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(54) **Title:** HANDOVER ENHANCEMENTS TO REDUCE INTERRUPTION AND LATENCY

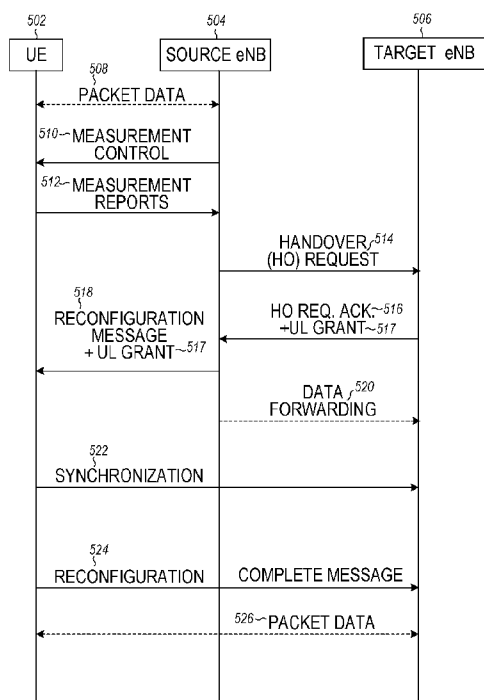


FIG. 5

(57) **Abstract:** Disclosed herein are user equipment (UE) and base station (eNB) apparatus and methodology for handover enhancements to reduce interruption time and handover latency. An apparatus of a UE is configured to communicate with a source evolved Node B (SeNB) and a target evolved Node B (TeNB). The UE includes memory and processing circuitry coupled to the memory. The processing circuitry is configured to acquire a Mobility Control Information message within an RRC Connection Reconfiguration message received from the SeNB in response to a handover decision; determine uplink (UL) resource grant based on the Mobility Control Information message; and engage in handover from the SeNB to the TeNB based on the UL resource grant, without initiating random access channel (RACH) acquisition from the TeNB. The processing circuitry is further configured to perform synchronization to the TeNB using UL resources specified by the UL resource grant.



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HANDOVER ENHANCEMENTS TO REDUCE INTERRUPTION AND LATENCY

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PRIORITY CLAIM

[0001] This application claims the benefit of priority to United States Provisional Patent Application Serial No. 62/317,345, filed April 1, 2016, and entitled “HANDOVER ENHANCEMENTS TO REDUCE INTERRUPTION
10 TIME AND HO LATENCY,” which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] Embodiments pertain to wireless communications. Some
15 embodiments relate to wireless networks including 3GPP (Third Generation Partnership Project) networks, 3GPP LTE (Long Term Evolution) networks, 3GPP LTE-A (LTE Advanced) networks, and 5G networks, although the scope of the embodiments is not limited in this respect. Some embodiments relate to handover (HO) enhancements to reduce interruption time and HO
20 latency.

BACKGROUND

[0003] With the increase in different types of devices communicating with various network devices, usage of 3GPP LTE systems has increased. The
25 penetration of mobile devices (user equipment or UEs) in modern society has continued to drive demand for a wide variety of networked devices in a number of disparate environments. The use of networked UEs using 3GPP LTE systems has increased in all areas of home and work life. Fifth generation (5G) wireless systems are forthcoming, and are expected to enable
30 even greater speed, connectivity, and usability.

[0004] One concern with UEs is latency involved in handovers (or cell reselection) between different base stations (e.g., enhanced eNode-Bs or

eNBs). Handovers may occur as a UE moves in a geographical location served by multiple eNBs and a determination is made to change the eNB providing communication services to the UE from the current eNB to another eNB. Due to the number of processes involved, the handover may take on the order of about 50 milliseconds (ms) or more, which is a substantial amount of time. The handover latency may, in certain circumstances, result in a period of relatively poor quality of service or even loss of service during the handover. This latency may be excessive for some wireless systems (e.g., 5G systems) with stricter end-to-end latency requirements. It may thus be desirable to reduce handover latency and thus produce seamless mobility for UEs.

BRIEF DESCRIPTION OF THE FIGURES

[0005] In the figures, which are not necessarily drawn to scale, like numerals may describe similar components in different views. Like numerals having different letter suffixes may represent different instances of similar components. Some embodiments are illustrated by way of example, and not limitation, in the following figures of the accompanying drawings.

[0006] FIG. 1 is a functional diagram of a 3GPP network in accordance with some embodiments.

[0007] FIG. 2 is a block diagram of a User Equipment (UE) in accordance with some embodiments.

[0008] FIG. 3 is a block diagram of an Evolved Node-B (eNB) in accordance with some embodiments.

25 [0009] FIG. 4A illustrates a handover (HO) procedure in accordance with some embodiments.

[0010] FIG. 4B illustrates various components of the service interruption time associated with the HO procedure of FIG. 4A.

[0011] FIG. 5 illustrates a HO procedure with reduced service interruption time, in accordance with some embodiments.

[0012] FIG. 6 illustrates example mobility_Control_Info signaling in accordance with some embodiments.

[0013] FIG. 7 illustrates example subframe selection of a source evolved Node B (SeNB) subframe corresponding to a target evolved Node B (TeNB) subframe in the uplink grant, in accordance with some embodiments.

[0014] FIG. 8 illustrates another example mobility_Control_Info signaling in accordance with some embodiments.

[0015] FIG. 9 is a flow diagram illustrating example functionalities for handover enhancements to reduce interruption time and handover latency according to some embodiments.

[0016] FIG. 10 illustrates a block diagram of a communication device such as an eNB or a UE, in accordance with some embodiments.

DETAILED DESCRIPTION

[0017] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. A number of examples are described in the context of 3GPP communication systems and components thereof. It will be understood that principles of the embodiments are applicable in other types of communication systems, such as Wi-Fi or Wi-Max networks, Bluetooth or other personal-area networks, Zigbee or other home-area networks, wireless mesh networks, and the like, without limitation, unless expressly limited by a corresponding claim. Given the benefit of the present disclosure, persons skilled in the relevant technologies will be able to engineer suitable variations to implement principles of the embodiments in other types of communication systems. Various diverse embodiments may incorporate structural, logical, electrical, process, and other differences. 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 presently-known, and after-arising, equivalents of those claims.

[0018] FIG. 1 shows an example of a portion of an end-to-end network architecture of a Long Term Evolution (LTE) network with various components of the network in accordance with some embodiments. As used herein, LTE and LTE-A networks and devices are referred to merely as LTE networks and devices. The network 100 may comprise a radio access network

(RAN) (e.g., as depicted, the E-UTRAN or evolved universal terrestrial radio access network) 101 and the core network 120 (e.g., shown as an evolved packet core (EPC)) coupled together through an S1 interface 115. For convenience and brevity, only a portion of the core network 120, as well as the RAN 101, is shown in the example.

[0019] The core network 120 includes a mobility management entity (MME) 122, a serving gateway (serving GW) 124, and packet data network gateway (PDN GW) 126. The RAN 101 includes Evolved Node-B's (eNB) 104 (which may operate as base stations) for communicating with User Equipment (UE) 102. The eNBs 104 may include macro eNBs and low power (LP) eNBs, such as micro, pico or femto eNBs. In accordance with some embodiments, the eNB 104 may transmit a downlink control message to the UE 102 to indicate an allocation of physical uplink control channel (PUCCH) channel resources. The UE 102 may receive the downlink control message from the eNB 104, and may transmit an uplink control message to the eNB 104 in at least a portion of the PUCCH channel resources.

[0020] The MME 122 is similar in function to the control plane of legacy Serving GPRS Support Nodes (SGSN). The MME 122 manages mobility aspects in access such as gateway selection and tracking area list management. The serving GW 124 terminates the interface toward the RAN 101, and routes data packets between the RAN 101 and the core network 120. In addition, it may be a local mobility anchor point for inter-eNB handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement. The serving GW 124 and the MME 122 may be implemented in one physical node or separate physical nodes. The PDN GW 126 terminates a SGi interface toward the packet data network (PDN). The PDN GW 126 routes data packets between the EPC 120 and the external PDN, and may be a key node for policy enforcement and charging data collection. It may also provide an anchor point for mobility with non-LTE accesses. The external PDN can be any kind of IP network, as well as an IP Multimedia Subsystem (IMS) domain. The PDN GW 126 and the serving GW 124 may be implemented in one physical node or separated physical nodes.

[0021] The eNBs 104 (macro, micro, pico or femto) may terminate the air interface protocol and may be the first point of contact for a UE 102. At least some of the eNBs 104 may be in a cell 106, in which the eNBs 104 of the cell 106 may be controlled by the same processor or set of processors. In some embodiments, an eNB 104 may be in a single cell 106, while in other embodiments the eNB 104 may be a member of multiple cells 106. In some embodiments, an eNB 104 may fulfill various logical functions for the RAN 101 including but not limited to RNC (radio network controller functions) such as radio bearer management, uplink and downlink dynamic radio resource management and data packet scheduling, and mobility management. In accordance with embodiments, UEs 102 may be configured to communicate Orthogonal frequency-division multiplexing (OFDM) communication signals with an eNB 104 over a multicarrier communication channel in accordance with an OFDMA communication technique. The OFDM signals may comprise a plurality of orthogonal subcarriers. Each of the eNBs 104 may be able to transmit a reconfiguration message to each UE 102 that is connected to that eNB 104. The reconfiguration message may contain reconfiguration information including one or more parameters that indicate specifics about reconfiguration of the UE 102 upon a mobility scenario (e.g., handover) to reduce the latency involved in the handover. The parameters may include physical layer and layer 2 reconfiguration indicators, and a security key update indicator. The parameters may be used to instruct the UE 102 to avoid or skip one or more of the processes indicated to decrease messaging between the UE 102 and the network. The network may be able to automatically route packet data between the UE 102 and the new eNB 104 and may be able to provide the desired information between the eNBs 104 involved in the mobility. The application, however, is not limited to this, however, and additional embodiments are described in more detail below.

[0022] In an example, one of the eNBs in cell 106 can be a source eNB and the other eNB can be a target eNB (indicated as SeNB and TeNB in FIG. 1) for purposes of a handover (HO) of the UE from the SeNB to the TeNB. Additionally, UL grant information can be provided to the UE in a connection reconfiguration message 130, which can be used to initiate the HO. By providing UL grant information with the reconfiguration message 130, HO

can be performed without a random access channel (RACH) procedure, which reduces the HO latency and service interruption.

5 **[0023]** The S1 interface 115 is the interface that separates the RAN 101 and the EPC 120. It is split into two parts: the S1-U, which carries traffic data between the eNB 104 and the serving GW 124, and the S1-MME, which is a signaling interface between the eNB 104 and the MME 122. The X2 interface is the interface between eNB 104. The X2 interface comprises two parts, the X2-C and X2-U. The X2-C is the control plane interface between the eNB 104, while the X2-U is the user plane interface between the eNB 104.

10 **[0024]** With cellular networks, LP cells are typically used to extend coverage to indoor areas where outdoor signals do not reach well, or to add network capacity in areas with very dense phone usage, such as train stations. As used herein, the term low power (LP) eNB refers to any suitable relatively low power eNB for implementing a narrower cell (narrower than a macro cell) such as a femtocell, a picocell, or a micro cell. Femtocell eNBs are typically provided by a mobile network operator to its residential or enterprise customers. A femtocell is typically the size of a residential gateway or smaller and generally connects to the user's broadband line. Once plugged in, the femtocell connects to the mobile operator's mobile network and provides extra coverage in a range of typically 30 to 50 meters for residential femtocells. Thus, a LP eNB might be a femtocell eNB since it is coupled through the PDN GW 126. Similarly, a picocell is a wireless communication system typically covering a small area, such as in-building (offices, shopping malls, train stations, etc.), or more recently in-aircraft. A picocell eNB can generally connect through the X2 link to another eNB such as a macro eNB through its base station controller (BSC) functionality. Thus, LP eNB may be implemented with a picocell eNB since it is coupled to a macro eNB via an X2 interface. Picocell eNBs or other LP eNBs may incorporate some or all functionality of a macro eNB. In some cases, this may be referred to as an access point base station or enterprise femtocell.

25 **[0025]** Communication over an LTE network may be split up into 10ms frames, each of which contains ten 1ms subframes. Each subframe, in turn, may contain two slots of 0.5ms. Each slot may contain 6-7 symbols,

depending on the system used. A resource block (RB) (also called physical resource block (PRB)) may be the smallest unit of resources that can be allocated to a UE. A resource block may be 180 kHz wide in frequency and 1 slot long in time. In frequency, resource blocks may be either 12 x 15 kHz subcarriers or 24 x 7.5 kHz subcarriers wide. For most channels and signals, 12 subcarriers may be used per resource block. In Frequency Division Duplexed (FDD) mode, both the uplink and downlink frames may be 10ms and may be frequency (full-duplex) or time (half-duplex) separated. In Time Division Duplexed (TDD), the uplink and downlink subframes may be transmitted on the same frequency and may be multiplexed in the time domain. A downlink resource grid may be used for downlink transmissions from an eNB to a UE. The grid may be a time-frequency grid, which is the physical resource in the downlink in each slot. Each column and each row of the resource grid may correspond to one OFDM symbol and one OFDM subcarrier, respectively. The duration of the resource grid in the time domain may correspond to one slot. The smallest time-frequency unit in a resource grid may be denoted as a resource element. Each resource grid may comprise a number of the above resource blocks, which describe the mapping of certain physical channels to resource elements. Each resource block may comprise 12 (subcarriers) * 14 (symbols) = 168 resource elements.

