the UE 102 is to check all residual CC1 EC-PCHs in the multi-frame. It should be noted that embodiments are not limited to these example values for "C" or for the bitmap B0-B20.

[0093] In one EC-PCH group, there may be several users that are scheduled simultaneously, in some cases, which may cause an overload for some EC-PCHs. In addition, it may also be possible that some other EC-PCHs are not scheduled at all. In accordance with a predetermined EC-PICH bit mapping, an EC-GSM-IoT device may know and/or determine which EC-PCHs are unused. This information may indicate how many EC-PCHs are to be checked in the multi-frame if extended mode is detected after EC-PCH decoding.

[0094] As a non-limiting example of scheduling, the eNB 104 may schedule EC-PCHs of a highest CC with a highest priority, as flexibility of allocation may be lower than allocation of EC-PCHs of lower CCs due to the larger number of TDMA frames spanned by EC-PCHs of higher CCs.

[0095] In some embodiments, EC-GSM-IoT devices of operating in CC1 may first decode the EC-PICH message to check whether any CC1 EC-PCHs are scheduled. If so, the CC1 device may decode one or more of the EC-PCHs indicated by the EC-PICH. As the CC1 EC-PCHs may be dynamically allocated, the EC-PCHs of CC1 of a first position (within the sequence of EC-PCHs for CC1) may be allocated to EC-PCHs of CC1 that span unused (i.e. not allocated) TDMA frames if the TDMA frames of the first position are blocked. In addition, when a particular EC-PCH is overloaded (such as a number of users to be paged), the network may offload one or more paging messages to EC-PCHs of unused TDMA frames and may indicate this in the EC-PICH. Such a dynamic allocation of EC-

PCHs of CC1 may increase an EC-PCH scheduling throughput, in some cases.

[0096] FIG. 13 illustrates the operation of another method of communication in accordance with some embodiments. In some embodiments, one or more of the operations shown in FIG. 13 may be used by CC1 users for decoding of EC-PICH and EC-PCH. In some embodiments, CC2, CC3 and/or CC4 users may use one or more operations of legacy method for decoding of EC-PICH and EC-PCH. However, it may also be possible, in some cases, that the CC2, CC3 and/or CC4 users to perform one or more operations shown in FIG. 13 for decoding of EC-PICH and EC-PCH.

[0097] FIG. 14 illustrates the operation of another method of communication in accordance with some embodiments. As mentioned previously regarding the method 700, embodiments of the method 1400 may include additional or even fewer operations or processes in comparison to what is illustrated in FIG. 14 and embodiments of the method 1400 are not necessarily limited to the chronological order that is shown in FIG. 14. In describing the method 1400, reference may be made to FIGs. 1-13, although it is understood that the method 1400 may be practiced with any other suitable systems, interfaces and components. In addition, embodiments of the method 1400 may be applicable to UEs 102, eNBs 104, APs, STAs and/or other wireless or mobile devices. The method 1400 may also be applicable to an apparatus for a UE 102, eNB 104 and/or other device described above.

[0098] It should be noted that the method 1400 may be practiced by a UE 102 and may include exchanging of elements, such as frames, signals, messages and/or other elements, with an eNB 104. Similarly, the method 700 may be practiced at an eNB 104 and may include exchanging of such elements with a UE 102. In some cases, operations and techniques described as part of the method 700 may be relevant to the method 1400. In addition, embodiments of the method 700 may include operations performed at the UE 102 that are reciprocal to or similar to other operations described herein performed at the eNB 104. For instance, an operation of the method 1400 may include reception of a message from the eNB 104 by the UE 102 while an operation of the method

700 may include transmission of the same message or similar message by the eNB 104.

[0099] In addition, previous discussion of various techniques and concepts may be applicable to the method 700 in some cases, including paging, paging messages, IMSI, bitmap of paging indicators, paging groups, EC-PCH, EC-PICH, EC-SCH, diversity repetition, TDMA, TDMA frames, TDMA slots, multi-frames, EC-GSM-IoT, coverage enhancement, coverage classes (CCs) and/or others. In addition, the examples shown in FIGs. 5-6 and 8-12 may also be applicable, in some cases, although the scope of embodiments is not limited in this respect.

[00100] At operation 1405, a UE 102 may receive an EC-PICH message from an eNB 104 during a multi-frame. At operation 1410, the UE 102 may determine, based at least partly on the received EC-PICH message, an allocation of EC-PCHs in the multi-frame. At operation 1415, the UE 102 may decode one or more paging messages that are received from the eNB in accordance with the allocation of the EC-PCHs. At operation 1420, the UE 102 may determine, based at least partly on one or more decoded paging messages, whether the UE 102 is paged by the eNB 104 during the multi-frame. In some embodiments, the UE 102 may determine, based at least partly on the decoded paging messages, whether a paging group that includes the UE 102 is paged by the eNB 104 during the multi-frame. Accordingly, the UE 102 may also determine the paging group that includes the UE 102 in some cases. For instance, the UE 102 may be mapped to the paging group based on factors such as an IMSI of the UE 102, another identifier of the UEs 102 and/or other factors. It should be noted that some embodiments may include one or more operations from the method 1400 and one or more operations of the method 1300.

[00101] In Example 1, an apparatus for an Evolved Node-B (eNB) may comprise memory. The apparatus may further comprise processing circuitry. The processing circuitry may be configured to encode, for transmission, a bitmap of enhanced coverage paging channel (EC-PCH) indicators that indicate whether a group of EC-PCHs are allocated during a multi-frame for paging of one or more User Equipments (UEs). The multi-frame may comprise multiple time-division multiple-access (TDMA) frames. The TDMA frames may be divided in

accordance with a group of TDMA slots. The group of TDMA slots may include an EC-PCH time slot allocated for the EC-PCHs during the multi-frame. A first portion of the EC-PCH indicators may be mapped in accordance with a first division of the multi-frame that includes a first portion of the EC-PCHs that span a first predetermined number of the TDMA frames. A second portion of the EC-PCH indicators may be mapped in accordance with a second division of the multi-frame that includes a second portion of the EC-PCHs that span a second predetermined number of the TDMA frames.

[00102] In Example 2, the subject matter of Example 1, wherein the first portion of the EC-PCHs may be allocated for paging of UEs of a first coverage class (CC). The second portion of the EC-PCHs may be allocated for paging of UEs of a second CC. The EC-PCHs of the first and second portions may span different numbers of the TDMA frames to enable different diversity gains at the UEs in accordance with a predetermined mapping between the diversity gains and the CCs.

[00103] In Example 3, the subject matter of one or any combination of Examples 1-2, wherein the TDMA frames spanned by the EC-PCHs of the first portion may substantially overlap the TDMA frames spanned by the EC-PCHs of the second portion.

[00104] In Example 4, the subject matter of one or any combination of Examples 1-3, wherein at least a portion of the EC-PCHs may span multiple TDMA frames to enable diversity repetition of paging messages within the EC-PCHs.

[00105] In Example 5, the subject matter of one or any combination of Examples 1-4, wherein the group of EC-PCHs may further include a third portion of the EC-PCHs that span a third predetermined number of TDMA frames. The processing circuitry may be further configured to allocate one or more EC-PCHs for the multi-frame. At least some of the allocated EC-PCHs may span different numbers of TDMA frames. The allocation may be restricted to combinations of EC-PCHs for which TDMA frames spanned by the allocated EC-PCHs are non-overlapping.

[00106] In Example 6, the subject matter of one or any combination of Examples 1-5, wherein the EC-PCHs in the first portion may span 2 TDMA frames. The EC-PCHs in the second portion may span 8 TDMA frames. A third portion of the EC-PCH indicators may be mapped in accordance with a third division of the multi-frame that includes a third portion of the EC-PCHs that span 16 TDMA frames of the multi-frame.

[00107] In Example 7, the subject matter of one or any combination of Examples 1-6, wherein the first portion of the EC-PCHs may include 16 non-overlapping EC-PCHs in an EC-PCH portion of the multi-frame that spans 32 consecutive TDMA frames. The second portion of the EC-PCHs may include 4 non-overlapping EC-PCHs in the EC-PCH portion. The third portion of the EC-PCHs may include 2 non-overlapping EC-PCHs in the EC-PCH portion.

[00108] In Example 8, the subject matter of one or any combination of Examples 1-7, wherein the EC-PCHs of the first portion may be reserved for paging of UEs of a first coverage class (CC). The EC-PCHs of the second portion may be reserved for paging of UEs of a second CC. The EC-PCHs of the third portion may be reserved for paging of UEs of a third CC or a fourth CC. The paging of UEs of the third CC may include a transmission of a paging message in one of the EC-PCHs of the third portion during the multi-frame. The paging of UEs of the fourth CC may include transmissions of the paging message in one of the EC-PCHs of the third portion during the multi-frame and may further include transmissions of the paging message during of each of three adjacent multi-frames.

[00109] In Example 9, the subject matter of one or any combination of Examples 1-8, wherein the bitmap may include 22 bits and may be included in an enhanced coverage paging information channel (EC-PICH) message that includes 25 bits. Sixteen bits of the bitmap may be mapped to the EC-PCHs of the first portion, 4 bits of the bitmap may be mapped to the EC-PCHs of the second portion, and 2 bits of the bitmap may be mapped to the EC-PCHs of the third portion. Three bits of the EC-PICH may indicate a number of extended EC-PCHs that are allocated in the multi-frame. Values of the bits of the bitmap may indicate whether or not corresponding EC-PCHs are allocated during the multi-frame.

[00110] In Example 10, the subject matter of one or any combination of Examples 1-9, wherein the multi-frame may comprise 51 TDMA frames, 19 consecutive TDMA frames of the 51 TDMA frames may be part of a control portion, and 32 consecutive TDMA frames of the 51 TDMA frames may be part of an EC-PCH portion for allocation of the EC-PCHs. Two TDMA frames of the control portion may be allocated for repetition of an enhanced coverage paging information channel (EC-PICH) message that includes the bitmap. Five TDMA frames of the control portion may be allocated for transmission of one or more enhanced coverage synchronization channel (EC-SCH) messages.

