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(54) Title: SOFTWARE DEFINED NETWORK SWITCH AND EVOLVED NODE-B (ENB) FOR MULTIPLE BEARER CONNECTIVITY

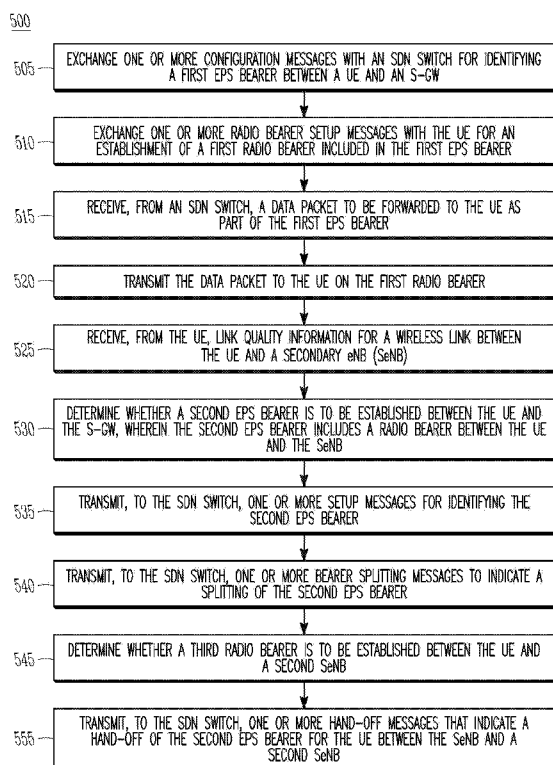


FIG. 5

(57) Abstract: Embodiments of a Master Evolved Node-B (MeNB), a software-defined network (SDN) switch, and methods for multiple bearer connectivity are generally described herein. The MeNB may receive, from a software-defined network (SDN) switch, a data packet to be forwarded to a User Equipment (UE) as part of a first Evolved Packet System (EPS) bearer between a Serving Gateway (S-GW) and the UE. The MeNB may transmit the data packet to the UE on a first radio bearer included in the first EPS bearer. The MeNB may further transmit, to the SDN switch, a configuration message to identify a second EPS bearer between the S-GW and the UE. The second EPS bearer may include a second radio bearer between the UE and a secondary Evolved Node-B (SeNB), and may exclude radio bearers between the UE and the MeNB.



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SOFTWARE DEFINED NETWORK SWITCH AND EVOLVED NODE-B
(ENB) FOR MULTIPLE BEARER CONNECTIVITY

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TECHNICAL FIELD

[0001] Embodiments pertain to wireless communications. Some
embodiments relate to wireless networks including 3GPP (Third Generation
10 Partnership Project) networks, 3GPP LTE (Long Term Evolution) networks, and
3GPP LTE-A (LTE Advanced) networks, although the scope of the
embodiments is not limited in this respect. Some embodiments relate to Evolved
Packet System (EPS) bearers. Some embodiments relate to multiple bearer
connectivity.

15

BACKGROUND

[0002] A mobile network may support communication with mobile
20 devices. In some cases, an available throughput for a mobile device or for the
network in general may be relatively low. In addition, connectivity issues
between the mobile device and base stations may occur in some situations. As
an example, a base station in the network may have a high demand at a particular
location or at a certain time. In such a case, the throughput available to the
25 mobile device may be lower than desired and connectivity for the mobile device
may be unstable or unavailable. Accordingly, there is a general need for
methods and systems for increasing throughput and/or improving connectivity in
these and other scenarios.

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BRIEF DESCRIPTION OF THE DRAWINGS

- [0003] FIG. 1 is a functional diagram of a 3GPP network in accordance with some embodiments;
- 5 [0004] FIG. 2 is a block diagram of a User Equipment (UE) in accordance with some embodiments;
- [0005] FIG. 3 is a block diagram of an Evolved Node-B (eNB) in accordance with some embodiments;
- [0006] FIG. 4 is a block diagram of a Software Defined Network (SDN) switch in accordance with some embodiments;
- 10 [0007] FIG. 5 illustrates the operation of a method of communication according to multiple bearer connectivity in accordance with some embodiments;
- [0008] FIG. 6 illustrates the operation of another method of communication according to multiple bearer connectivity in accordance with some embodiments;
- 15 [0009] FIG. 7 illustrates example scenarios for communication according to multiple bearer connectivity in accordance with some embodiments;
- [0010] FIG. 8 illustrates example scenarios for communication according to multiple bearer connectivity in accordance with some embodiments;
- 20 [0011] FIG. 9 illustrates an example control/data packet in accordance with some embodiments;
- [0012] FIG. 10 illustrates example software layers for an SDN switch in accordance with some embodiments; and
- 25 [0013] FIG. 11 illustrates a block diagram of an example machine in accordance with some embodiments.

DETAILED DESCRIPTION

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[0014] The following description and the drawings sufficiently illustrate specific embodiments to enable those skilled in the art to practice them. Other embodiments may incorporate structural, logical, electrical, process, and other

changes. Portions and features of some embodiments may be included in, or substituted for, those of other embodiments. Embodiments set forth in the claims encompass all available equivalents of those claims.

[0015] FIG. 1 is a functional diagram of a 3GPP network in accordance with some embodiments. The network comprises a radio access network (RAN) (e.g., as depicted, the E-UTRAN or evolved universal terrestrial radio access network) 100 and the core network 120 (e.g., shown as an evolved packet core (EPC)) coupled together through the software-defined network (SDN) switch 115. For convenience and brevity sake, only a portion of the core network 120, as well as the RAN 100, is shown.