[0026] In some embodiments, a downlink resource grid may be used for downlink transmissions from an eNB 104 to a UE 102, while uplink transmission from the UE 102 to the eNB 104 may utilize similar techniques. The grid may be a time-frequency grid, called a resource grid or time-frequency resource grid, which is the physical resource in the downlink in each slot. Such a time-frequency plane representation is a common practice for OFDM systems, which makes it intuitive for radio resource allocation. Each column and each row of the resource grid correspond to one OFDM symbol and one OFDM subcarrier, respectively. The duration of the resource grid in the time domain corresponds to one slot in a radio frame. The smallest time-frequency unit in a resource grid is denoted as a resource element (RE). Each resource grid comprises a number of resource blocks (RBs), which describe the mapping of certain physical channels to resource elements. Each resource block comprises a collection of resource elements in the frequency

domain and may represent the smallest quanta of resources that currently can be allocated. There are several different physical downlink channels that are conveyed using such resource blocks. Two example physical downlink channels are the physical downlink shared channel and the physical down link control channel.

[0027] There may be several different physical downlink channels that are conveyed using such resource blocks. Two of these physical downlink channels may be the physical down link control channel (PDCCH) and the physical downlink shared channel (PDSCH). Each subframe may be partitioned into the PDCCH and the PDSCH.

[0028] The physical downlink shared channel (PDSCH) carries user data and higher-layer signaling to a UE 102 (FIG. 1). The physical downlink control channel (PDCCH) carries information about the transport format and resource allocations related to the PDSCH channel, among other things. It also informs the UE 102 about the transport format, resource allocation, and hybrid automatic repeat request (HARQ) information related to the uplink shared channel. Typically, downlink scheduling (e.g., assigning control and shared channel resource blocks to UE 102 within a cell) may be performed at the eNB 104 based on channel quality information fed back from the UE 102 to the eNB 104, and then the downlink resource assignment information may be sent to the UE 102 on the control channel (PDCCH) used for (assigned to) the UE 102.

[0029] The PDCCH uses CCEs (control channel elements) to convey the control information. Before being mapped to resource elements, the PDCCH complex-valued symbols are first organized into quadruplets, which are then permuted using a sub-block inter-leaver for rate matching. Each PDCCH is transmitted using one or more of these control channel elements (CCEs), where each CCE corresponds to nine sets of four physical resource elements known as resource element groups (REGs). Four QPSK symbols are mapped to each REG. The PDCCH can be transmitted using one or more CCEs, depending on the size of downlink control information (DCI) and the channel condition. There may be four or more different PDCCH formats

defined in LTE with different numbers of CCEs (e.g., aggregation level, L=1, 2, 4, or 8).

[0030] 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), or memory (shared, dedicated, or group) that executes one or more software or firmware programs, a combinational logic circuit, 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 or software.

[0031] FIG. 2 is a functional diagram of a User Equipment (UE) in accordance with some embodiments. The UE 200 may be suitable for use as a UE 102 as depicted in FIG. 1. In some embodiments, the UE 200 may include application circuitry 202, baseband circuitry 204, Radio Frequency (RF) circuitry 206, front-end module (FEM) circuitry 208, and multiple antennas 210A-210D, coupled together at least as shown. In some embodiments, other circuitry or arrangements may include one or more elements or components of the application circuitry 202, the baseband circuitry 204, the RF circuitry 206 or the FEM circuitry 208, and may also include other elements or components in some cases. As an example, “processing circuitry” may include one or more elements or components, some or all of which may be included in the application circuitry 202 or the baseband circuitry 204. As another example, “transceiver circuitry” may include one or more elements or components, some or all of which may be included in the RF circuitry 206 or the FEM circuitry 208. These examples are not limiting, however, as the processing circuitry or the transceiver circuitry may also include other elements or components in some cases.

[0032] The application circuitry 202 may include one or more application processors. For example, the application circuitry 202 may include circuitry such as, but not limited to, one or more single-core or multi-

core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with or may include memory/storage and may be configured to execute instructions stored
5 in the memory/storage to enable various applications or operating systems to run on the system to perform one or more of the functionalities described herein.

[0033] The baseband circuitry 204 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The
10 baseband circuitry 204 may include one or more baseband processors or control logic to process baseband signals received from a receive signal path of the RF circuitry 206 and to generate baseband signals for a transmit signal path of the RF circuitry 206. Baseband processing circuitry 204 may interface with the application circuitry 202 for generation and processing of the
15 baseband signals and for controlling operations of the RF circuitry 206. For example, in some embodiments, the baseband circuitry 204 may include a second generation (2G) baseband processor 204a, third generation (3G) baseband processor 204b, fourth generation (4G) baseband processor 204c, or other baseband processor(s) 204d for other existing generations, generations in
20 development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 204 (e.g., one or more of baseband processors 204a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 206. The radio control functions may include, but are not limited to, signal
25 modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 204 may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 204 may include Low
30 Density Parity Check (LDPC) encoder/decoder functionality, optionally alongside other techniques such as, for example, block codes, convolutional codes, turbo codes, or the like, which may be used to support legacy protocols. Embodiments of modulation/demodulation and encoder/decoder functionality

are not limited to these examples and may include other suitable functionality in other embodiments.

[0034] In some embodiments, the baseband circuitry 204 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (EUTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), or radio resource control (RRC) elements. A central processing unit (CPU) 204e of the baseband circuitry 204 may be configured to run elements of the protocol stack for signaling of the PHY, MAC, RLC, PDCP or RRC layers. In some embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (DSP) 204f. The audio DSP(s) 204f may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments. Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the baseband circuitry 204 and the application circuitry 202 may be implemented together such as, for example, on a system on chip (SOC).

[0035] In some embodiments, the baseband circuitry 204 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 204 may support communication with an evolved universal terrestrial radio access network (EUTRAN) or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 204 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[0036] RF circuitry 206 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 206 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless

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

[0037] In some embodiments, the RF circuitry 206 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 206 may include mixer circuitry 206a, amplifier circuitry 206b and filter circuitry 206c. The transmit signal path of the RF circuitry 206 may include filter circuitry 206c and mixer circuitry 206a. RF circuitry 206 may also include synthesizer circuitry 206d for synthesizing a frequency for use by the mixer circuitry 206a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 206a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 208 based on the synthesized frequency provided by synthesizer circuitry 206d. The amplifier circuitry 206b may be configured to amplify the down-converted signals and the filter circuitry 206c may be a low-pass filter (LPF) or band-pass filter (BPF) configured to remove unwanted signals from the down-converted signals to generate output baseband signals. Output baseband signals may be provided to the baseband circuitry 204 for further processing. In some embodiments, the output baseband signals may be zero-frequency baseband signals, although this is not a requirement. In some embodiments, mixer circuitry 206a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect. In some embodiments, the mixer circuitry 206a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 206d to generate RF output signals for the FEM circuitry 208. The baseband signals may be provided by the baseband circuitry 204 and may be filtered by filter circuitry 206c. The filter circuitry 206c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

[0038] In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion or upconversion respectively. In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a may be arranged for direct downconversion or direct upconversion, respectively. In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a of the transmit signal path may be configured for super-heterodyne operation.

[0039] In some embodiments, the output baseband signals and the input baseband signals may be analog baseband signals, although the scope of the embodiments is not limited in this respect. In some alternate embodiments, the output baseband signals and the input baseband signals may be digital baseband signals. In these alternate embodiments, the RF circuitry 206 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 204 may include a digital baseband interface to communicate with the RF circuitry 206. 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.

[0040] In some embodiments, the synthesizer circuitry 206d may be a fractional-N synthesizer or a fractional N/N+1 synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 206d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider. The synthesizer circuitry 206d may be configured to synthesize an output frequency for use by the mixer circuitry 206a of the RF circuitry 206 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 206d may be a fractional N/N+1 synthesizer. In some embodiments, frequency input may be

provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry 204 or the applications processor 202 depending on the desired output frequency. In some embodiments, a divider control input (e.g., N) may
5 be determined from a look-up table based on a channel indicated by the applications processor 202.

[0041] Synthesizer circuitry 206d of the RF circuitry 206 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and
10 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
15 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.

[0042] In some embodiments, synthesizer circuitry 206d may be
20 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
25 phases with respect to each other. In some embodiments, the output frequency may be a LO frequency (fLO). In some embodiments, the RF circuitry 206 may include an IQ/polar converter.

[0043] FEM circuitry 208 may include a receive signal path, which may include circuitry configured to operate on RF signals received from one
30 or more of the antennas 210A-D, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 206 for further processing. FEM circuitry 208 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided

by the RF circuitry 206 for transmission by one or more of the one or more antennas 210A-D.

[0044] In some embodiments, the FEM circuitry 208 may include a TX/RX switch to switch between transmit mode and receive mode operation.

5 The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 206). The transmit signal path of the FEM circuitry 208 may include a power amplifier (PA) to
10 amplify input RF signals (e.g., provided by RF circuitry 206), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 210. In some embodiments, the UE 200 may include additional elements such as, for example, memory/storage, display, camera, sensor, or input/output (I/O) interface.

15 **[0045]** FIG. 3 is a functional diagram of an Evolved Node-B (eNB) in accordance with some embodiments. It should be noted that in some embodiments, the eNB 300 may be a stationary non-mobile device. The eNB 300 may be suitable for use as an eNB 104 as depicted in FIG. 1. The components of eNB 300 may be included in a single device or a plurality of
20 devices. The eNB 300 may include physical layer (PHY) 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 301A-B. As an example, the physical layer circuitry 302 may perform various encoding and decoding functions that may
25 include formation of baseband signals for transmission and decoding of received signals. For example, physical layer circuitry 302 may include LDPC encoder/decoder functionality, optionally along-side other techniques such as, for example, block codes, convolutional codes, turbo codes, or the like, which may be used to support legacy protocols. Embodiments of
30 modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments. 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

5 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

10 described herein. The eNB 300 may also include one or more interfaces 310, which may enable communication with other components, including other eNB 104 (FIG. 1), components in the EPC 120 (FIG. 1) or other network components. In addition, the interfaces 310 may enable communication with other components that may not be shown in FIG. 1, including components

15 external to the network. The interfaces 310 may be wired or wireless or a combination thereof.

[0046] The antennas 210A-D (in the UE) and 301A-B (in the eNB) may comprise one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, patch antennas, loop

20 antennas, microstrip antennas or other types of antennas suitable for transmission of RF signals. In some multiple-input multiple-output (MIMO) embodiments, the antennas 210A-D, 301A-B may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result.

25 **[0047]** In some embodiments, the UE 200 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

30 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 or transmit information wirelessly. In some embodiments, the UE 200 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 200, eNB 300 or other device
5 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.

[0048] Although the UE 200 and the eNB 300 are each illustrated as
10 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), or other hardware elements. For example, some elements may comprise one or more microprocessors, DSPs, field-
15 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.

[0049] 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
25 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
30 and may be configured with instructions stored on a computer-readable storage device.

[0050] It should be noted that in some embodiments, an apparatus used by the UE 200 or eNB 300 may include various components of the UE 200 or

the eNB 300 as shown in FIG. 2 and FIG. 3. Accordingly, techniques and operations described herein that refer to the UE 200 (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.

[0051] FIG. 4A illustrates a handover (HO) procedure in accordance with some embodiments. In some embodiments, the source eNB and target eNB 404, 406 shown in FIG. 4A may be the eNBs 104a and 104b shown in FIG. 1, and the UE 402 may be the UE 102 shown in FIG. 1. FIG. 4A illustrates signaling procedures associated with a handover preparation phase 430 and a handover execution phase 432. Prior to handover preparation 430, UE is connected with the Source eNB (SeNB) 404, and packet data 408 is communicated between the UE 402 and the SeNB 404. The packet data 408 may be transmitted in either direction, from the UE 402 to the SeNB 404 or from the SeNB 404 to the UE 402.

[0052] The SeNB 404 may transmit various control signals 410 to the UE 402 from time to time. Among these control signals may be measurement control signals 410, Layer 3 (network) signaling. The SeNB 404 may request that the UE 402 take measurements in accordance to the measurement control signals 410. Specifically, Channel State Information (CSI) measurements taken by the UE 402 may be used by the SeNB 404 (or core network) to estimate the channel quality and determine whether handover is desired. CSI measurements may measure Cell-specific Reference Signals (CRS), CSI Reference Signals (CSI-RS) or other Channel State Information-Interference Measurement (CSI-IM) signals transmitted by the SeNB 404 for measurement purposes.