[00111] In Example 11, the subject matter of one or any combination of Examples 1-10, wherein the processing circuitry may be further configured to, when one of the EC-PCHs of the first portion is allocated, encode a first paging message for repetition in the TDMA frames of one of the EC-PCHs of the first portion for transmission. The processing circuitry may be further configured to, when one of the EC-PCHs of the second portion is allocated, encode a second paging message for repetition in the TDMA frames of one of the EC-PCHs of the second portion for transmission. The paging messages may include an international mobile subscriber identity (IMSI) that identifies a UE that is to be paged.

[00112] In Example 12, the subject matter of one or any combination of Examples 1-11, wherein the eNB may be arranged to operate in accordance with a Third Generation Partnership Project (3GPP) global system for mobile (GSM) protocol. The eNB may be further arranged to operate in accordance with an enhanced coverage GSM internet-of-things (EC-GSM-IoT) protocol.

[00113] In Example 13, the subject matter of one or any combination of Examples 1-12, wherein the apparatus may further include a transceiver to transmit the bitmap of EC-PCH indicators.

[00114] In Example 14, the subject matter of one or any combination of Examples 1-13, wherein the processing circuitry may include a baseband processor to encode the bitmap of EC-PCH indicators.

[00115] In Example 15, a computer-readable storage medium may store instructions for execution by one or more processors to perform operations for communication by an Evolved Node-B (eNB). The operations may configure the one or more processors to determine an allocation of a group of enhanced coverage paging channels (EC-PCHs) for transmission of paging messages to one or more User Equipments (UEs) during a multi-frame. The operations may further configure the one or more processors to encode, for transmission during a control portion of the multi-frame, an enhanced coverage paging information channel (EC-PICH) message that includes a bitmap of EC-PCH paging indicators to indicate the allocation. An EC-PCH portion of the multi-frame may be reserved for the EC-PCH allocation. The EC-PCH portion may include multiple TDMA frames. The EC-PCHs of the group may span variable numbers of the TDMA frames. At least some of the EC-PCHs may be allocated in overlapping TDMA frames.

[00116] In Example 16, the subject matter of Example 15, wherein the group of EC-PCHs may include multiple portions of EC-PCHs. The EC-PCHs in different portions may span different numbers of the TDMA frames. The EC-PCHs in different portions may be allocated for paging of UEs of different coverage classes (CCs). The EC-PCHs in different portions may span the different numbers of the TDMA frames to enable different diversity gains at the UEs in accordance with a predetermined mapping between different diversity gains and the CCs.

[00117] In Example 17, the subject matter of one or any combination of Examples 15-16, wherein the control portion may include multiple TDMA frames. The EC-PICH may be encoded for diversity repetition in multiple TDMA frames of the control portion.

[00118] In Example 18, an apparatus for a User Equipment (UE) may comprise memory. The apparatus may further comprise processing circuitry. The processing circuitry may be configured to decode an enhanced coverage paging information channel (EC-PICH) message from an Evolved Node-B (eNB) in a control portion of a multi-frame. The processing circuitry may be further configured to determine, based on the EC-PICH message, an allocation of enhanced coverage paging channels (EC-PCHs) during an EC-PCH portion of the multi-frame. The EC-PICH message may include a bitmap of EC-PCH indicators mapped to a group of candidate EC-PCHs. The EC-PCH portion may include multiple TDMA frames. The EC-PCHs of the group may span variable numbers of the TDMA frames. At least some of the EC-PCHs may be allocated in overlapping TDMA frames.

[00119] In Example 19, the subject matter of Example 18, wherein the EC-PCH portion may include 32 TDMA frames. A first portion of the EC-PCHs may include 16 non-overlapping EC-PCHs that each span 2 TDMA frames. A second portion of the EC-PCHs may include 4 non-overlapping EC-PCHs that each span 8 TDMA frames. A third portion of the EC-PCHs may include 2 non-overlapping EC-PCHs that each span 16 TDMA frames.

[00120] In Example 20, the subject matter of one or any combination of Examples 18-19, wherein the EC-PICH message may include 25 bits, 3 bits of the EC-PICH may indicate a number of EC-PCHs allocated in the multi-frame, the bitmap may include 22 bits, 16 bits of the bitmap may be mapped to the EC-PCHs of the first portion, 4 bits of the bitmap may be mapped to the EC-PCHs of the second portion, and 2 bits of the bitmap may be mapped to the EC-PCHs of the third portion. Values of the bits of the bitmap may indicate whether or not corresponding EC-PCHs are allocated during the multi-frame.

[00121] In Example 21, the subject matter of one or any combination of Examples 18-20, wherein the TDMA frames of the EC-PCH portion of the multi-frame may be divided in accordance with a group of TDMA slots. The group of TDMA slots may include an EC-PCH time slot allocated for the EC-PCHs during the multi-frame.

[00122] In Example 22, the subject matter of one or any combination of Examples 18-21, wherein the group of EC-PCHs may include multiple portions of EC-PCHs. The EC-PCHs in different portions may span different numbers of the TDMA frames. The EC-PCHs in different portions may be allocated for paging of UEs of different coverage classes (CCs). The processing circuitry may be further configured to determine, based on one or more decoded EC-PCH messages received in EC-PCHs allocated to a CC in which the UE operates, whether the UE is paged by the eNB.

[00123] In Example 23, the subject matter of one or any combination of Examples 18-22, wherein the UE may be arranged to operate in accordance with a Third Generation Partnership Project (3GPP) global system for mobile (GSM) protocol. The UE may be further arranged to operate in accordance with an enhanced coverage GSM internet-of-things (EC-GSM-IoT) protocol.

[00124] In Example 24, the subject matter of one or any combination of Examples 18-23, wherein the apparatus may further include a transceiver to receive the EC-PICH message.

[00125] In Example 25, the subject matter of one or any combination of Examples 18-24, wherein the processing circuitry may include a baseband processor to decode the EC-PICH message and to determine the allocation of EC-PCHs.

[00126] In Example 26, an apparatus for an Evolved Node-B (eNB) may comprise means for determining an allocation of a group of enhanced coverage paging channels (EC-PCHs) for transmission of paging messages to one or more User Equipments (UEs) during a multi-frame. The apparatus may further comprise means for encoding, for transmission during a control portion of the multi-frame, an enhanced coverage paging information channel (EC-PICH) message that includes a bitmap of EC-PCH paging indicators to indicate the allocation. An EC-PCH portion of the multi-frame may be reserved for the EC-PCH allocation. The EC-PCH portion may include multiple TDMA frames. The EC-PCHs of the group may span variable numbers of the TDMA frames. At least some of the EC-PCHs may be allocated in overlapping TDMA frames.

[00127] In Example 27, the subject matter of Example 26, wherein the group of EC-PCHs may include multiple portions of EC-PCHs. The EC-PCHs in different portions may span different numbers of the TDMA frames. The EC-PCHs in different portions may be allocated for paging of UEs of different coverage classes (CCs). The EC-PCHs in different portions may span the different numbers of the TDMA frames to enable different diversity gains at the UEs in accordance with a predetermined mapping between different diversity gains and the CCs.

[00128] In Example 28, the subject matter of one or any combination of Examples 26-27, wherein the control portion may include multiple TDMA frames. The EC-PICH may be encoded for diversity repetition in multiple TDMA frames of the control portion.

[00129] The Abstract is provided to comply with 37 C.F.R. Section 1.72(b) requiring an abstract that will allow the reader to ascertain the nature and gist of the technical disclosure. It is submitted with the understanding that it will

not be used to limit or interpret the scope or meaning of the claims. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate embodiment.

CLAIMS

What is claimed is:

1. An apparatus for an Evolved Node-B (eNB), the apparatus comprising: memory; and processing circuitry, configured to:

encode, for transmission, a bitmap of enhanced coverage paging channel (EC-PCH) indicators that indicate whether a group of EC-PCHs are allocated during a multi-frame for paging of one or more User Equipments (UEs),

wherein the multi-frame comprises multiple time-division multiple-access (TDMA) frames, the TDMA frames are divided in accordance with a group of TDMA slots, and the group of TDMA slots includes an EC-PCH time slot allocated for the EC-PCHs during the multi-frame,

wherein a first portion of the EC-PCH indicators are mapped in accordance with a first division of the multi-frame that includes a first portion of the EC-PCHs that span a first predetermined number of the TDMA frames, and

wherein a second portion of the EC-PCH indicators are mapped in accordance with a second division of the multi-frame that includes a second portion of the EC-PCHs that span a second predetermined number of the TDMA frames.

2. The apparatus according to claim 1, wherein:

the first portion of the EC-PCHs are allocated for paging of UEs of a first coverage class (CC),

the second portion of the EC-PCHs are allocated for paging of UEs of a second CC, and

the EC-PCHs of the first and second portions span different numbers of the TDMA frames to enable different diversity gains at the UEs in accordance with a predetermined mapping between the diversity gains and the CCs.

3. The apparatus according to claims 1 or 2, wherein the TDMA frames spanned by the EC-PCHs of the first portion substantially overlap the TDMA frames spanned by the EC-PCHs of the second portion.

4. The apparatus according to claim 1, wherein at least a portion of the EC-PCHs span multiple TDMA frames to enable diversity repetition of paging messages within the EC-PCHs.

5. The apparatus according to claim 1, wherein:

the group of EC-PCHs further includes a third portion of the EC-PCHs that span a third predetermined number of TDMA frames,

the processing circuitry is further configured to allocate one or more EC-PCHs for the multi-frame,

at least some of the allocated EC-PCHs span different numbers of TDMA frames, and

the allocation is restricted to combinations of EC-PCHs for which TDMA frames spanned by the allocated EC-PCHs are non-overlapping.

6. The apparatus according to claim 1, wherein:

the EC-PCHs in the first portion span 2 TDMA frames,

the EC-PCHs in the second portion span 8 TDMA frames, and

a third portion of the EC-PCH indicators are mapped in accordance with a third division of the multi-frame that includes a third portion of the EC-PCHs that span 16 TDMA frames of the multi-frame.

7. The apparatus according to claim 6, wherein:

the first portion of the EC-PCHs includes 16 non-overlapping EC-PCHs in an EC-PCH portion of the multi-frame that spans 32 consecutive TDMA frames,

the second portion of the EC-PCHs includes 4 non-overlapping EC-PCHs in the EC-PCH portion, and

the third portion of the EC-PCHs includes 2 non-overlapping EC-PCHs in the EC-PCH portion.