[0053] From the measurements, calculations of the channel quality may be subsequently determined and reported to the SeNB 404 by the UE 402 through measurement reports 412. The measurement report 412 may include, for example, CSI feedback information. The CSI feedback may include a Channel Quality Indicator (CQI) and may be sent from the UE 402 to the SeNB 404 to indicate, for example, a suitable downlink transmission data rate, i.e., a Modulation and Coding Scheme (MCS) value, for communications

between the SeNB 404 and the UE 402. The information provided by the CQI may include both channel quality and desired transport block size.

[0054] The CQI may be, for example, a 4-bit integer (i.e., 15 different values) and may be based on an observed signal-to-interference-plus-noise ratio (SINR) at the UE 402. The CQI may take into account the UE 402 capability, such as the number of antennas and the type of receiver used for detection, which may be then used by the SeNB 404 to select an optimum MCS level for downlink (DL) scheduling and data transmission. The CSI and CQI may be reported either periodically or aperiodically. A periodic CQI report may be carried by using the PUCCH or, if the UE 402 is to send UL data in the same subframe as a scheduled periodic CQI report, the periodic CQI report may instead use the PUSCH. A periodic CQI report may be supplemented by an aperiodic CQI report, in particular if UL data is scheduled during the same subframe as a scheduled periodic CQI report.

[0055] In addition to the source cell 404 determining the appropriate characteristics to use for uplink (UL) and DL transmissions associated with the UE 402, the CSI feedback in the measurement report 412 may be used by the SeNB 404 to determine whether or not handover of the UE 402 is to occur (e.g., handover from SeNB 404 to TeNB 406). If not, packet data may continue to be transmitted between the UE 402 and the SeNB 404 until the next CSI feedback is received by the SeNB 404 via the reports 412. The CSI feedback may contain CSI information associated with other cells, including the TeNB 406, or the SeNB 404 may obtain CSI feedback information associated with the TeNB 406 from the TeNB 406, for example.

[0056] Based on the measurement reports 412, the SeNB 404 may determine it is appropriate to switch communication with the UE from the SeNB 404 to the TeNB 406, and it may issue a handover request 414 to the TeNB 406. The TeNB 406 can prepare the handover by sending a handover request acknowledgement message 416. The handover request acknowledgement message 416 can include a transparent container to be sent to the UE 402 as a radio resource control (RRC) message to perform the handover. In an example, the container can include a cell radio network

temporary identifier (C-RNTI), TeNB 406 security algorithm identifiers, a dedicated random access channel (RACH) preamble for RACH acquisition, and so forth.

[0057] The SeNB 404 then generates the RRC reconfiguration message 418 (e.g., an RRC_Connection_Reconfiguration message), which can include Mobility Control Information with additional parameters for use in the handover. In an example, the RRC reconfiguration message may be generated by the TeNB 406 and sent to the SeNB 404 for forwarding to the UE 402.

[0058] After RRC reconfiguration message 418 is received by the UE 402, packet data communication between the US 402 and SeNB 404 stops in preparation for handover. Any packet data 420 that is for communication to the UE 402, is being forwarded to the TeNB 406 for subsequent delivery to the UE 402 after handover is completed.

[0059] After receiving the RRC reconfiguration message 418 with the Mobility Control Information, the UE 402 may perform synchronization 422 to the TeNB 406 and may access the TeNB 406 via RACH, following a contention-free or a contention-based procedure based on whether a dedicated RACH preamble was included in the reconfiguration message 418. The target eNB 406 may respond with an uplink (UL) grant and timing advance (TA) information 424 for completion of the handover. When the UE 402 has successfully accessed the TeNB 406, the UE 402 may send a reconfiguration complete message 426 (e.g., RRC_Connection_Reconfiguration_Complete message) to the TeNB 406 to confirm the handover. After the handover, packet data 428 may be exchanged between the UE 402 and the TeNB 406, although the scope of the embodiments is not limited in this respect.

[0060] FIG. 4B illustrates various components of the service interruption time associated with the HO procedure of FIG. 4A. More specifically, FIG. 4B illustrates latency components associated with the handover execution phase illustrated in the handover process of FIG. 4A. Example latencies of various executed tasks is illustrated below, in Table 1:

Component/ Step	Description	Time (ms)
7	RRC Connection Reconfiguration Incl. <i>mobilityControlInfo</i>	15
9.1	Target cell search	0
9.2	UE processing time for RF/baseband re-tuning, security update	20
9.3	Delay to acquire first available PRACH in target eNB	0.5/2.5
9.4	PRACH preamble transmission	1
10	UL Allocation + TA for UE	3/5
11	UE sends RRC Connection Reconfiguration Complete	6
	Minimum/Typical Total delay [ms]	45.5/49.5

TABLE 1

[0061] Step 7 is associated with the communication of the reconfiguration message 418. Steps 9.1-9.4 are associated with various functionalities performed during the synchronization 422. Step 10 is associated with the UL and TA grant 424. Step 11 is associated with the communication of the reconfiguration complete message 426. As seen in Table 1, typical delay during the handover procedure of FIG. 4A is about 45-50ms. The total delay value in Table 1 assume successful transmission at a first attempt. However, this may not always be true, especially for handover scenarios where channel quality may be degraded. The actual delay values can be higher if some of the above-listed steps require retransmissions.

[0062] Referring to Table 1, the total latency during HO process consists of various elements, as depicted in FIG. 4B. Service interruption time 440 in handover can be defined as the duration between the time when UE stops transmission/reception with the SeNB 404 (e.g., after receiving message 418) and the time when TeNB 406 resumes transmission/reception with the UE 402 (e.g., after message 426 is received by the TeNB 406).

[0063] As seen in FIG. 4B, most of the service interruption time 440 may be due to the following three components:

[0064] - RRC procedure delay 442, including RRC signaling processing (Step 7 in Table 1) associated with the communication of the reconfiguration message 418;

[0065] - UE processing time 444, including delay for RF/baseband retuning, deriving TeNB 406 specific keys, configuring security algorithm to be used in target cell, and so forth (Step 9.2 in Table 1); and

[0066] - RACH related delay 446 associated with RACH functionalities and UL/TA allocation, including delay to acquire first RACH occasion in the target cell (Steps 9.3 to 11 in Table 1).

[0067] In an example, handover latency and service interruption time 440 may be reduced by preventing delays associated with Steps 9.3, 9.4 and 10, as presented in Table 1. More specifically, the UL grant information can be transmitted earlier in the handover sequence seen in FIG. 4A (e.g., with the reconfiguration message 418), preventing the need for (and delay associated with) processing the UL allocation received as a separate message 424. Additionally, the receiving the UL grant earlier, in message 418, the RACH acquisition procedure (e.g., during synchronization 422) for sending the reconfiguration complete message 426 may be skipped as well, contributing to further reduction of the service interruption time 440.

[0068] FIG. 5 illustrates a HO procedure with reduced service interruption time, in accordance with some embodiments. Referring to FIG. 5, the illustrated HO procedure is similar to the procedure illustrated in FIG. 4A, with changes to the UL grant and TA determination. More specifically, the 20 UE 502, SeNB 504 and TeNB 506 correspond to the UE 402, SeNB 404 and TeNB 406. Additionally, the communication of packet data 508, measurement control message 510, measurement reports 512, handover request 514, data forwarding 520, reconfiguration complete message 524, and 25 packet data 526 communication are similar to communication of the following: communication of packet data 408, measurement control message 410, measurement reports 412, handover request 414, data forwarding 420, reconfiguration complete message 424, and packet data 426 from FIG. 4A.

[0069] In an example, the handover request acknowledgement 30 message 516 may include an UL grant information 517. The UL grant 517 may include configuration (or other information) about the UL grant of the TeNB 506 reserved for the UE 502 to use for the handover and to send the reconfiguration complete message 524. The SeNB 504 can forward the UL

grant information 517 to the UE 502 together with the reconfiguration message 518.

- [0070] After receiving the reconfiguration message 518 (e.g., RRC_Connection_Reconfiguration message) including the Mobility Control Information, the UE 502 performs synchronization 522 to the TeNB 506 using the UL grant information 517. In instances when the UL grant information 517 is not included with the reconfiguration message 518, then the UE 502 may access the TeNB 506 via RACH, following a contention-free procedure if a dedicated RACH preamble was included in the Mobility Control Information, or following a contention-based procedure if no dedicated preamble was included. In this regard, communication of the UL grant and TA information 424 may be skipped in the HO procedure of FIG. 5, and communication with the TeNB 506 may be established without the need for a RACH procedure. Consequently, handover latency and service interruption time 440 may be reduced with the HO procedure in FIG. 5 since Steps 9.3, 9.4 and 10, as presented in Table 1, can be skipped.

- [0071] In addition to deriving the UL allocation from the UL grant 517, the UE 502 can also estimate the timing advance (TA) information prior to communicating the reconfiguration complete message 524. More specifically, the UE 502 can obtain downlink (DL) propagation delay difference between the SeNB 504 and the TeNB 506. Assuming uplink (UL) propagation delay is the same as the DL propagation delay, the UE 502 may derive the TA for the TeNB 506 from the SeNB 504 TA and the propagation delay difference T1 (between the SeNB 504 and the UE 502) and T2 (between the TeNB 506 and the UE 502). For example, $TA_{TeNB} = TA_{SeNB} - 2 * (T1 - T2)$. Other methods of estimating TeNB TA may also be utilized.

[0072] Target eNB Uplink Grant Information

- [0073] In an example, the TeNB 506 can provide the UL grant 517 for use by the UE 502 continually on periodic subframes, where the period can be configurable, starting after a configurable timing offset. In one option, the offset can be either calculated/estimated by the SeNB 504 and included in the handover request 514, which the TeNB 506 may take into account to make a final determination of the offset value. In another option, the offset value can

be solely estimated/calculated by the TeNB 506 and included with the UL grant 517. In both instances, the actual start time of the UL grant may be determined by the TeNB 506, although the scope of the embodiments is not limited in this respect.

5 **[0074]** FIG. 6 illustrates an example Mobility Control Information signaling (*mobilityControlInfo*) included with the reconfiguration message 518, in accordance with some embodiments. The additional signaling for configuring the UL grant during a HO is indicated with reference 610 in FIG. 6, and may include: ul-ConfigInfo, ul-StartTime, ul-StartSFN, ul-
10 StartSubframe, implicitReleaseAfter, and/or ul-StartOffset.

[0075] Since the TeNB 506 sends the UL grant information 517 to SeNB 504 which needs to forward it to the UE 502, there is an inherent delay from the UL grant information 517 being sent by the TeNB 506 until the time it is actually used by the UE 502. Therefore, it may be beneficial to not start
15 the allocation immediately but provide the information about when the allocation will start (i.e., use the ul-StartTime information in the additional signaling 610). In addition, the allocation may be repeated up to a certain limit (i.e., the implicitReleaseAfter information) - if the UL grant is not used by the UE before that limit, the TeNB 506 can assume that the UE 502 is not
20 interested in handover and may stop the allocation. In this instance, the UE 502 can fall back to handover procedure using RACH (e.g., as illustrated in FIG. 4A). The following is a brief description of the additional signaling 610, which can be included as part of the Mobility Control Information:

[0076] ul-ConfigInfo

25 **[0077]** This information may provide configuration of the UL resource grant(s) to be used by the UE 502 to send the reconfiguration message 518 (e.g., an RRC_Connection_Reconfiguration_Complete message).

[0078] implicitReleaseAfter

[0079] This information may indicate a number of skipped
30 transmissions by the UE 502 to the TeNB 506 before implicit release. Value e2 can correspond to two transmissions, e3 can correspond to three transmissions and so on.

[0080] schedInterval

[0081] This information may indicate a TeNB 506 scheduling interval in uplink during handover (the value can be provided in number of sub-frames). For example, value sf1 corresponds to one sub-frame (i.e., UL grant available every subframe), sf2 corresponds to two sub-frames and so on.

5 [0082] ul-StartTime

[0083] This information may indicate the start time in terms of TeNB 506 system frame number (SFN) and subframe index, at which the allocation starts. ul-StartTime can include ul-StartSFN (indicating the TeNB SFN at which the UL allocation starts) and ul-StartSubframe (indicating the TeNB subframe index at which the UL allocation starts).

10 [0084] ul-StartOffset

[0085] This information may be used in lieu of the ul-StartTime, and may be used to indicate the UL grant start time. Put another way, the UL start time may be determined by using the ul-StartTime or by using the offset value (ul-StartOffset), as explained above. In instances when an offset is used, the offset can be considered offset starting from the instant the UE 502 receives the Mobility Control Information with the message 518. There is a possibility that the UE 502 may receive this information late and some of the early UL grant is useless. In addition, the UE may find the UL grant if the periodicity (i.e., schedInterval) is one, but for other periodicities, there may be cases where the UE cannot determine exact subframe index corresponding to the grant (e.g., due to processing or communication delays from the time offset is determined by the network to the time UE gets it). For this purpose, pre-defined configurations (described below) can be useful.