8. The apparatus according to claim 7, wherein:

the EC-PCHs of the first portion are reserved for paging of UEs of a first coverage class (CC),

the EC-PCHs of the second portion are reserved for paging of UEs of a second CC,

the EC-PCHs of the third portion are reserved for paging of UEs of a third CC or a fourth CC,

the paging of UEs of the third CC includes a transmission of a paging message in one of the EC-PCHs of the third portion during the multi-frame, and

the paging of UEs of the fourth CC includes transmissions of the paging message in one of the EC-PCHs of the third portion during the multi-frame and further includes transmissions of the paging message during of each of three adjacent multi-frames.

9. The apparatus according to any of claims 4-8, wherein:

the bitmap includes 22 bits and is included in an enhanced coverage paging information channel (EC-PICH) message that includes 25 bits,

16 bits of the bitmap are mapped to the EC-PCHs of the first portion, 4 bits of the bitmap are mapped to the EC-PCHs of the second portion, and 2 bits of the bitmap are mapped to the EC-PCHs of the third portion,

3 bits of the EC-PICH indicate a number of extended EC-PCHs that are allocated in the multi-frame, and

values of the bits of the bitmap indicate whether or not corresponding EC-PCHs are allocated during the multi-frame.

10. The apparatus according to claim 1, wherein:

the multi-frame comprises 51 TDMA frames,

19 consecutive TDMA frames of the 51 TDMA frames are part of a control portion,

32 consecutive TDMA frames of the 51 TDMA frames are part of an EC-PCH portion for allocation of the EC-PCHs,

two TDMA frames of the control portion are allocated for repetition of an enhanced coverage paging information channel (EC-PICH) message that includes the bitmap, and

five TDMA frames of the control portion are allocated for transmission of one or more enhanced coverage synchronization channel (EC-SCH) messages.

11. The apparatus according to claim 1, the processing circuitry further configured to:

when one of the EC-PCHs of the first portion is allocated, encode a first paging message for repetition in the TDMA frames of one of the EC-PCHs of the first portion for transmission; and

when one of the EC-PCHs of the second portion is allocated, encode a second paging message for repetition in the TDMA frames of one of the EC-PCHs of the second portion for transmission,

wherein the paging messages include an international mobile subscriber identity (IMSI) that identifies a UE that is to be paged.

12. The apparatus according to claim 1, wherein:

the eNB is arranged to operate in accordance with a Third Generation Partnership Project (3GPP) global system for mobile (GSM) protocol, and

the eNB is further arranged to operate in accordance with an enhanced coverage GSM internet-of-things (EC-GSM-IoT) protocol.

13. The apparatus according to claim 1, wherein the apparatus further includes a transceiver to transmit the bitmap of EC-PCH indicators.

14. The apparatus according to any of claims 10-13, wherein the processing circuitry includes a baseband processor to encode the bitmap of EC-PCH indicators.

15. A computer-readable storage medium that stores instructions for execution by one or more processors to perform operations for communication

by an Evolved Node-B (eNB), the operations to configure the one or more processors to:

determine an allocation of a group of enhanced coverage paging channels (EC-PCHs) for transmission of paging messages to one or more User Equipments (UEs) during a multi-frame; and

encode, for transmission during a control portion of the multi-frame, an enhanced coverage paging information channel (EC-PICH) message that includes a bitmap of EC-PCH paging indicators to indicate the allocation,

wherein an EC-PCH portion of the multi-frame is reserved for the EC-PCH allocation, the EC-PCH portion includes multiple TDMA frames, and the EC-PCHs of the group span variable numbers of the TDMA frames, and

wherein at least some of the EC-PCHs are allocated in overlapping TDMA frames.

16. The computer-readable storage medium according to claim 15, wherein:

the group of EC-PCHs includes multiple portions of EC-PCHs,

the EC-PCHs in different portions span different numbers of the TDMA frames,

the EC-PCHs in different portions are allocated for paging of UEs of different coverage classes (CCs), and

the EC-PCHs in different portions span the different numbers of the TDMA frames to enable different diversity gains at the UEs in accordance with a predetermined mapping between different diversity gains and the CCs.

17. The computer-readable storage medium according to claim 15, wherein:

the control portion includes multiple TDMA frames, and

the EC-PICH is encoded for diversity repetition in multiple TDMA frames of the control portion.

18. An apparatus for a User Equipment (UE), the apparatus comprising: memory; and processing circuitry, configured to:

decode an enhanced coverage paging information channel (EC-PICH) message from an Evolved Node-B (eNB) in a control portion of a multi-frame;

determine, based on the EC-PICH message, an allocation of enhanced coverage paging channels (EC-PCHs) during an EC-PCH portion of the multi-frame,

wherein the EC-PICH message includes a bitmap of EC-PCH indicators mapped to a group of candidate EC-PCHs, and

wherein the EC-PCH portion includes multiple TDMA frames, the EC-PCHs of the group span variable numbers of the TDMA frames, and at least some of the EC-PCHs are allocated in overlapping TDMA frames.

19. The apparatus according to claim 18, wherein:

the EC-PCH portion includes 32 TDMA frames,

a first portion of the EC-PCHs includes 16 non-overlapping EC-PCHs that each span 2 TDMA frames,

a second portion of the EC-PCHs includes 4 non-overlapping EC-PCHs that each span 8 TDMA frames, and

a third portion of the EC-PCHs includes 2 non-overlapping EC-PCHs that each span 16 TDMA frames.

20. The apparatus according to claim 19, wherein:

the EC-PICH message includes 25 bits,

3 bits of the EC-PICH indicate a number of EC-PCHs allocated in the multi-frame,

the bitmap includes 22 bits,

16 bits of the bitmap are mapped to the EC-PCHs of the first portion, 4 bits of the bitmap are mapped to the EC-PCHs of the second portion, and 2 bits of the bitmap are mapped to the EC-PCHs of the third portion, and

values of the bits of the bitmap indicate whether or not corresponding EC-PCHs are allocated during the multi-frame.

21. The apparatus according to claim 18, wherein:

the TDMA frames of the EC-PCH portion of the multi-frame are divided in accordance with a group of TDMA slots, and

the group of TDMA slots includes an EC-PCH time slot allocated for the EC-PCHs during the multi-frame.

22. The apparatus according to claim 18, wherein:

the group of EC-PCHs includes multiple portions of EC-PCHs,

the EC-PCHs in different portions span different numbers of the TDMA frames,

the EC-PCHs in different portions are allocated for paging of UEs of different coverage classes (CCs), and

the processing circuitry is further configured to determine, based on one or more decoded EC-PCH messages received in EC-PCHs allocated to a CC in which the UE operates, whether the UE is paged by the eNB.

23. The apparatus according to claim 18, wherein:

the UE is arranged to operate in accordance with a Third Generation Partnership Project (3GPP) global system for mobile (GSM) protocol, and

the UE is further arranged to operate in accordance with an enhanced coverage GSM internet-of-things (EC-GSM-IoT) protocol.

24. The apparatus according to claim 18, wherein the apparatus further includes a transceiver to receive the EC-PICH message.

25. The apparatus according to claim 18, wherein the processing circuitry includes a baseband processor to decode the EC-PICH message and to determine the allocation of EC-PCHs.

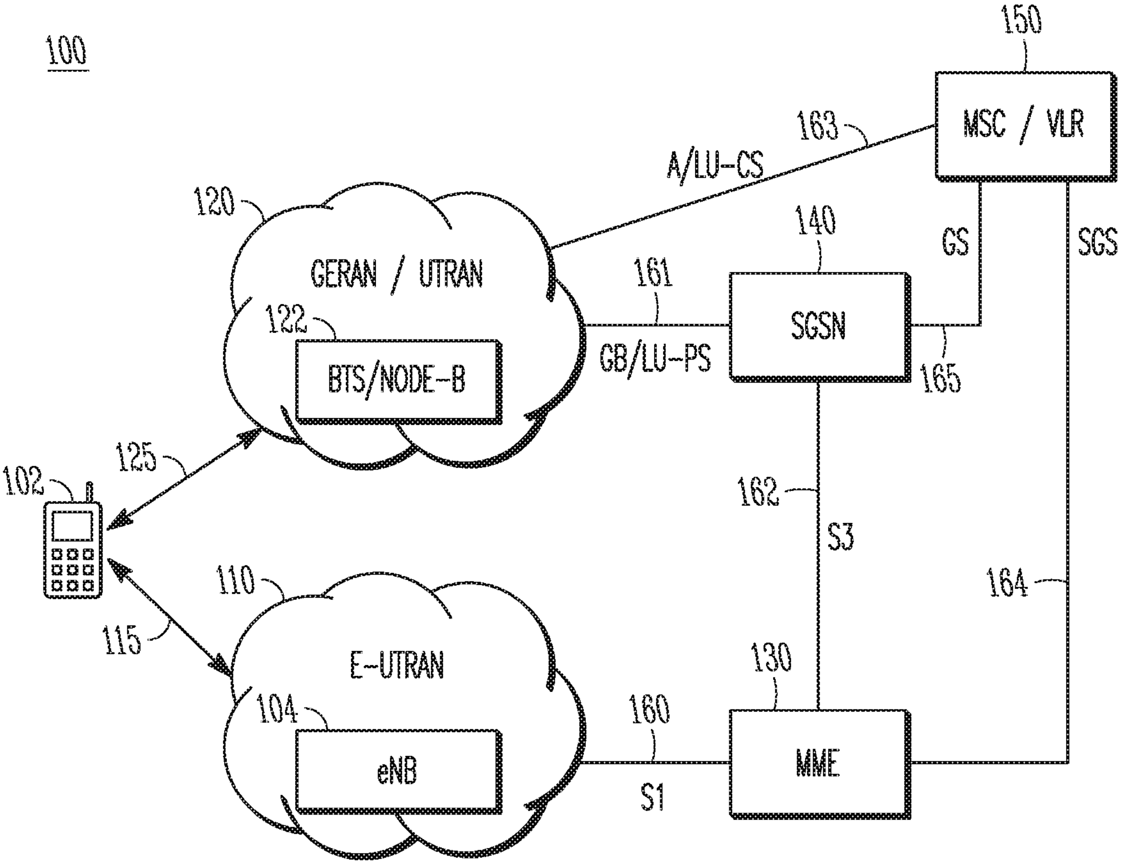

100
150
MSC / VLR
163
A/LU-CS
120
140
GS
SGS
GERAN / UTRAN
161
SGSN
122
BTS/NODE-B
GB/LU-PS
165
125
102
162
S3
110
164
115
E-UTRAN
130
104
160
eNB
MME
S1

FIG. 1

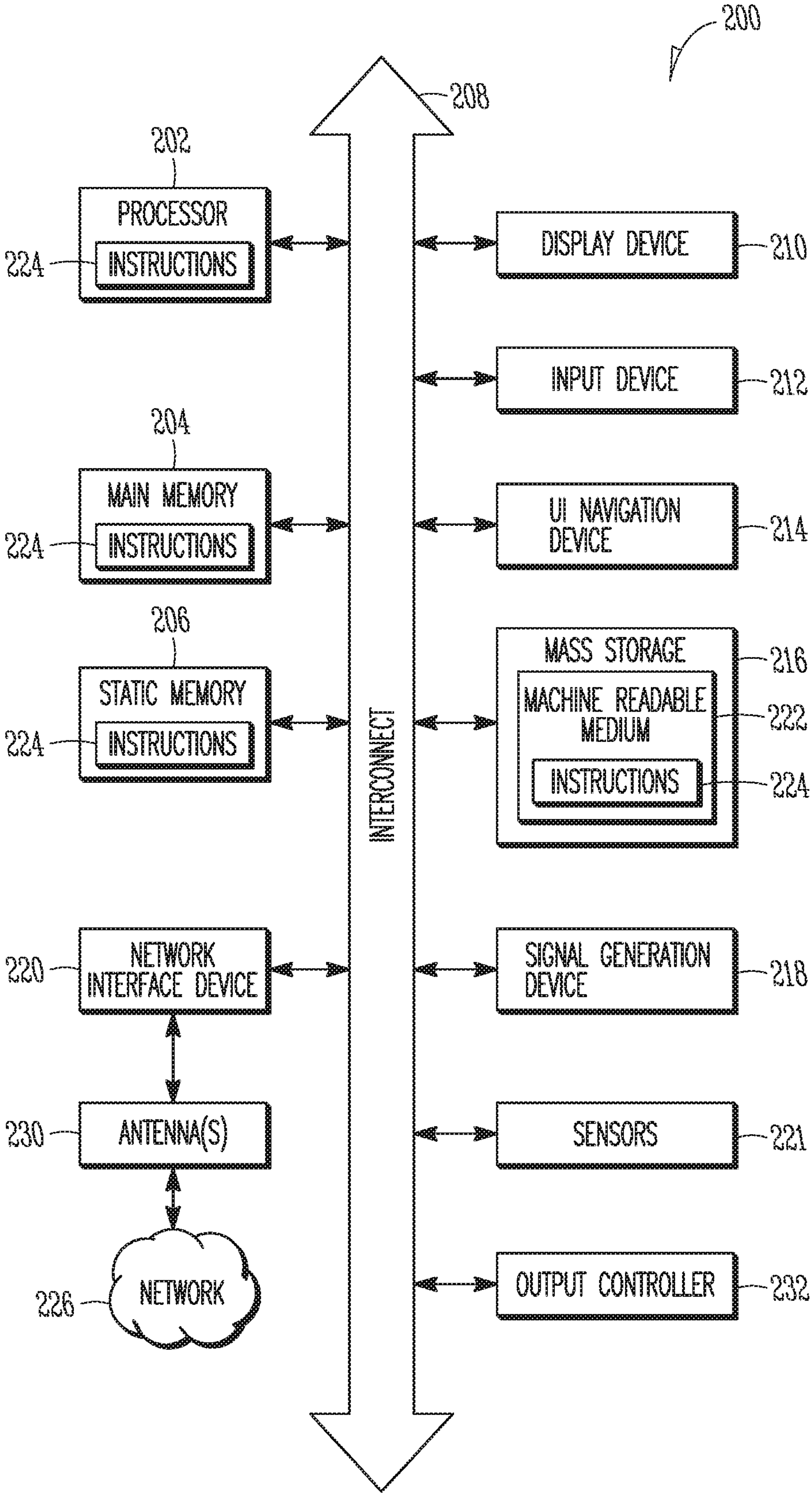

200
208
202
PROCESSOR
224
INSTRUCTIONS
DISPLAY DEVICE
210
INPUT DEVICE
212
204
MAIN MEMORY
224
INSTRUCTIONS
UI NAVIGATION DEVICE
214
206
STATIC MEMORY
224
INSTRUCTIONS
INTERCONNECT
MASS STORAGE
216
MACHINE READABLE MEDIUM
222
INSTRUCTIONS
224
220
NETWORK INTERFACE DEVICE
SIGNAL GENERATION DEVICE
218
230
ANTENNA(S)
SENSORS
221
226
NETWORK
OUTPUT CONTROLLER
232

FIG. 2

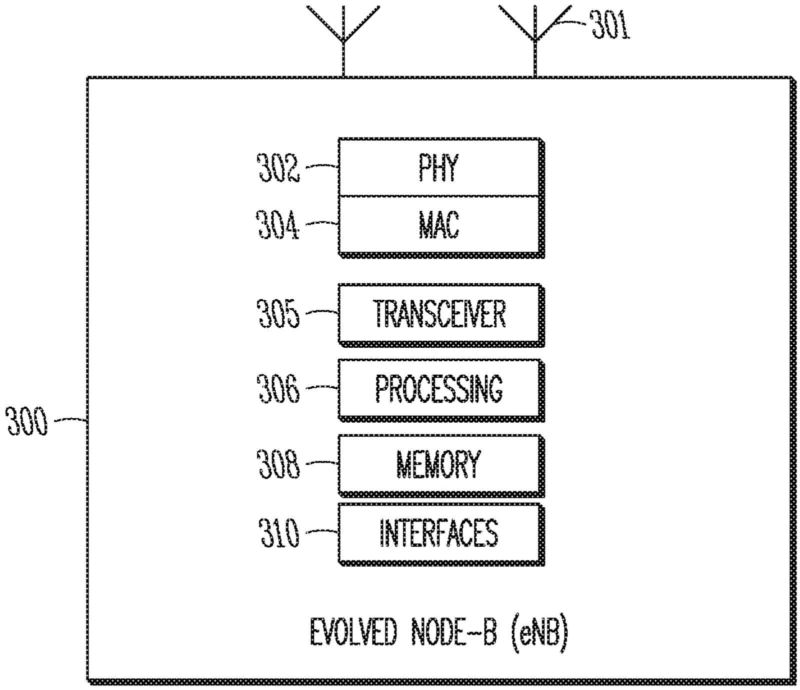
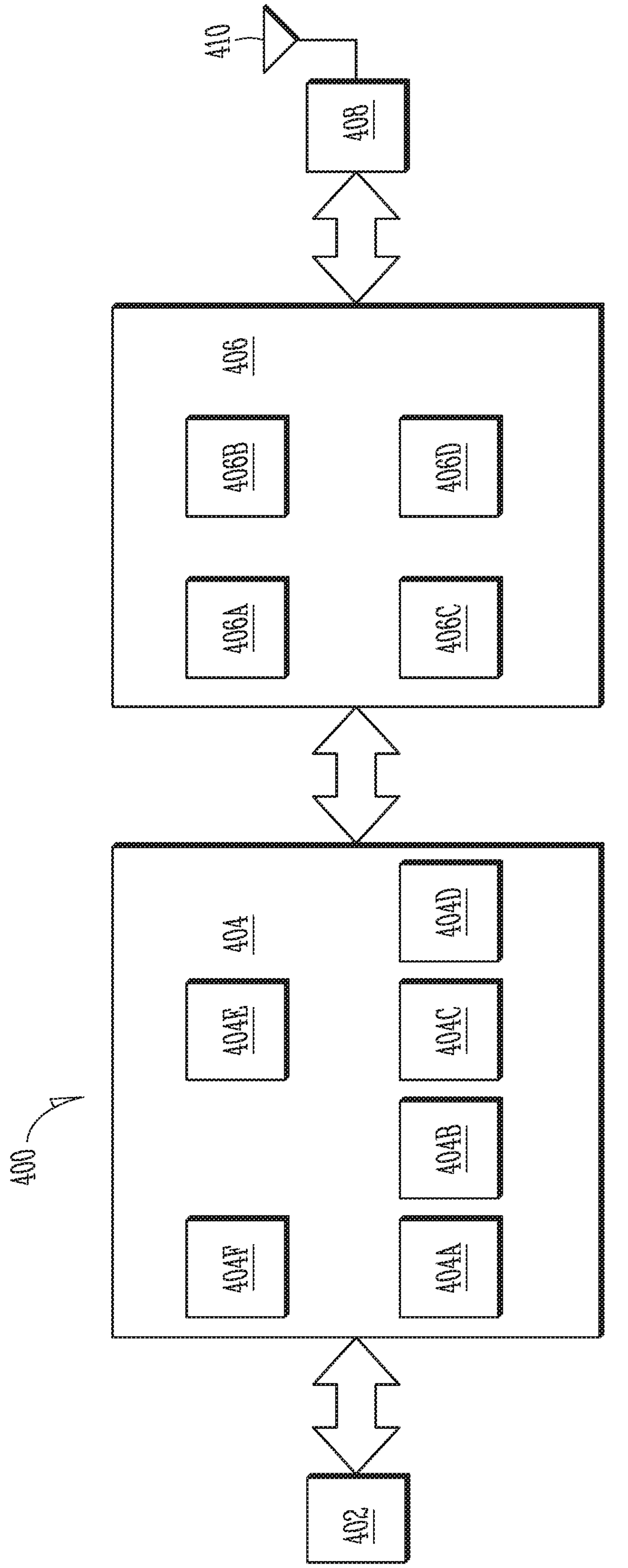

301
302
PHY
304
MAC
305
TRANSCEIVER
306
PROCESSING
300
308
MEMORY
310
INTERFACES
EVOLVED NODE-B (eNB)