25 [0086] In an example, the StartOffset may be considered offset starting from the instant the UE receives the UL grant 517 with the additional signaling 610, accounting for the UE processing time.

[0087] In an example, instead of, or in addition to, the periodic UL grant information included in the Mobility Control Information, a set of UL grant configurations for RACH-less handover may be pre-defined. For example, configuration 1: every 2nd subframe in a radio frame can be used for the RACH-less handover UL; and configuration 2: every 1st and 6th subframe can be used for RACH-less handover UL. The network can provide/signal the

configuration number to the UE 502, and the UE can use the UL grant corresponding to the pre-defined configuration.

[0088] In an example, one or more of the above parameters may be absent when ul-ConfigInfo is signaled. In such case, default values for the parameters may be used instead. For example, if the schedInterval is not signaled as part of additional signaling 610, a default value can be one subframe, or any other predefined value.

[0089] Determining SeNB SFN and Subframe Index for Handover

[0090] FIG. 7 illustrates example subframe selection of a source evolved Node B (SeNB) subframe corresponding to a target evolved Node B (TeNB) subframe in the uplink grant, in accordance with some embodiments. Referring to FIG. 7, there is illustrated SeNB subframe timing 702 and TeNB subframe timing 704.

[0091] As described above, ul-StartTime may include ul-StartSFN and ul-StartSubframe, which indicate UL grants start at SFN and subframe associated with the TeNB 506, not the SeNB 504. For example, ul-StartTime may indicate TeNB subframe 710 as the starting subframe for the UL grant.

[0092] The UE 502 may calculate the SFN and subframe index corresponding to the SeNB 504, at which the UE should start UL based on the combination of timing difference between the cells (e.g., timing difference 712, which may be available to the UE 502 based on measurements it had performed) and information contained in ul-StartTime. Since source and target eNBs may have misaligned subframe boundaries, a rule on how to map source eNB timing to target eNB may be defined. As the TeNB subframe (e.g., 710) may overlap with two SeNB subframes in time domain (e.g., 706 and 708), there may be several options as to which SeNB subframe the UE may select:

[0093] (1) The earlier subframe whenever the overlap starts. As seen in FIG. 7, the overlap with subframe 710 may include SFs 706 and 708. The earlier subframe 706 may be selected.

[0094] (2) The later one (i.e., the second overlapped subframe). Under this option, the second subframe 708 may be selected as a SeNB subframe corresponding to subframe 710.

[0095] (3) Whichever subframe corresponding to SeNB is overlapped more with the TeNB subframe. As seen in FIG. 7, region 714 (which overlaps with subframe 706) is bigger than region 716 (which overlaps with SeNB subframe 708); therefore, subframe 706 may be selected as the corresponding
5 SeNB subframe.

[0096] The same rule needs to be followed by the TeNB to ensure the timing of UL grant provided by the TeNB (i.e., when it is expecting transmission from the UE) is aligned with what the UE calculates and uses for actual transmission. Given that there may be a difference between the timing-
10 difference-estimations by the UE and the source and/or target eNB, the UE and eNB subframe boundaries may be misaligned after the calculations. For example, if the subframes are overlapped only for 5 microseconds in UE's estimation but perfectly aligned according to TeNB's estimation (due to estimation errors in either or both nodes), the UE may mis-interpret and
15 transmit on the wrong subframe. On the other hand, if the third option above is used, similar mis-interpretation can occur when the overlap is around 50%. Therefore, the above options can be further enhanced by using a fourth option to estimate the corresponding SeNB subframe:

[0097] (4) In instances when the overlapping subframe ratio is larger than a certain threshold (e.g. 75%, 80% etc.), then the UE 502 can select the subframe which has the larger overlap; otherwise, the UE may select the earlier subframe whenever the overlap starts, or the later one (i.e., the second overlapped subframe). The threshold may be predefined or configurable by network signaling (e.g., RRC signaling) to the UE.
20

[0098] Alternatively, the TeNB 506 can calculate the start time in terms of SeNB subframe based on timing difference and signal it to the UE by including it in the HO command (e.g., 518). Under this example, the TeNB 506 and the UE 502 may follow the same rule on deciding on which of the overlapped subframes to select (i.e., the above four options for SeNB
25 subframe selection can be used here as well).
30

[0099] In another example, the TeNB 506 may provide a periodic UL grant 517 for use by the UE 502 in the form of a Semi-Persistent Scheduling (SPS) UL grant configuration, which may be included in the Mobility Control

Information inside message 518. The benefit of reusing SPS-like UL configuration is that it can provide the periodic UL, maximum number of skipped UL (with implicit release), configurable periodicity as well as two interval configuration, in instances when periodic transmissions and periodic UL allocation are used. FIG. 8 illustrates another example Mobility Control Information signaling which can be used in instances of reusing SPS configuration messaging to provide UL grant information to the UE. The additional signaling associated with UL grant based on SPS configuration messages is referenced as 810 in FIG. 8.

10 **[00100]** Referring to FIG. 8, the ul-ConfigInfo, ul-StartTime, ul-StartSFN, and ul-StartSubframe may be the same as the corresponding parameters described above in reference to FIG. 6 (implicitReleaseAfter and schedInterval may be omitted in this scenario as these fields are already included in the SPS configuration message). Additionally, TeNB-to-SeNB
15 subframe mapping may be used here as well, similar to the subframe determination techniques (four options) described above, although the scope of the embodiments is not limited in this respect.

[00101] Handover Subframe information in the Handover Command

[00102] In an example, a handover subframe (HO subframe) may be
20 used to reduce the service interruption time of the UE. More specifically, the HO subframe may indicate a subframe index that is sent to the UE to indicate when the UE should stop reception from the source eNB and start listening to target eNB for UL grant. Alternatively, the HO subframe may indicate a subframe index when the UE should stop reception from the source eNB. The
25 target eNB may reserve the UL resources for the UE starting at the HO subframe, and the UE may start communicating to target eNB starting at the HO subframe. The subframe index may be an index to an SFN and subframe of the SeNB, or SFN and subframe associated with the TeNB. In instances when the HO subframe indicates TeNB subframe, then a mapping procedure
30 may be performed, as described in reference to FIG. 7 above. By providing information indicative of when the UE can stop reception from the source eNB and start listening to target eNB for UL grant or start communicating with

target eNB as described above, the service interruption time (e.g., from receiving 518 to sending 524 in FIG. 5) may be reduced.

[00103] In an example, the SeNB 504 may suggest a “handover subframe” index for consideration by the TeNB 506 by including it in the handover request message 514 (FIG. 5). Alternatively, the SeNB 504 may signal the HO subframe index value to the TeNB 506 using a separate message. There may be multiple options as to how the TeNB 506 takes this information into account:

[00104] (1) The TeNB 506 may accept this value and include the HO subframe in the HO request acknowledgment (i.e., 516). Alternatively, the TeNB may signal the HO subframe index value to the SeNB 504 using a separate message.

[00105] (2) The TeNB 506 may reject the HO subframe value suggested by the SeNB because of admission control or other reasons, but can calculate a new HO subframe index value on its own and include it in the HO request acknowledgment 516. Alternatively, the TeNB 506 may negotiate the handover subframe with the SeNB before deciding and including it in the HO request acknowledgment. Alternatively, the TeNB may signal the HO subframe index value to the SeNB 504 using a separate message.

[00106] In another example, the TeNB 506 may decide a HO subframe indicating when the UE may start listening to the TeNB for an uplink grant. When the TeNB 506 sends the handover acknowledgement (516) to the SeNB 504, it may include the HO subframe information in the acknowledgement message 516. The TeNB 506 may also signal this value to the SeNB 504 separately, or alternatively, the SeNB 504 can look into the HO acknowledgement (516) for this value. Source eNB may stop downlink transmission to the UE starting at the “handover subframe” signaled by the target eNB and the UE may stop reception from the source eNB at the handover subframe. The UE may then start listening to the target eNB for an UL grant. Alternatively, the target eNB may reserve the UL resources for the UE starting at the HO subframe, and the UE may start communicating to target eNB starting at the HO subframe.

[00107] In another example, the SeNB 504 and the TeNB 506 may negotiate the HO subframe back and forth, in instances when the TeNB 506 cannot accept the handover subframe suggested by the SeNB 504 or vice versa. The agreed upon handover subframe may then be sent to the UE in the
5 Mobility Control Information in message 518.

[00108] FIG. 9 is a flow diagram illustrating example functionalities for handover enhancements to reduce interruption time and handover latency according to some embodiments. Referring to FIGS. 5 and 9, the example method 900 may be performed by an apparatus of an evolved Node B (eNB)
10 configured to operate as a source eNB (SeNB) and communicate with a target evolved Node B (TeNB) and user equipment (UE). At 910, the SeNB may decode a handover request acknowledgement message from the TeNB in response to a handover request. The handover request acknowledgement message may include an uplink (UL) resource grant by the TeNB for the UE.
15 At 920, a Mobility Control Information message may be updated with the UL resource grant. At 930, the Mobility Control Information message may be encoded in an RRC Connection Reconfiguration message for transmission to the UE. In an example, the RRC Connection Reconfiguration message may be configured to instruct the UE to use the UL resource grant of the TeNB to
20 initiate handover from the SeNB to the TeNB without using random access channel (RACH) acquisition from the TeNB.

[00109] FIG. 10 illustrates a block diagram of a communication device such as an eNB or a UE, in accordance with some embodiments. In alternative embodiments, the communication device 1000 may operate as a
25 standalone device or may be connected (e.g., networked) to other communication devices. In a networked deployment, the communication device 1000 may operate in the capacity of a server communication device, a client communication device, or both in server-client network environments. In an example, the communication device 1000 may act as a peer
30 communication device in peer-to-peer (P2P) (or other distributed) network environment. The communication device 1000 may be a UE, eNB, PC, a tablet PC, a STB, a PDA, a mobile telephone, a smart phone, a web appliance, a network router, switch or bridge, or any communication device capable of

executing instructions (sequential or otherwise) that specify actions to be taken by that communication device. Further, while only a single communication device is illustrated, the term "communication device" shall also be taken to include any collection of communication devices that individually or jointly
5 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.

[00110] Examples, as described herein, may include, or may operate on, logic or a number of components, modules, or mechanisms. Modules are
10 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
15 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 communication device readable medium. In an example, the software, when executed by the underlying
20 hardware of the module, causes the hardware to perform the specified operations.

[00111] 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.,
25 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
30 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.

[00112] Communication device (e.g., UE) 1000 may include a hardware processor 1002 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 1004 and a static memory 1006, some or all of which may
5 communicate with each other via an interlink (e.g., bus) 1008. The communication device 1000 may further include a display unit 1010, an alphanumeric input device 1012 (e.g., a keyboard), and a user interface (UI) navigation device 1014 (e.g., a mouse). In an example, the display unit 1010, input device 1012 and UI navigation device 1014 may be a touch screen
10 display. The communication device 1000 may additionally include a storage device (e.g., drive unit) 1016, a signal generation device 1018 (e.g., a speaker), a network interface device 1020, and one or more sensors 1021, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The communication device 1000 may include an output controller
15 1028, 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.).

[00113] The storage device 1016 may include a communication device
20 readable medium 1022 on which is stored one or more sets of data structures or instructions 1024 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 1024 may also reside, completely or at least partially, within the main memory 1004, within static memory 1006, or within the hardware processor 1002 during
25 execution thereof by the communication device 1000. In an example, one or any combination of the hardware processor 1002, the main memory 1004, the static memory 1006, or the storage device 1016 may constitute communication device readable media.

[00114] While the communication device readable medium 1022 is
30 illustrated as a single medium, the term "communication device readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) configured to store the one or more instructions 1024.

[00115] The term "communication device readable medium" may include any medium that is capable of storing, encoding, or carrying instructions for execution by the communication device 1000 and that cause the communication device 1000 to perform any one or more of the techniques of the present disclosure, or that is capable of storing, encoding or carrying data structures used by or associated with such instructions. Non-limiting communication device readable medium examples may include solid-state memories, and optical and magnetic media. Specific examples of communication device readable media may include: non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; Random Access Memory (RAM); and CD-ROM and DVD-ROM disks. In some examples, communication device readable media may include non-transitory communication device readable media. In some examples, communication device readable media may include communication device readable media that is not a transitory propagating signal.

[00116] The instructions 1024 may further be transmitted or received over a communications network 1026 using a transmission medium via the network interface device 1020 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 1020 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 1026. In an example, the network interface device 1020 may include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), MIMO, or multiple-input
5 single-output (MISO) techniques. In some examples, the network interface device 1020 may wirelessly communicate using Multiple User MIMO techniques. The term "transmission medium" shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution by the communication device 1000, and includes digital or
10 analog communications signals or other intangible medium to facilitate communication of such software.

[00117] Additional notes and examples:

[00118] Example 1 is an apparatus of a user equipment (UE) configured to communicate with a source evolved Node B (SeNB) and a target evolved
15 Node B (TeNB), the UE comprising: memory; and processing circuitry coupled to the memory, the processing circuitry configured to: acquire a Mobility Control Information message within an RRC Connection Reconfiguration message received from the SeNB in response to a handover decision; determine uplink (UL) resource grant based on the Mobility Control
20 Information message; and engage in handover from the SeNB to the TeNB based on the UL resource grant, without initiating random access channel (RACH) acquisition from the TeNB.

[00119] In Example 2, the subject matter of Example 1 optionally includes wherein the processing circuitry is further configured to: perform
25 synchronization to the TeNB using UL resources specified by the UL resource grant.

[00120] In Example 3, the subject matter of any one or more of Examples 1–2 optionally include wherein the processing circuitry is further configured to: decode synchronization information from the TeNB without the
30 RACH acquisition.

[00121] In Example 4, the subject matter of any one or more of Examples 2–3 optionally include wherein the processing circuitry is further

configured to: communicate an RRC Connection Reconfiguration Complete message to the TeNB to confirm the handover.

5 **[00122]** In Example 5, the subject matter of any one or more of Examples 1–4 optionally include wherein the Mobility Control Information message comprises a field defining the UL resource grant.

10 **[00123]** In Example 6, the subject matter of any one or more of Examples 1–5 optionally include wherein the Mobility Control Information message comprises: an Implicit Release field defining a number of skipped transmissions by the UE to the TeNB before the UL resource grant is withdrawn.

[00124] In Example 7, the subject matter of any one or more of Examples 1–6 optionally include wherein the Mobility Control Information message comprises: a Scheduling Interval field defining periodicity of the UL resource grant available to the UE.

15 **[00125]** In Example 8, the subject matter of any one or more of Examples 1–7 optionally include wherein the Mobility Control Information message comprises: a UL Start Time field defining a TeNB system frame number (SFN) and a TeNB subframe index at which the UL resource grant starts.

20 **[00126]** In Example 9, the subject matter of Example 8 optionally includes wherein the processing circuitry is further configured to: calculate a SeNB SFN and a SeNB subframe index at which UL allocation starts, the SeNB SFN and the SeNB subframe index corresponding to the TeNB SFN and the TeNB subframe index respectively; and engage in the handover from
25 the SeNB to the TeNB based on the calculated SeNB SFN and SeNB subframe index.

[00127] In Example 10, the subject matter of any one or more of Examples 1–9 optionally include wherein the Mobility Control Information message comprises: a UL Start Offset field defining a timing offset, the timing
30 offset indicating a subsequent time at which the UL resource grant starts.

[00128] In Example 11, the subject matter of any one or more of Examples 1–10 optionally include wherein the Mobility Control Information

message comprises: a Semi-Persistent Scheduling (SPS) message defining the UL resource grant.

[00129] In Example 12, the subject matter of any one or more of Examples 1–11 optionally include wherein the processing circuitry is further
5 configured to: determine downlink propagation delay difference between the SeNB and the TeNB; and determine timing advance (TA) for the handover to the TeNB based on the downlink propagation delay difference.

[00130] In Example 13, the subject matter of any one or more of Examples 1–12 optionally include wherein the processing circuitry is further
10 configured to: initiate RACH acquisition from the TeNB for handover, upon determining the Mobility Control Information message does not contain the UL resource grant information.

[00131] In Example 14, the subject matter of any one or more of Examples 1–13 optionally include a transceiver coupled to an antenna, the
15 transceiver configured to receive the RRC Connection Reconfiguration message from the SeNB.

[00132] Example 15 is an apparatus of an evolved Node B (eNB) configured to operate as a source eNB (SeNB) and communicate with a target evolved Node B (TeNB) and user equipment (UE), the apparatus comprising:
20 memory; and processing circuitry, the processing circuitry configured to: decode a handover request acknowledgement message from the TeNB in response to a handover request, the handover request acknowledgement message comprising an uplink (UL) resource grant by the TeNB for the UE; update a Mobility Control Information message with the UL resource grant;
25 and encode the Mobility Control Information message in an RRC Connection Reconfiguration message for transmission to the UE, wherein the RRC Connection Reconfiguration message is configured to instruct the UE to use the UL resource grant of the TeNB to initiate handover from the SeNB to the TeNB without using random access channel (RACH) acquisition from the
30 TeNB.

[00133] In Example 16, the subject matter of Example 15 optionally includes wherein the processing circuitry is further configured to: encode the

UL resource grant as a Semi-Persistent Scheduling (SPS) message inside the Mobility Control Information message.

[00134] In Example 17, the subject matter of any one or more of Examples 15–16 optionally include wherein the processing circuitry is further
5 configured to: encode a handover subframe in the handover request for transmission to the TeNB, the handover subframe comprising an index of a SeNB subframe and/or SeNB SFN.

[00135] In Example 18, the subject matter of Example 17 optionally includes wherein the SeNB subframe indicates a subframe at which the UE is
10 to stop transmission to the SeNB and initiate listening to the TeNB for the UL resource grant.

[00136] In Example 19, the subject matter of any one or more of Examples 17–18 optionally include wherein the SeNB subframe indicates a subframe at which the UE is to stop transmission to the SeNB and use an UL
15 grant starting from the subframe.

[00137] In Example 20, the subject matter of any one or more of Examples 18–19 optionally include wherein the handover request acknowledgement message from the TeNB includes information of the handover subframe.

20 **[00138]** In Example 21, the subject matter of any one or more of Examples 18–20 optionally include wherein the processing circuitry is configured to decode a message from the TeNB with information of the handover subframe.

[00139] In Example 22, the subject matter of any one or more of
25 Examples 20–21 optionally include wherein the processing circuitry is further configured to: upon receiving the handover request acknowledgement message with the handover subframe information, encode the handover subframe in the RRC Connection Reconfiguration message for transmission to the UE.

[00140] In Example 23, the subject matter of any one or more of
30 Examples 17–22 optionally include wherein the handover request acknowledgement message from the TeNB includes a new handover subframe provided by the TeNB, in place of the handover subframe provided by the SeNB.

[00141] In Example 24, the subject matter of Example 23 optionally includes wherein the new handover subframe comprises an index of a TeNB subframe, at which the UE is to stop transmission to the SeNB and initiate listening to the TeNB for the UL resource grant.

5 [00142] In Example 25, the subject matter of any one or more of Examples 15–24 optionally include a transceiver coupled to an antenna, the transceiver configured to transmit the RRC Connection Reconfiguration message to the UE.

[00143] Example 26 is a computer-readable storage medium that stores
10 instructions for execution by one or more processors of an evolved Node B (eNB) configured to operate as a target eNB (TeNB) and communicate with a source evolved Node B (SeNB) and user equipment (UE), the one or more processors to configure the TeNB to: in response to a handover request from the SeNB, generate a handover request acknowledgement message to the
15 SeNB, the handover request acknowledgement message comprising: configuration information for an uplink (UL) resource grant to the UE for performing a handover; periodicity information identifying when the UL resource grant is available to the UE; and a TeNB system frame number (SFN) and a TeNB subframe index at which the UL resource grant starts; and
20 determine the handover has completed based on a RRC Connection Reconfiguration Complete message received from the UE.

[00144] In Example 27, the subject matter of Example 26 optionally includes wherein the handover request acknowledgement message further comprises: information defining a number of skipped transmissions by the UE
25 to the TeNB before the UL resource grant is withdrawn.

[00145] In Example 28, the subject matter of any one or more of Examples 26–27 optionally include wherein the one or more processors further configure the TeNB to: receive synchronization information from the UE for performing the handover, without using random access channel
30 (RACH) procedure with the UE.

[00146] Example 29 is an apparatus of an evolved Node B (eNB) configured to operate as a target eNB (TeNB) and communicate with a source evolved Node B (SeNB) and user equipment (UE), the apparatus comprising:

means for generating a handover request acknowledgement message to the SeNB, the generating in response to a handover request from the SeNB, wherein the handover request acknowledgement message comprises: configuration information for an uplink (UL) resource grant to the UE for performing a handover; periodicity information identifying when the UL resource grant is available to the UE; and a TeNB system frame number (SFN) and a TeNB subframe index at which the UL resource grant starts; and means for determining the handover has completed based on a RRC Connection Reconfiguration Complete message received from the UE.

- 10 **[00147]** In Example 30, the subject matter of Example 29 optionally includes wherein the handover request acknowledgement message further comprises: information defining a number of skipped transmissions by the UE to the TeNB before the UL resource grant is withdrawn.

- 15 **[00148]** In Example 31, the subject matter of any one or more of Examples 29–30 optionally include wherein the apparatus further comprises: means for receiving synchronization information from the UE for performing the handover, without using random access channel (RACH) procedure with the UE.

- 20 **[00149]** The above detailed description includes references to the accompanying drawings, which form a part of the detailed description. The drawings show, by way of illustration, specific embodiments that may be practiced. These embodiments are also referred to herein as “examples.” Such examples may include elements in addition to those shown or described. However, also contemplated are examples that include the elements shown or described. Moreover, also contemplated are examples using any combination or permutation of those elements shown or described (or one or more aspects thereof), either with respect to a particular example (or one or more aspects thereof), or with respect to other examples (or one or more aspects thereof) shown or described herein.

- 30 **[00150]** Publications, patents, and patent documents referred to in this document are incorporated by reference herein in their entirety, as though individually incorporated by reference. In the event of inconsistent usages between this document and those documents so incorporated by reference, the

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

[00151] In this document, the terms “a” or “an” are used, as is common
5 in patent documents, to include one or more than one, independent of any other instances or usages of “at least one” or “one or more.” In this document, the term “or” is used to refer to a nonexclusive or, such that “A or B” includes “A but not B,” “B but not A,” and “A and B,” unless otherwise indicated. In the appended claims, the terms “including” and “in which” are used as the
10 plain-English equivalents of the respective terms “comprising” and “wherein.” Also, in the following claims, the terms “including” and “comprising” are open-ended, that is, a system, device, article, or process that includes elements in addition to those listed after such a term in a claim are still deemed to fall within the scope of that claim. Moreover, in the following claims, the terms
15 “first,” “second,” and “third,” etc. are used merely as labels, and are not intended to suggest a numerical order for their objects.

[00152] The above description is intended to be illustrative, and not restrictive. For example, the above-described examples (or one or more aspects thereof) may be used in combination with others. Other embodiments
20 may be used, such as by one of ordinary skill in the art upon reviewing the above description. The Abstract is to allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. Also, in the above Detailed Description, various features may be grouped together to streamline the disclosure. However, the claims may not set forth every feature
25 disclosed herein as embodiments may feature a subset of said features. Further, embodiments may include fewer features than those disclosed in a particular example. Thus, the following claims are hereby incorporated into the Detailed Description, with a claim standing on its own as a separate
30 embodiment. The scope of the embodiments disclosed herein is to be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

CLAIMS

What is claimed is:

1. An apparatus of a user equipment (UE) configured to communicate
5 with a source evolved Node B (SeNB) and a target evolved Node B (TeNB),
the UE comprising:
memory; and
processing circuitry coupled to the memory, the processing circuitry
configured to:
10 acquire a Mobility Control Information message within an RRC
Connection Reconfiguration message received from the SeNB in
response to a handover decision;
determine uplink (UL) resource grant based on the Mobility
Control Information message; and
15 engage in handover from the SeNB to the TeNB based on the
UL resource grant, without initiating random access channel (RACH)
acquisition from the TeNB.
2. The apparatus of claim 1, wherein the processing circuitry is further
20 configured to:
perform synchronization to the TeNB using UL resources specified by
the UL resource grant.
3. The apparatus of claim 2, wherein the processing circuitry is further
25 configured to:
communicate an RRC Connection Reconfiguration Complete message
to the TeNB to confirm the handover.
4. The apparatus of claim 1, wherein the Mobility Control Information
30 message comprises a field defining the UL resource grant.

5. The apparatus of claim 1, wherein the Mobility Control Information message comprises:
an Implicit Release field defining a number of skipped transmissions by the UE to the TeNB before the UL resource grant is withdrawn.
- 5
6. The apparatus of claim 1, wherein the Mobility Control Information message comprises:
a Scheduling Interval field defining periodicity of the UL resource grant available to the UE.
- 10
7. The apparatus of claim 1, wherein the Mobility Control Information message comprises:
a UL Start Time field defining a TeNB system frame number (SFN) and a TeNB subframe index at which the UL resource grant starts.
- 15
8. The apparatus of claim 7, wherein to engage in the handover from the SeNB to the TeNB, the processing circuitry is further configured to:
calculate a SeNB SFN and a SeNB subframe index at which UL allocation starts, the SeNB SFN and the SeNB subframe index corresponding
20 to the TeNB SFN and the TeNB subframe index respectively; and
engage in the handover from the SeNB to the TeNB based on the calculated SeNB SFN and SeNB subframe index.
9. The apparatus of claim 1, wherein the Mobility Control Information
25 message comprises:
a UL Start Offset field defining a timing offset, the timing offset indicating a subsequent time at which the UL resource grant starts.
10. The apparatus of claim 1, wherein the Mobility Control Information
30 message comprises:
a Semi-Persistent Scheduling (SPS) message defining the UL resource grant.