FIG. 3



USER EQUIPMENT (UE)

FIG. 4

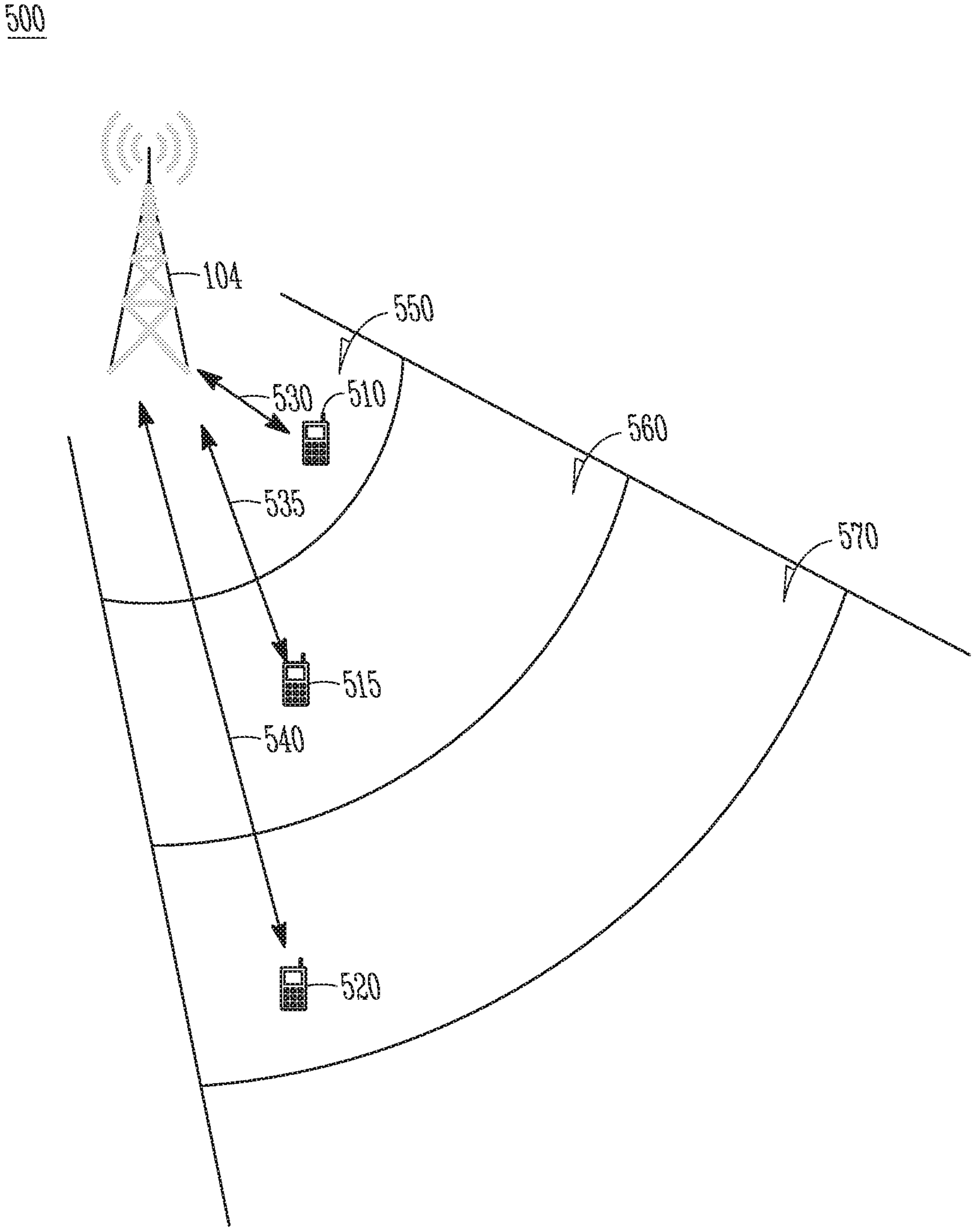


FIG. 5

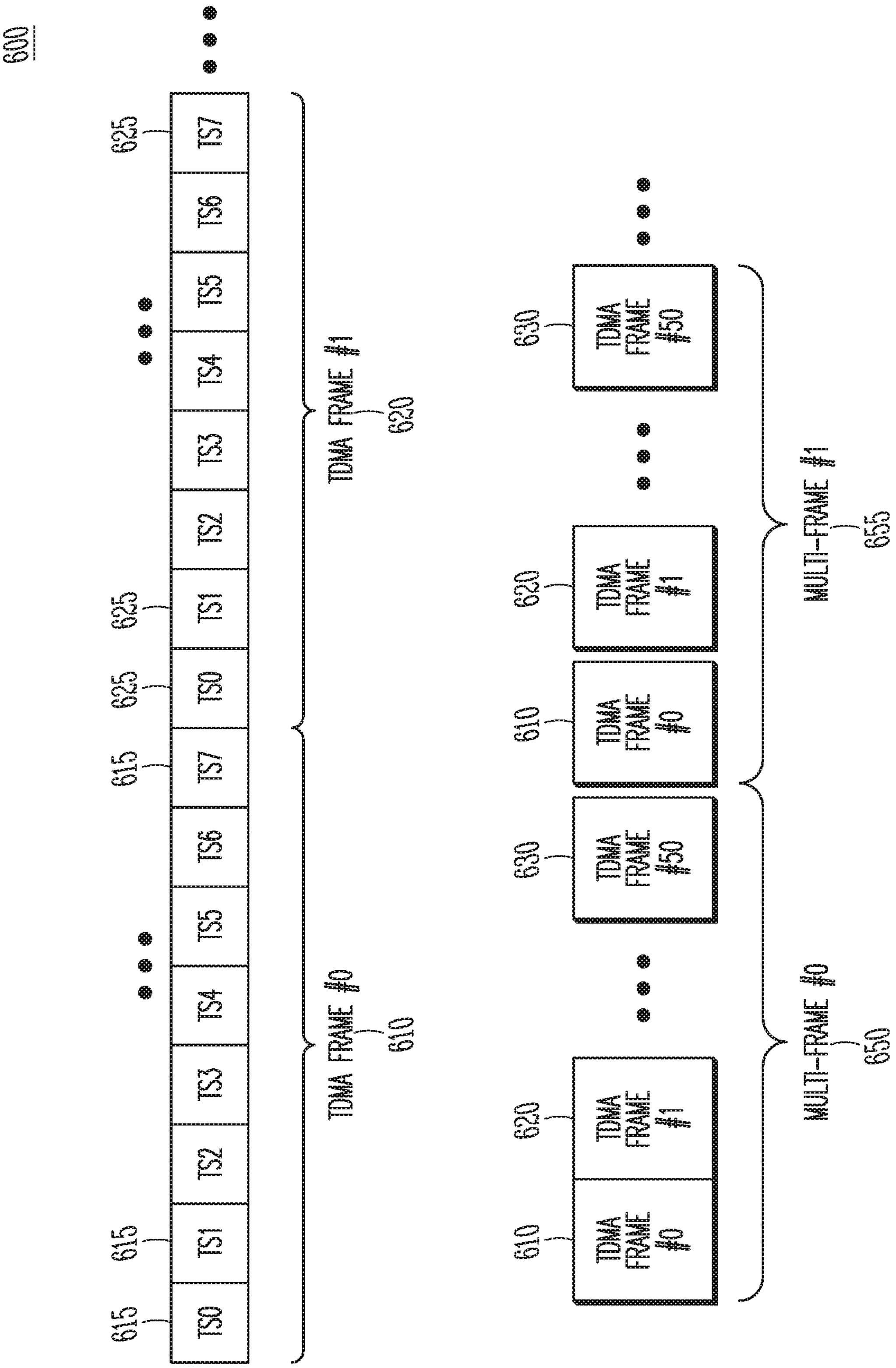

600
TS0
TS1
TS2
TS3
TS4
TS5
TS6
TS7
615
625
TDMA FRAME #0
610
TDMA FRAME #1
620
MULTI-FRAME #0
650
MULTI-FRAME #1
655
630
TDMA FRAME #0
TDMA FRAME #1
TDMA FRAME #50

FIG. 6

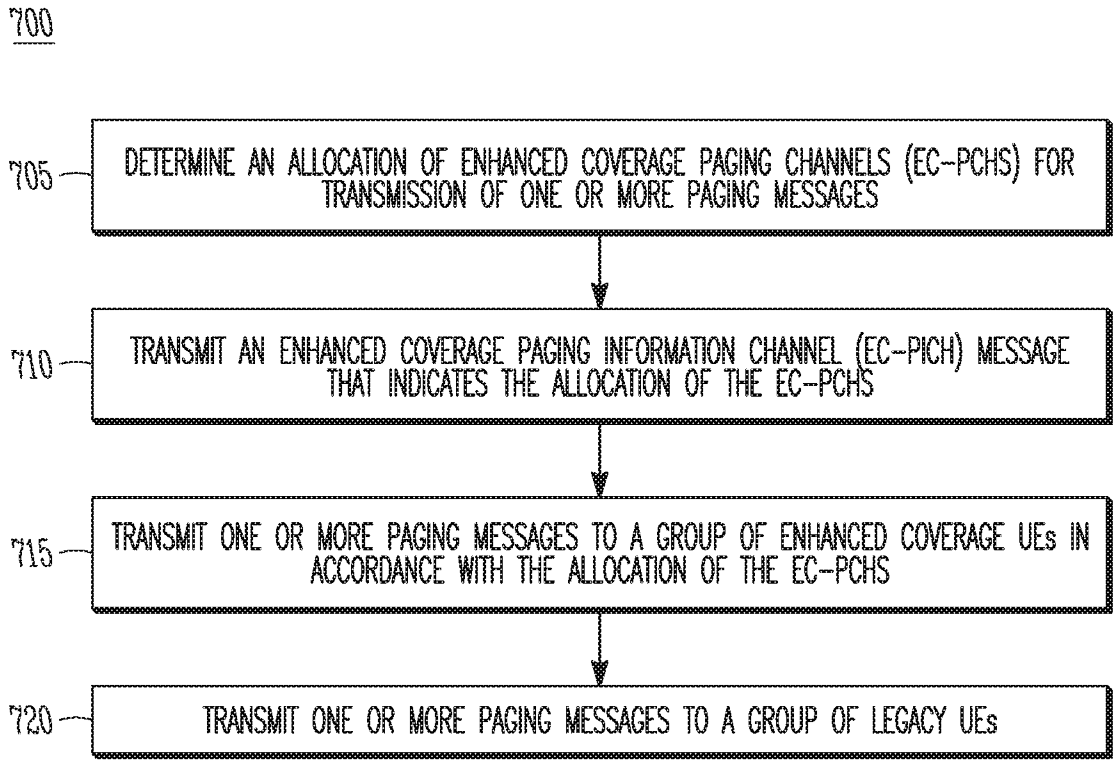

700
705
DETERMINE AN ALLOCATION OF ENHANCED COVERAGE PAGING CHANNELS (EC-PCHS) FOR TRANSMISSION OF ONE OR MORE PAGING MESSAGES
710
TRANSMIT AN ENHANCED COVERAGE PAGING INFORMATION CHANNEL (EC-PICH) MESSAGE THAT INDICATES THE ALLOCATION OF THE EC-PCHS
715
TRANSMIT ONE OR MORE PAGING MESSAGES TO A GROUP OF ENHANCED COVERAGE UEs IN ACCORDANCE WITH THE ALLOCATION OF THE EC-PCHS
720
TRANSMIT ONE OR MORE PAGING MESSAGES TO A GROUP OF LEGACY UEs