11. The apparatus of claim 1, wherein the processing circuitry is further configured to:
- determine downlink propagation delay difference between the SeNB and the TeNB; and
 - 5 determine timing advance (TA) for the handover to the TeNB based on the downlink propagation delay difference.
12. The apparatus of claim 1, wherein the processing circuitry is further configured to:
- 10 initiate RACH acquisition from the TeNB for handover, upon determining the Mobility Control Information message does not contain the UL resource grant information.
13. The apparatus of claim 1, further comprising:
- 15 a transceiver coupled to an antenna, the transceiver configured to receive the RRC Connection Reconfiguration message from the SeNB.
14. An apparatus of an evolved Node B (eNB) configured to operate as a source eNB (SeNB) and communicate with a target evolved Node B (TeNB) and user equipment (UE), the apparatus comprising:
- 20 memory; and
- processing circuitry, the processing circuitry configured to:
- decode a handover request acknowledgement message from the TeNB in response to a handover request, the handover request
 - 25 acknowledgement message comprising an uplink (UL) resource grant by the TeNB for the UE;
 - update a Mobility Control Information message with the UL resource grant; and
 - encode the Mobility Control Information message in an RRC
 - 30 Connection Reconfiguration message for transmission to the UE,
 - wherein the RRC Connection Reconfiguration message is configured to instruct the UE to use the UL resource grant of the TeNB to initiate handover from the SeNB to the TeNB without using random access channel (RACH) acquisition from the TeNB.

15. The apparatus of claim 14, wherein the processing circuitry is further configured to:
 encode the UL resource grant as a Semi-Persistent Scheduling (SPS)
5 message inside the Mobility Control Information message.
16. The apparatus of claim 14, wherein the processing circuitry is further configured to:
 encode a handover subframe in the handover request for transmission
10 to the TeNB, the handover subframe comprising an index of a SeNB subframe and/or SeNB SFN.
17. The apparatus of claim 16, wherein the SeNB subframe indicates a subframe at which the UE is to stop transmission to the SeNB and initiate
15 listening to the TeNB for the UL resource grant.
18. The apparatus of claim 17, wherein the handover request acknowledgement message from the TeNB includes information of the handover subframe.
20
19. The apparatus of claim 18, wherein the processing circuitry is further configured to:
 upon receiving the handover request acknowledgement message with
the handover subframe information, encode the handover subframe in the
25 RRC Connection Reconfiguration message for transmission to the UE.
20. The apparatus of claim 16, wherein the handover request acknowledgement message from the TeNB includes a new handover subframe provided by the TeNB, in place of the handover subframe provided by the
30 SeNB.

21. The apparatus of claim 20, wherein the new handover subframe comprises an index of a TeNB subframe, at which the UE is to stop transmission to the SeNB and initiate listening to the TeNB for the UL resource grant.
- 5
22. The apparatus of claim 14, further comprising:
a transceiver coupled to an antenna, the transceiver configured to transmit the RRC Connection Reconfiguration message to the UE.
- 10 23. A computer-readable storage medium that stores instructions for execution by one or more processors of an evolved Node B (eNB) configured to operate as a target eNB (TeNB) and communicate with a source evolved Node B (SeNB) and user equipment (UE), the one or more processors to configure the TeNB to:
- 15 in response to a handover request from the SeNB, generate a handover request acknowledgement message to the SeNB, the handover request acknowledgement message comprising:
- configuration information for an uplink (UL) resource grant to the UE for performing a handover;
- 20 periodicity information identifying when the UL resource grant is available to the UE; and
- a TeNB system frame number (SFN) and a TeNB subframe index at which the UL resource grant starts; and
- determine the handover has completed based on a RRC Connection Reconfiguration Complete message received from the UE.
- 25
24. The computer-readable storage medium of claim 23, wherein the handover request acknowledgement message further comprises:
- information defining a number of skipped transmissions by the UE to
- 30 the TeNB before the UL resource grant is withdrawn.

25. The computer-readable storage medium of claim 23, wherein the one or more processors further configure the TeNB to:

receive synchronization information from the UE for performing the handover, without using random access channel (RACH) procedure with the

5 UE.

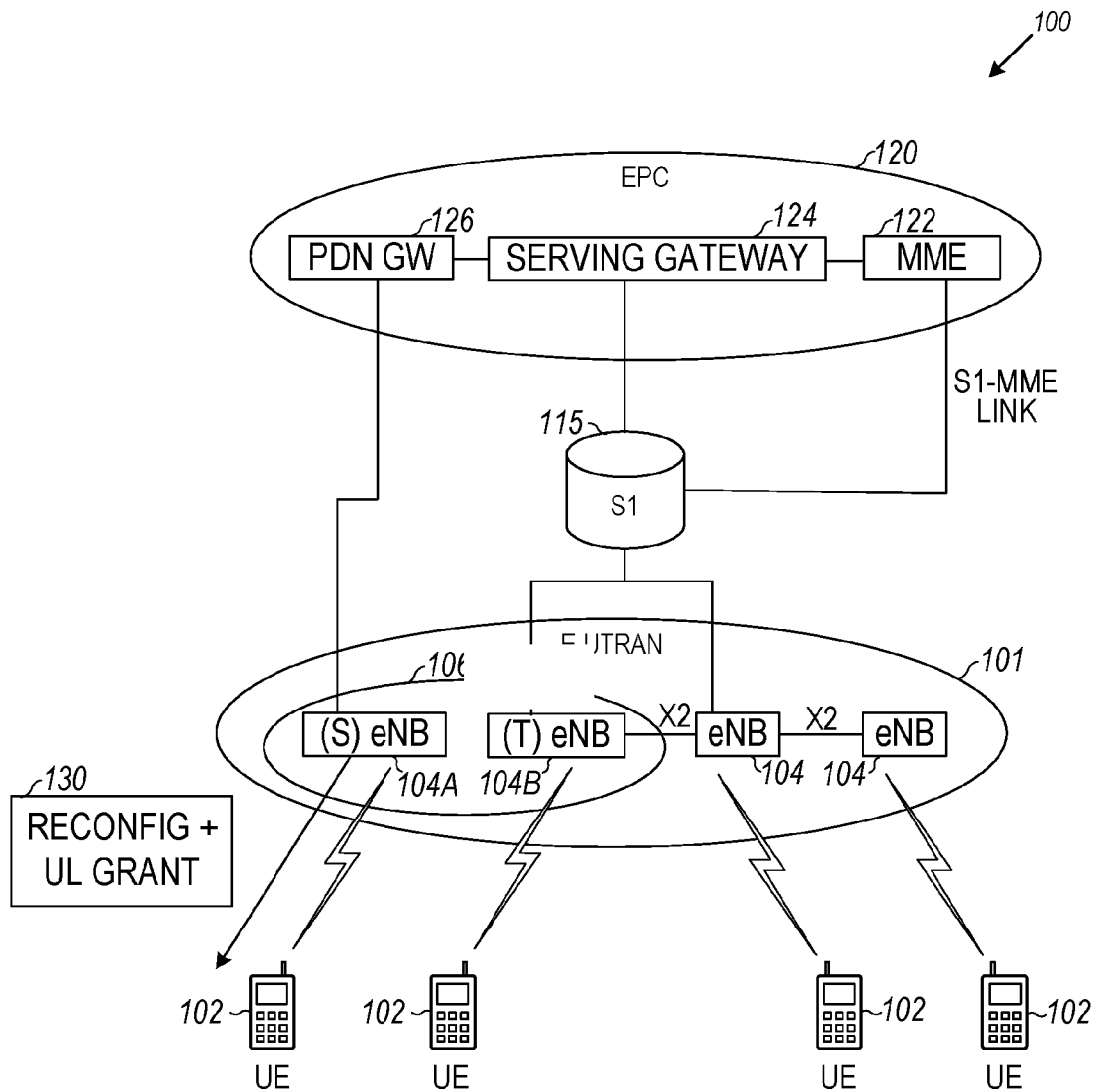


FIG. 1

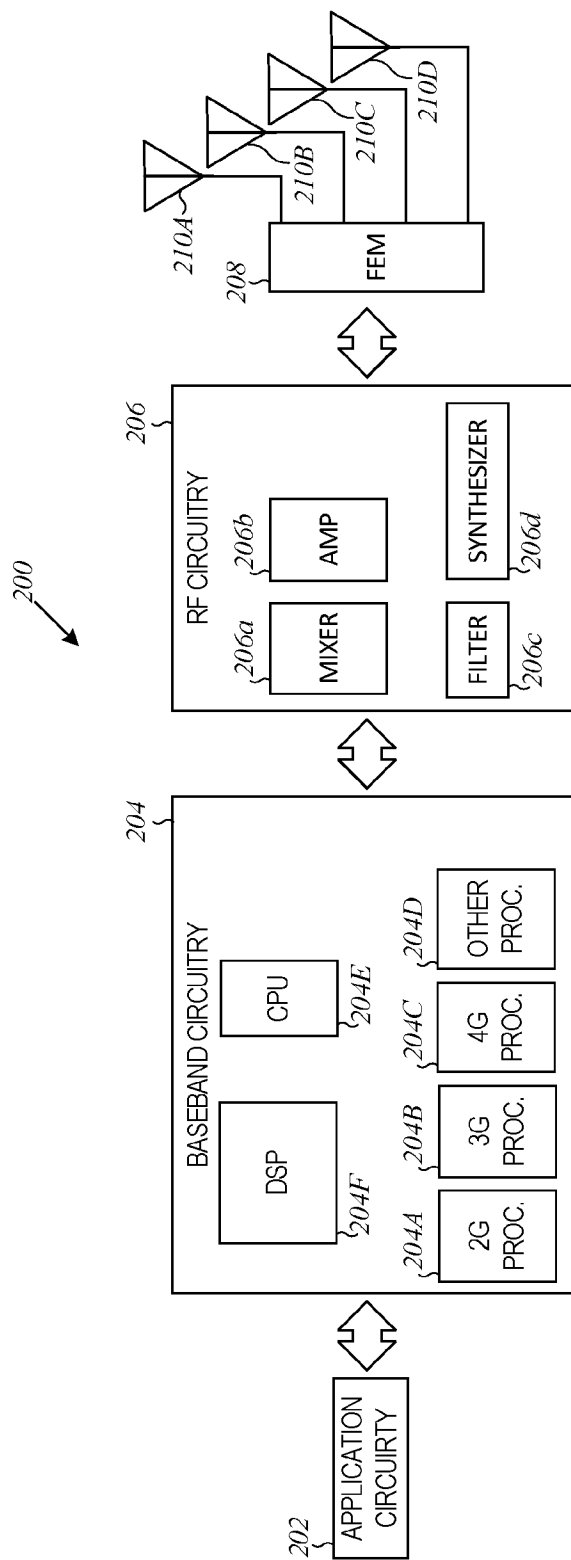


FIG. 2

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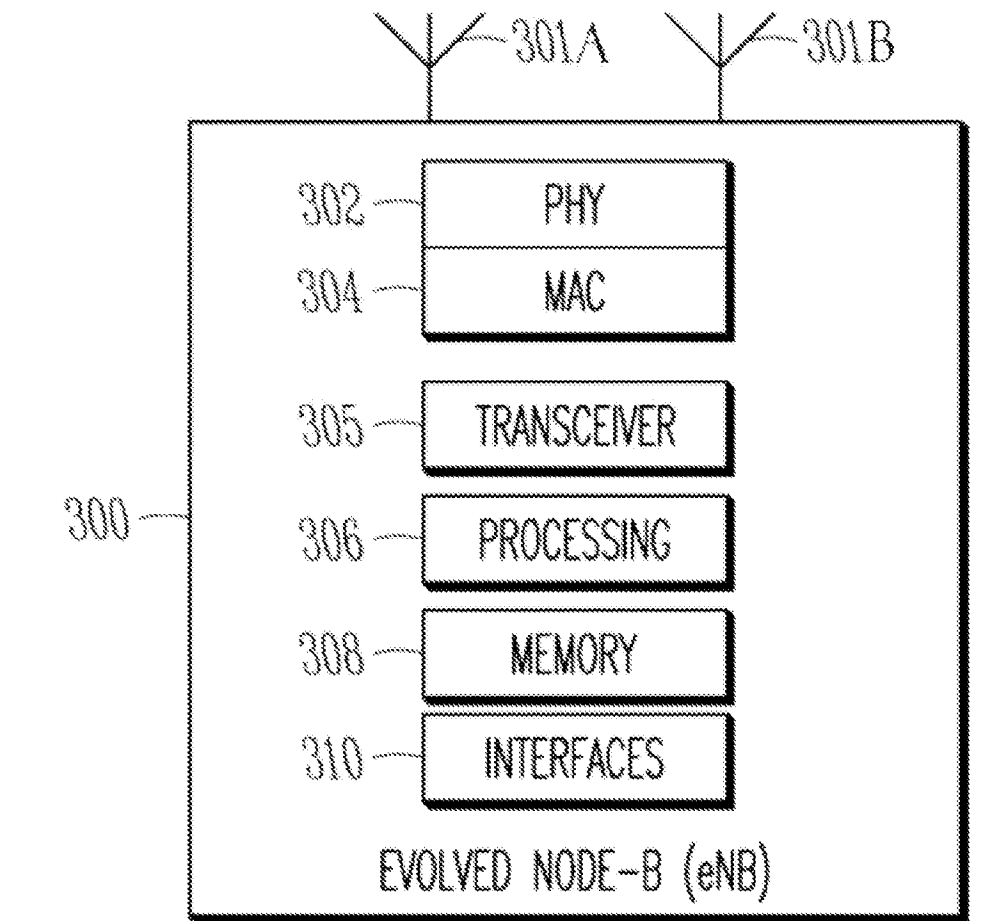