FIG. 7

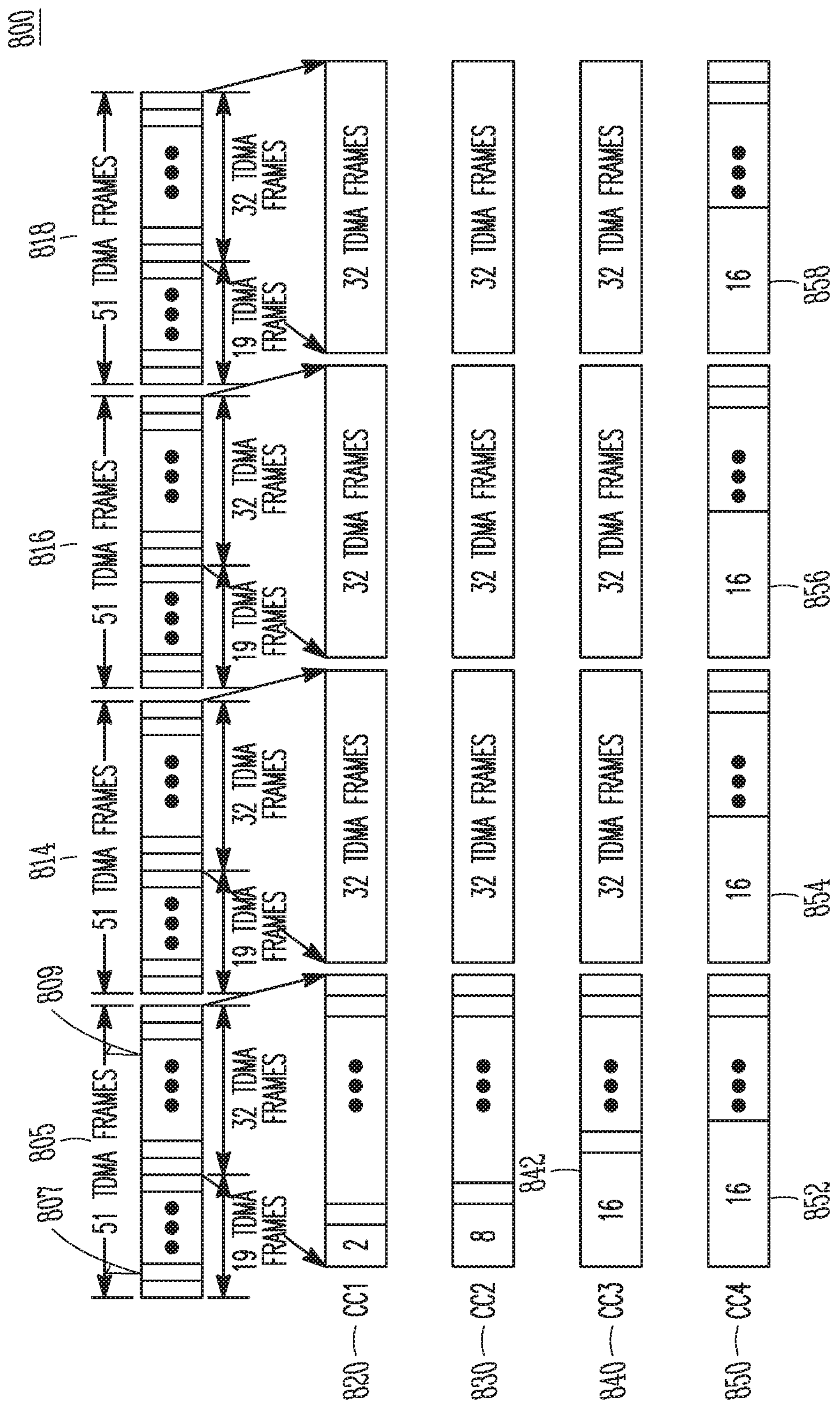

800
807
805
809
814
816
818
51 TDMA FRAMES
19 TDMA FRAMES
32 TDMA FRAMES
2
8
16
842
820 — CC1
830 — CC2
840 — CC3
850 — CC4
852
854
856
858

FIG. 8

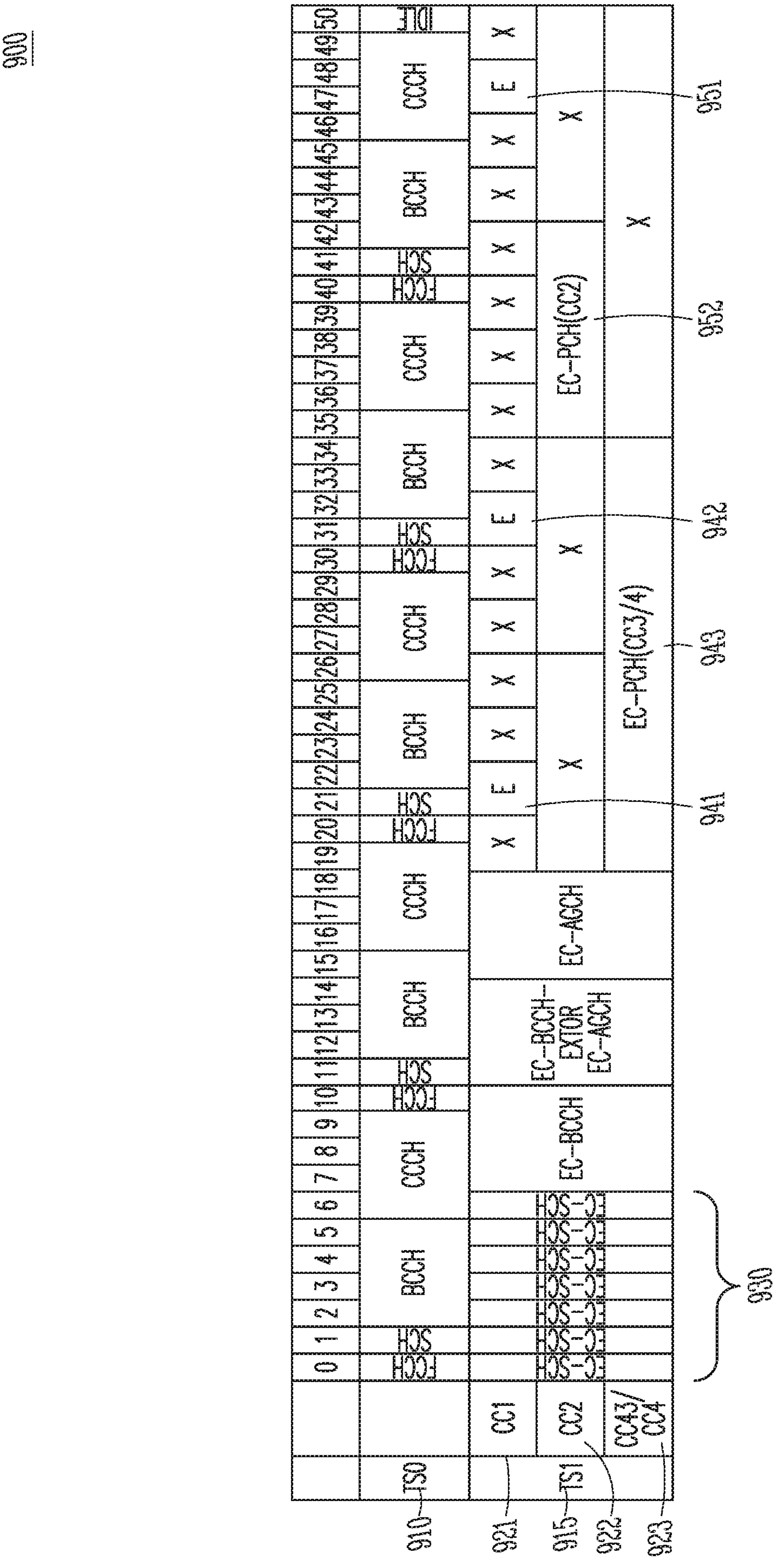

900
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50
FCCH
SCH
BCCH
CCCH
IDLE
CC1
CC2
CC43/CC4
EC-SCH
EC-BCCH
EC-BCCH-EXTOR EC-AGCH
EC-AGCH
X
E
EC-PCH(CC2)
EC-PCH(CC3/4)
910
TS0
921
915
TS1
922
923
930
941
942
943
951
952