FIG. 3

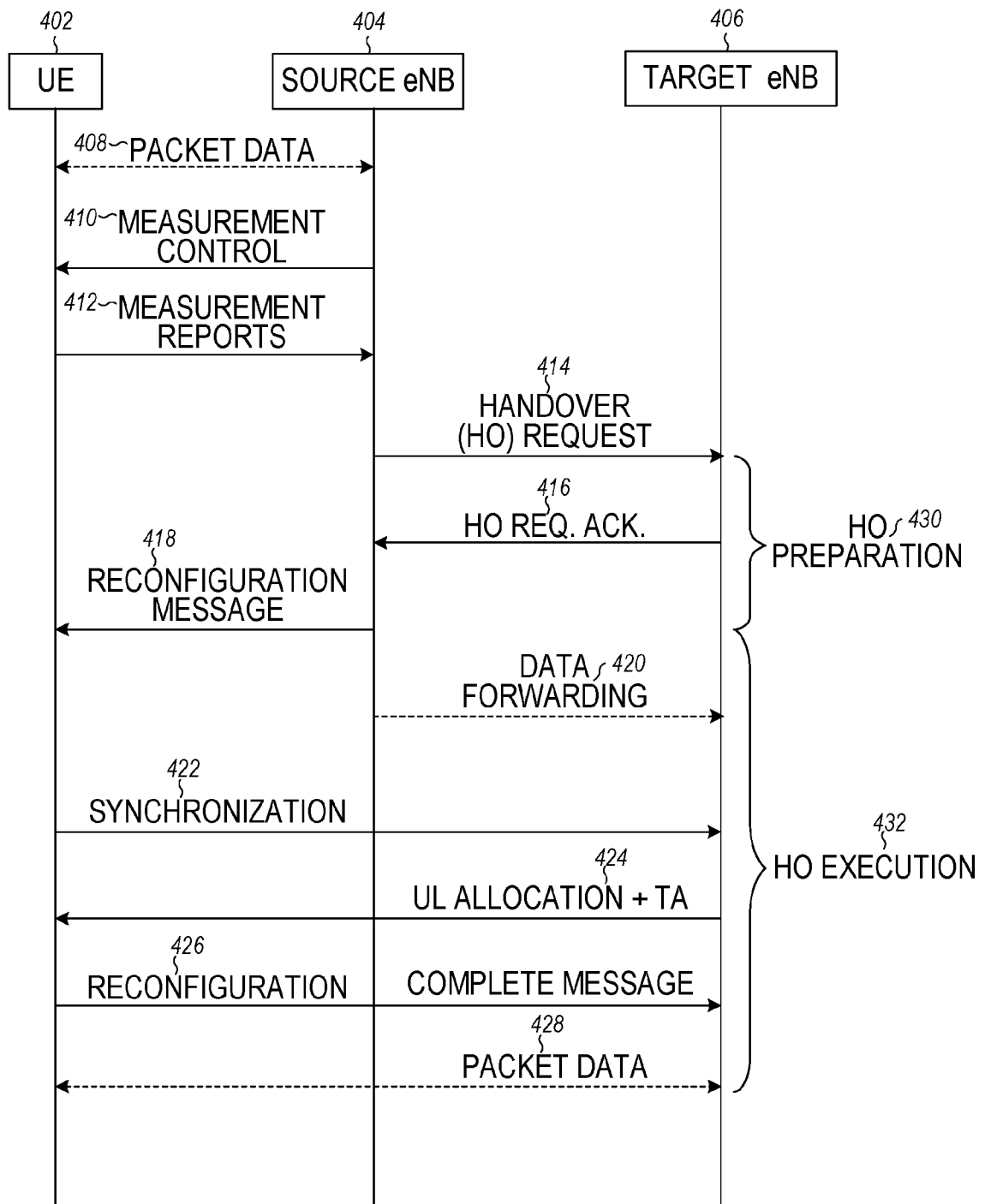


FIG. 4A

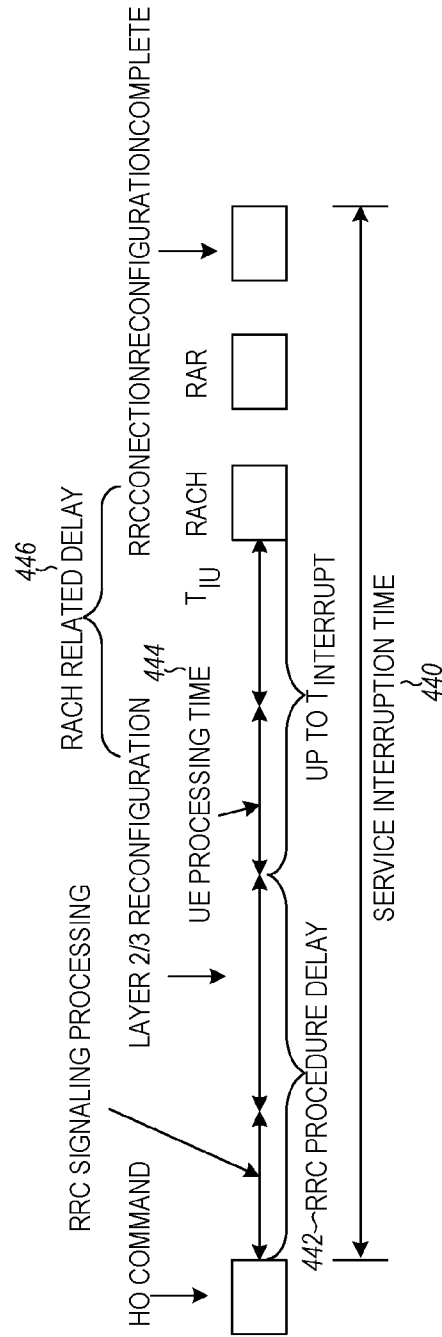


FIG. 4B

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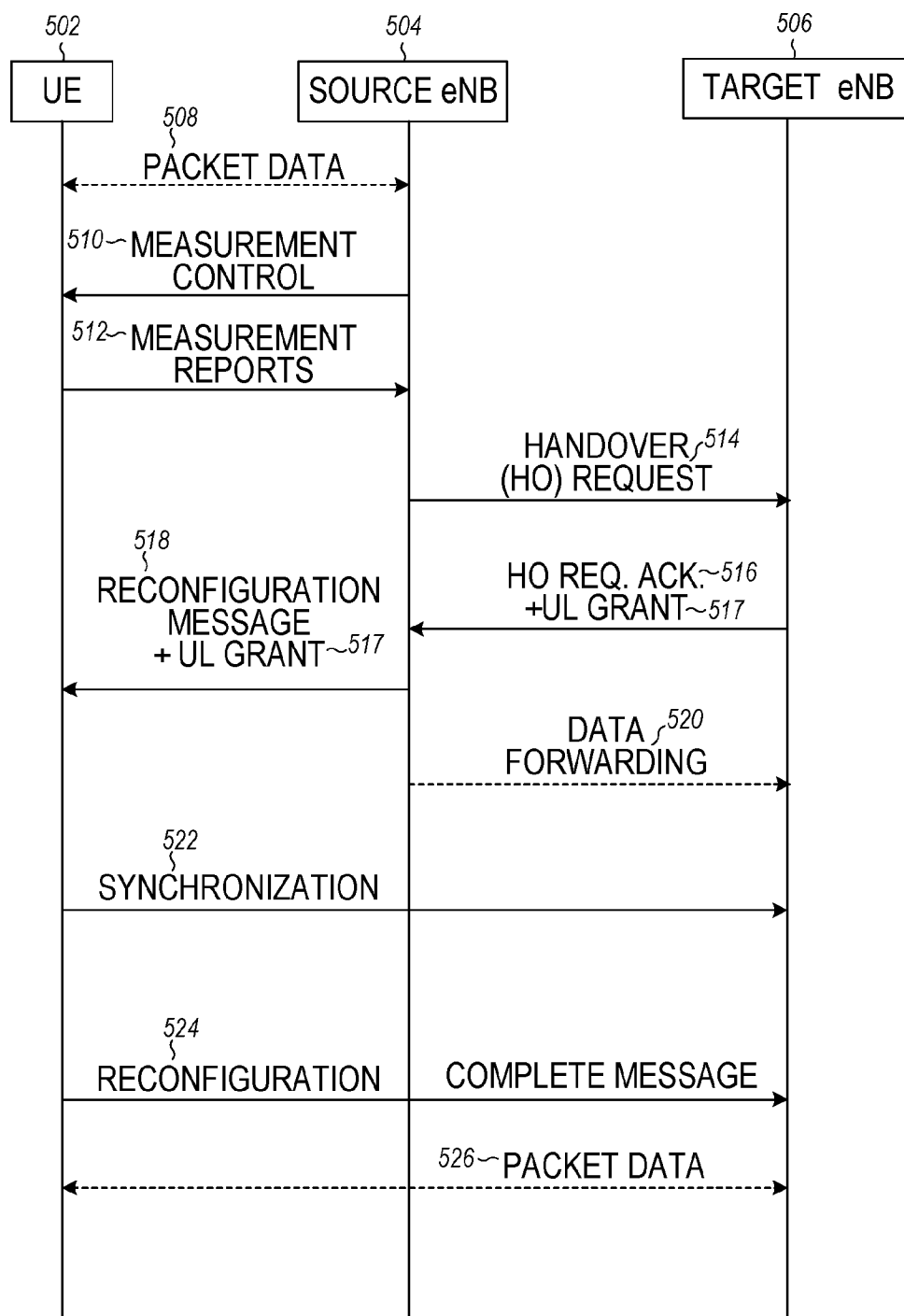


FIG. 5

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```

MobilityControlInfo ::= SEQUENCE {
    targetPhysCellId
    carrierFreq
    carrierBandwidth
    additionalSpectrumEmission
    t304
    newUE-Identity
    radioResourceConfigCommon
    rach-ConfigDedicated
    ...
    carrierFreq-v9e0
    drb-ContinueROHC-r11
    ul-ConfigInfo-r14
    ...
    UL-ConfigInfo-r14 ::= SEQUENCE {
        schedInterval
        ul-StartTime-r14
        ul-StartSFN
        ul-StartSubframe
        ul-StartOffset
        implicitReleaseAfter
    }
}

SEQUENCE {
    PhysCellId,
    CarrierFreqEUTRA
    CarrierBandwidthEUTRA
    AdditionalSpectrumEmission
    ENUMERATED {
        ms50, ms100, ms150, ms200, ms500, ms1000,
        ms2000, spare1},
    C-RNTI,
    RadioResourceConfigCommon,
    RACH-ConfigDedicated
    OPTIONAL, -- Need OP
    CarrierFreqEUTRA-v9e0
    OPTIONAL -- Need ON
    ENUMERATED {true}
    OPTIONAL -- Cond HO
    UL-ConfigInfo-r14
    OPTIONAL -- Need ON
}