FIG. 9

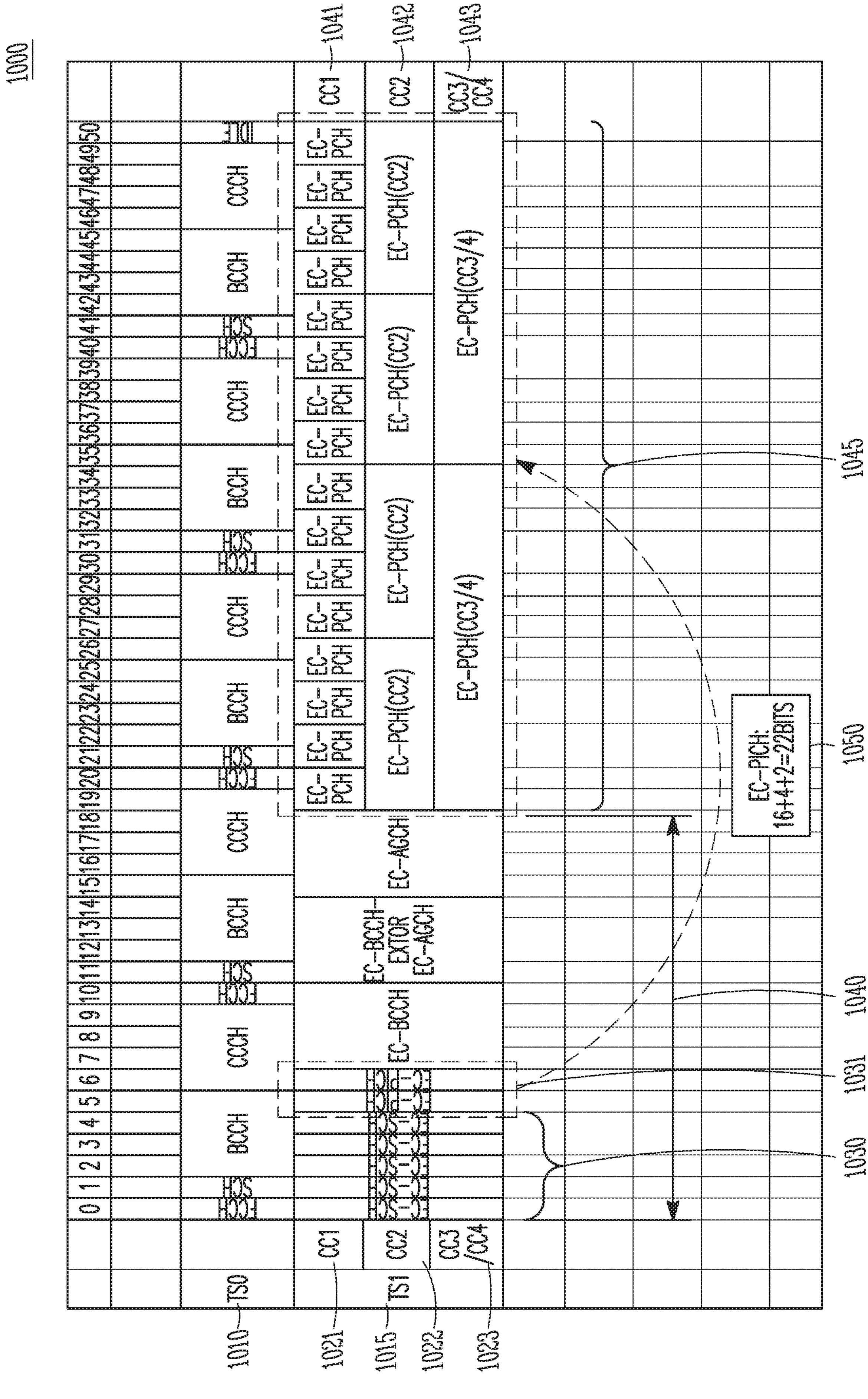

1000
TS0
TS1
CC1
CC2
CC3/CC4
BCCH
CCCH
FCCH
SCH
IDLE
EC-BCCH
EC-BCCH-EXT OR EC-AGCH
EC-AGCH
EC-PCH
EC-PCH(CC2)
EC-PCH(CC3/4)
EC-PICH: 16+4+2=22BITS
1010
1015
1021
1022
1023
1030
1031
1040
1041
1042
1043
1045
1050

FIG. 10

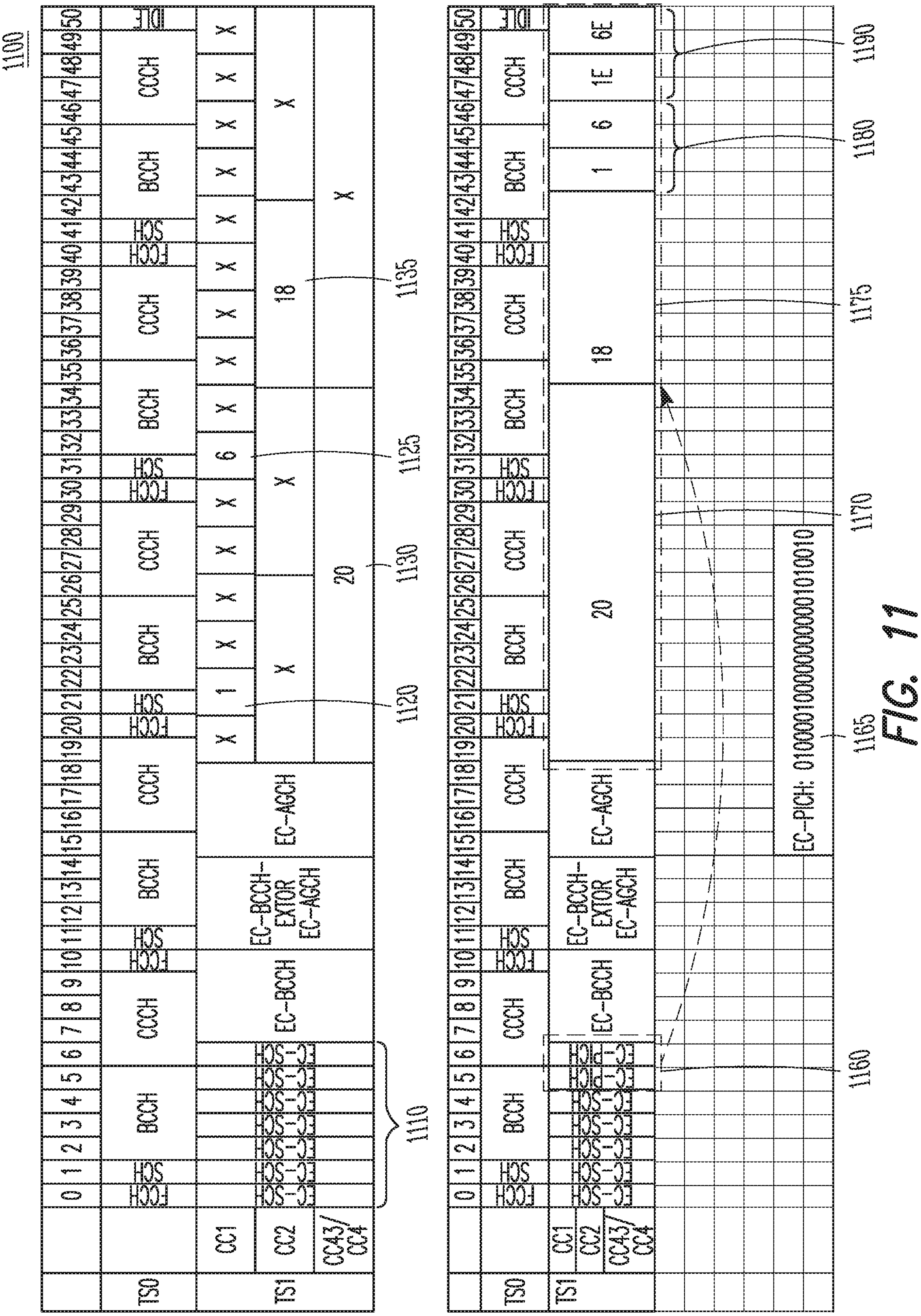
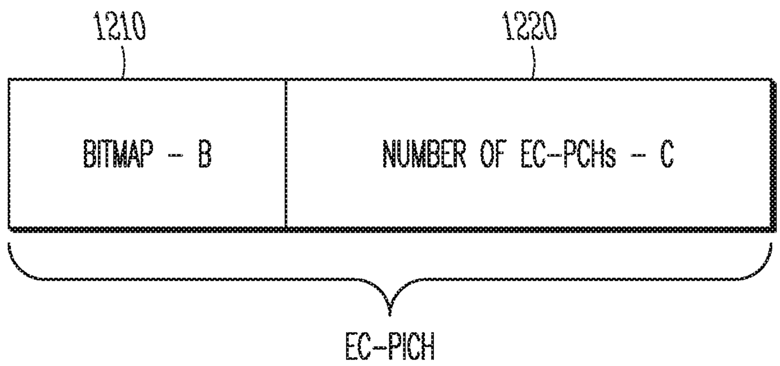

1100
TS0
TS1
CC1
CC2
CC3/
CC4
FCCH
SCH
BCCH
CCCH
IDLE
EC-SCH
EC-BCCH
EC-BCCH-
EXTOR
EC-AGCH
EC-AGCH
1110
1120
1125
1130
1135
18
20
1
6
1E
6E
EC-PICH: 01000010000000001010010
1160
1165
1170
1175
1180
1190

FIG. 11

1200



1250

EC-PICH CONTENT MAPPING								
	BIT NUMBER							
OCTET NO	7	6	5	4	3	2	1	0
0	B(7)	B(6)	B(5)	B(4)	B(3)	B(2)	B(1)	B(0)
1	B(15)	B(14)	B(13)	B(12)	B(11)	B(10)	B(9)	B(8)
2	C		B(21)	B(20)	B(19)	B(18)	B(17)	B(16)
3								C

FIG. 12

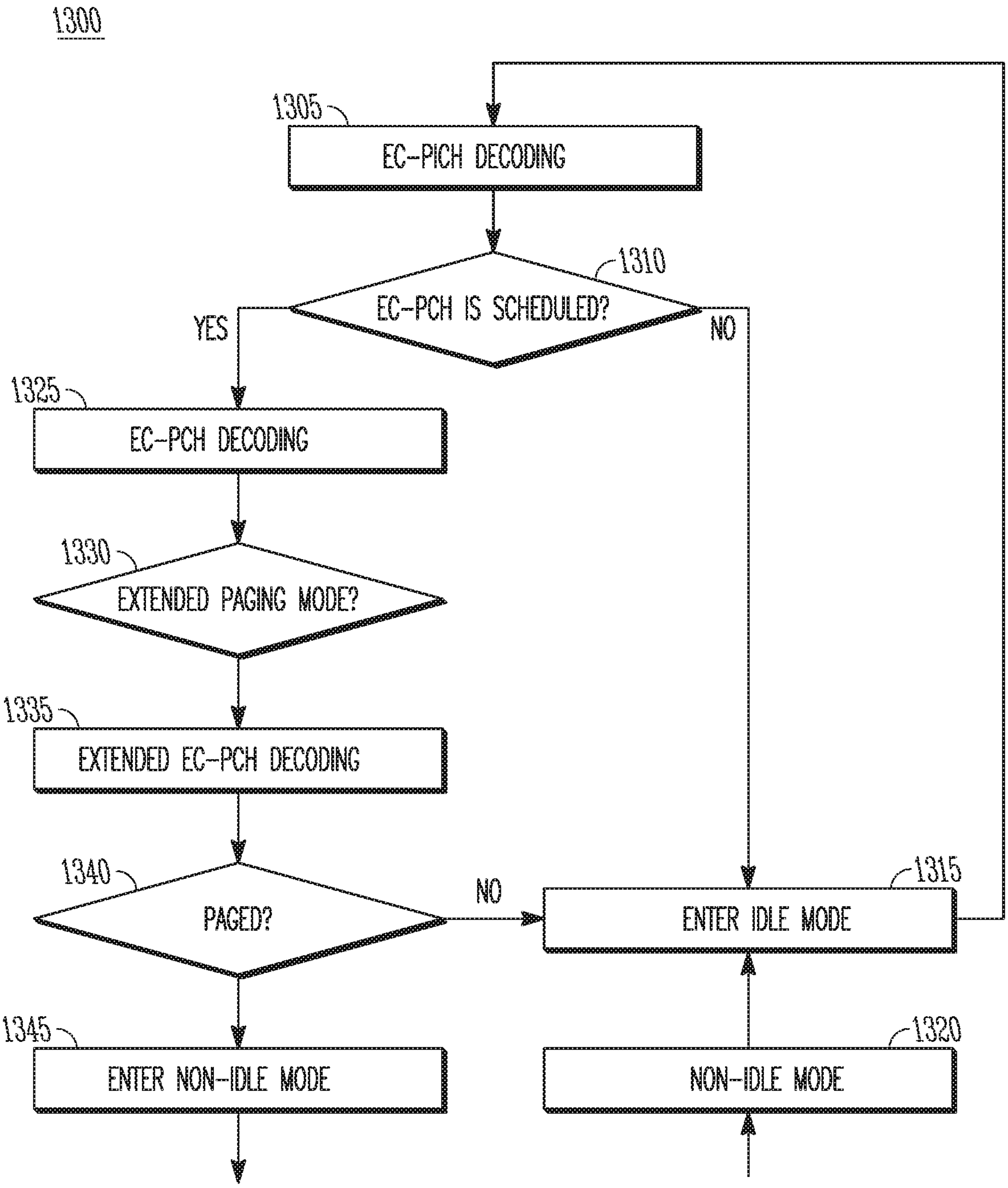

1300
1305
EC-PICH DECODING
1310
EC-PCH IS SCHEDULED?
YES
NO
1325
EC-PCH DECODING
1330
EXTENDED PAGING MODE?
1335
EXTENDED EC-PCH DECODING
1340
PAGED?
NO
1315
ENTER IDLE MODE
1345
ENTER NON-IDLE MODE
1320
NON-IDLE MODE

FIG. 13

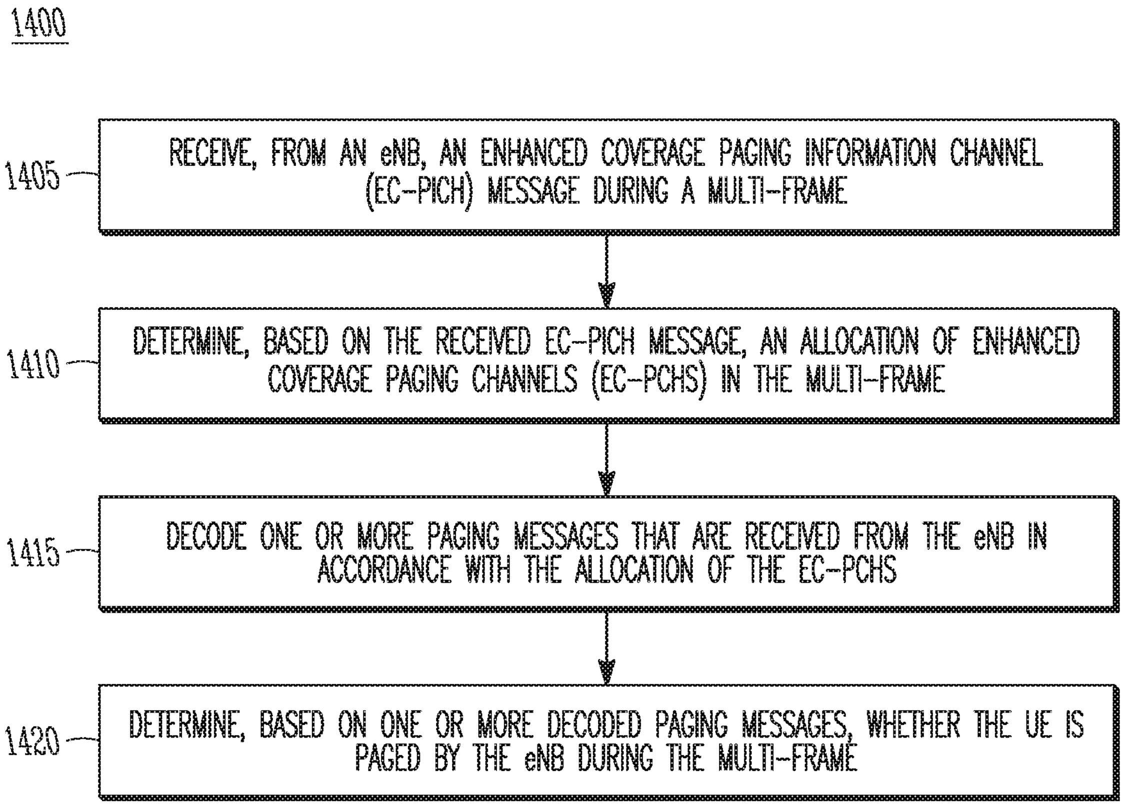

1400
1405
RECEIVE, FROM AN eNB, AN ENHANCED COVERAGE PAGING INFORMATION CHANNEL (EC-PICH) MESSAGE DURING A MULTI-FRAME
1410
DETERMINE, BASED ON THE RECEIVED EC-PICH MESSAGE, AN ALLOCATION OF ENHANCED COVERAGE PAGING CHANNELS (EC-PCHS) IN THE MULTI-FRAME
1415
DECODE ONE OR MORE PAGING MESSAGES THAT ARE RECEIVED FROM THE eNB IN ACCORDANCE WITH THE ALLOCATION OF THE EC-PCHS
1420
DETERMINE, BASED ON ONE OR MORE DECODED PAGING MESSAGES, WHETHER THE UE IS PAGED BY THE eNB DURING THE MULTI-FRAME

FIG. 14

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/042310

A. CLASSIFICATION OF SUBJECT MATTER

H04W 72/04(2009.01)i, H04W 68/02(2009.01)i, H04W 88/08(2009.01)i, H04W 88/02(2009.01)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)
H04W 72/04; H04W 74/08; H04W 68/02; H04Q 7/20; H04W 72/00; H04W 88/08; H04W 88/02

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: enhanced coverage paging channel (EC-PCH) indicator bitmap, multi-frame, group of EC-PCHs, TDMA frame, enhanced coverage paging information channel (EC-PICH), variable number of the TDMA frames, span, coverage class

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	NOKIA NETWORKS, `EC-PCH Enhancements for EC-EGPRS (Update of GP-160106)`, GP-160192, 3GPP TSG GERAN #69 Meeting, St. Julian's, Malta, 18 February 2016 See sections 2-2.2.	1-25
A	ERICSSON, `EC-GSM - Block format for EC-PCH and EC-AGCH`, GPC150111, 3GPP TSG GERAN Ad Hoc#1 on FS_IoT_LC, Sofia Antipolis, France, 03 February 2015 See sections 3-3.2.	1-25
A	US 2014-0098761 A1 (INTERDIGITAL PATENT HOLDINGS, INC.) 10 April 2014 See paragraphs [0278]-[0286].	1-25
A	US 2004-0147271 A1 (THIERRY BILLON et al.) 29 July 2004 See paragraphs [0035]-[0042]; and fig. 4.	1-25
A	US 2014-0192720 A1 (LG ELECTRONICS INC.) 10 July 2014 See paragraphs [0174]-[0205]; and figs. 16-19.	1-25

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
09 December 2016 (09.12.2016)	**09 December 2016 (09.12.2016)**

Name and mailing address of the ISA/KR	Authorized officer
International Application Division Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea	KANG, Hee Gok
Facsimile No. +82-42-481-8578	Telephone No. +82-42-481-8264

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/042310

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014-0098761 A1	10/04/2014	CN 104704884 A	10/06/2015
		EP 2904850 A1	12/08/2015
		HK 1213415 A1	30/06/2016
		JP 2015-537422 A	24/12/2015
		KR 10-2015-0064196 A	10/06/2015
		TW 201429174 A	16/07/2014
		WO 2014-055878 A1	10/04/2014
US 2004-0147271 A1	29/07/2004	FR 2849569 A1	02/07/2004
		FR 2849569 B1	11/03/2005
US 2014-0192720 A1	10/07/2014	CN 101946548 A	12/01/2011
		CN 101946548 B	25/12/2013
		KR 10-1169283 B1	02/08/2012
		US 2011-051668 A1	03/03/2011
		US 8660064 B2	25/02/2014
		WO 2009-148258 A2	10/12/2009
		WO 2009-148258 A3	11/03/2010