SEQUENCE {
    ENUMERATED {
        sf1, sf2, sf3, sf4, sf5, sf10, spare2,
        spare1},
    SEQUENCE {
        INTEGER (0..1023),
        INTEGER (0..9)
    }, OPTIONAL -- Need ON
    ENUMERATED {
        sf1, sf5, sf10, sf20, sf50, sf100, spare2,
        spare1}, OPTIONAL -- Need ON
    ENUMERATED {e2, e3, e4, e8}, OPTIONAL -- Need ON
}

```

FIG. 6

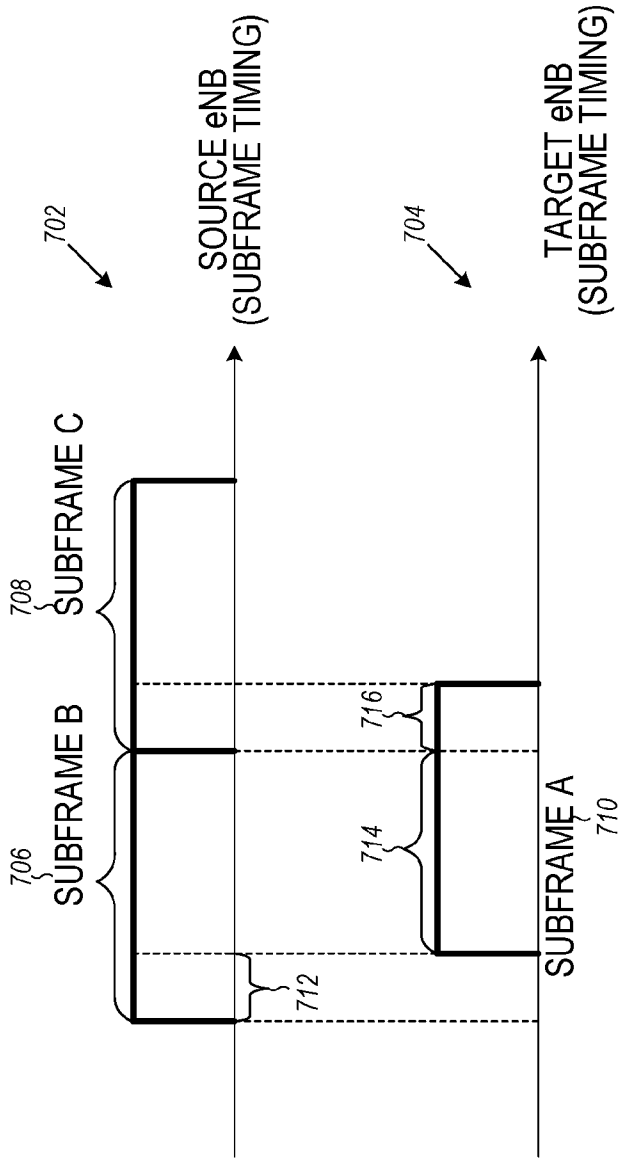


FIG. 7

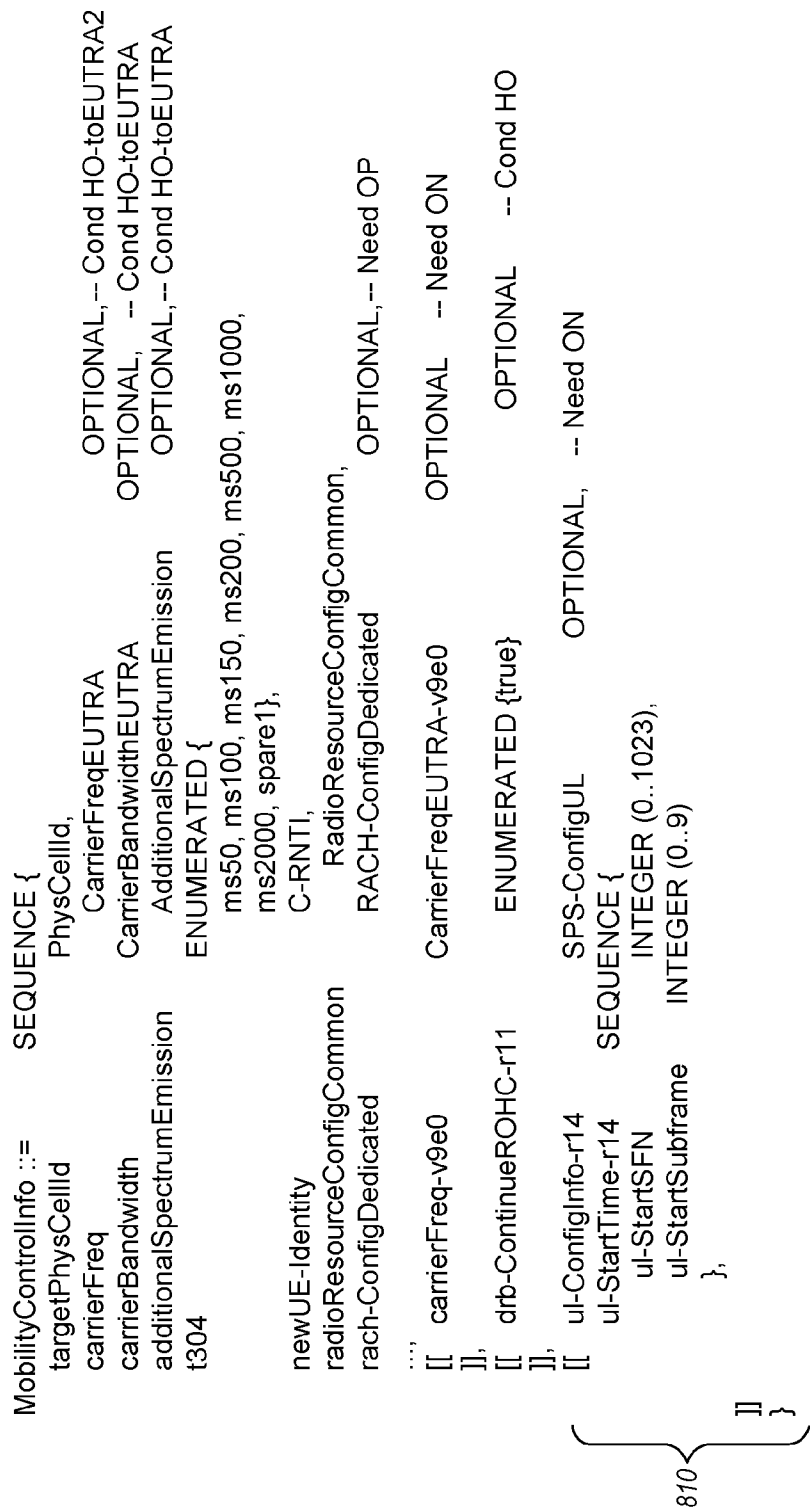


FIG. 8

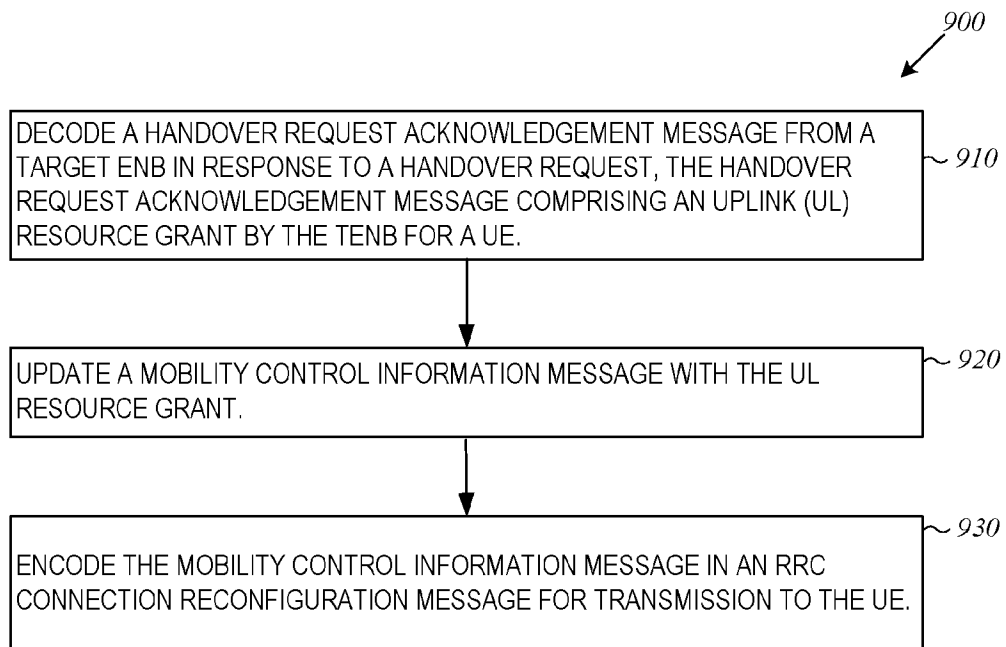


FIG. 9

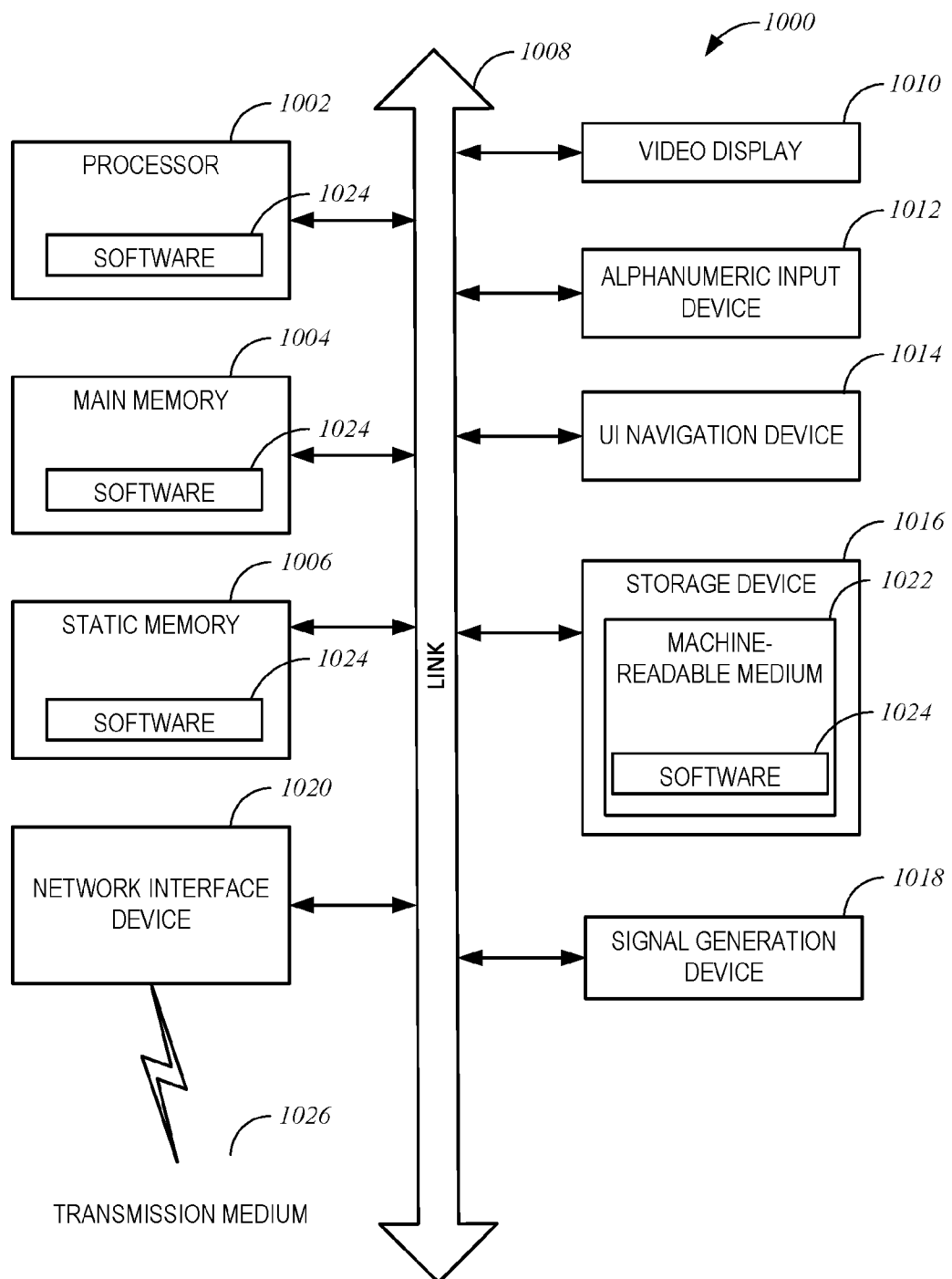


FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2016/040144**A. CLASSIFICATION OF SUBJECT MATTER****H04L 1/00(2006.01)i, H04W 76/04(2009.01)i, H04W 28/02(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)

H04L 1/00; H04L 5/00; H04W 74/08; H04W 88/08; H04W 72/14; H04W 36/30; H04W 36/00; H04W 76/04; H04W 28/02

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: handover, random access channel (RACH) acquisition, uplink resource grant

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015-0319774 A1 (BLACKBERRY LIMITED) 05 November 2015 See paragraphs [0027], [0034]-[0059], [0082]-[0085], [0109]; and figures 4-7.	23-25
Y		1-22
Y	US 2015-0105084 A1 (BLACKBERRY LIMITED) 16 April 2015 See paragraphs [0075], [0082], [0094], [0126], [0166]; and figures 6-10.	1-22
A	US 2016-0007262 A1 (ESMAEL HEJAZI DINAN) 07 January 2016 See paragraphs [0046]-[0089]; and figures 8-11.	1-25
A	US 2016-0088531 A1 (INTEL CORPORATION) 24 March 2016 See paragraphs [0014]-[0028]; and figures 2, 3.	1-25
A	US 2015-0201356 A1 (INTERDIGITAL PATENT HOLDINGS, INC.) 16 July 2015 See paragraphs [0041]-[0055]; and figures 2-4.	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

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"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

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/040144

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