[0016] The core network 120 includes a mobility management entity (MME) 122, a serving gateway (S-GW) 124, and packet data network gateway (PDN GW) 126. The RAN 100 includes Evolved Node-B's (eNBs) 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. In addition, as will be explained below, the eNBs 104 may be configured to operate as Master eNBs and/or Secondary eNB in some embodiments.

[0017] In some embodiments, one or more Evolved Packet System (EPS) bearers may be established for exchanging of data packets between the S-GW 124 and the UE 102. As will be described below, the eNB 104 and/or the S-GW 124 may be communicatively coupled to the SDN switch 115 in some embodiments. Accordingly, data packets may be exchanged as part of an EPS bearer using a path that may include the SDN switch 115 in some cases.

[0018] In some embodiments, a first eNB 104 may be configured to operate as an MeNB 104 and a second eNB 104 may be configured to operate as an SeNB 104. The MeNB 104 may receive, from the SDN switch 115, a data packet to be forwarded to the UE 102 as part of a first EPS bearer between the S-GW 124 and the UE 102. The MeNB 104 may transmit the data packet to the UE 102 on a first radio bearer included in the first EPS bearer. These embodiments will be described in more detail below.

[0019] 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 S-GW 124 terminates the interface toward the RAN 100, and routes data packets between the RAN 100 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
5 intercept, charging, and some policy enforcement. The S-GW 124 and the MME 122 may be implemented in one physical node or separate physical nodes. The PDN GW 126 terminates an 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
10 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 S-GW 124 may be implemented in one physical node or separated physical nodes.

[0020] The eNBs 104 (macro and micro) terminate the air interface
15 protocol and may be the first point of contact for a UE 102. In some embodiments, an eNB 104 may fulfill various logical functions for the RAN 100 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
20 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 Orthogonal Frequency Division Multiple Access (OFDMA) communication technique. The OFDM signals may comprise a plurality of orthogonal
25 subcarriers.

[0021] The S1 interface is the interface that separates the RAN 100 and the EPC 120. It is split into two parts: the S1-U, which carries traffic data between the eNBs 104 and the S-GW 124, and the S1-MME, which is a signaling interface between the eNBs 104 and the MME 122. The X2 interface is
30 the interface between eNBs 104. The X2 interface comprises two parts, the X2-C and X2-U. The X2-C is the control plane interface between the eNBs 104, while the X2-U is the user plane interface between the eNBs 104.

[0022] 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.

[0023] 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. With particular relevance to this disclosure, two of these physical
5 downlink channels are the physical downlink shared channel and the physical down link control channel.

[0024] 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
10 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 UEs 102 within a cell) may be performed at the eNB 104
15 based on channel quality information fed back from the UEs 102 to the eNB 104, and then the downlink resource assignment information may be sent to a UE 102 on the control channel (PDCCH) used for (assigned to) the UE 102.

[0025] The PDCCH uses CCEs (control channel elements) to convey the control information. Before being mapped to resource elements, the PDCCH
20 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.
25 The PDCCH can be transmitted using one or more CCEs, depending on the size of 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).

[0026] As used herein, the term "circuitry" may refer to, be part of, or
30 include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable hardware components that provide

the described functionality. In some embodiments, the circuitry may be implemented in, or functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware. Embodiments
5 described herein may be implemented into a system using any suitably configured hardware and/or software.

[0027] FIG. 2 is a block 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
10 application circuitry 202, baseband circuitry 204, Radio Frequency (RF) circuitry 206, front-end module (FEM) circuitry 208 and one or more antennas 210, coupled together at least as shown. In some embodiments, other circuitry or arrangements may include one or more elements and/or components of the application circuitry 202, the baseband circuitry 204, the RF circuitry 206 and/or
15 the FEM circuitry 208, and may also include other elements and/or components in some cases. As an example, “processing circuitry” may include one or more elements and/or components, some or all of which may be included in the application circuitry 202 and/or the baseband circuitry 204. As another example, “transceiver circuitry” may include one or more elements and/or components,
20 some or all of which may be included in the RF circuitry 206 and/or the FEM circuitry 208. These examples are not limiting, however, as the processing circuitry and/or the transceiver circuitry may also include other elements and/or components in some cases.

[0028] The application circuitry 202 may include one or more
25 application processors. For example, the application circuitry 202 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with and/or may
30 include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications and/or operating systems to run on the system.

[0029] The baseband circuitry 204 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 204 may include one or more baseband processors and/or control logic to process baseband signals received from a receive signal path of the RF circuitry 206 and to generate baseband signals for a transmit signal path of the RF circuitry 206. Baseband processing circuitry 204 may interface with the application circuitry 202 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 206. For example, in some embodiments, the baseband circuitry 204 may include a second generation (2G) baseband processor 204a, third generation (3G) baseband processor 204b, fourth generation (4G) baseband processor 204c, and/or other baseband processor(s) 204d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 204 (e.g., one or more of baseband processors 204a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 206. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 204 may include Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 204 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) encoder/decoder functionality. Embodiments of modulation/demodulation and encoder/decoder functionality are not limited to these examples and may include other suitable functionality in other embodiments.

[0030] In some embodiments, the baseband circuitry 204 may include elements of a protocol stack such as, for example, elements of an evolved universal terrestrial radio access network (EUTRAN) protocol including, for example, physical (PHY), media access control (MAC), radio link control (RLC), packet data convergence protocol (PDCP), and/or radio resource control (RRC) elements. A central processing unit (CPU) 204e of the baseband circuitry 204 may be configured to run elements of the protocol stack for signaling of the

PHY, MAC, RLC, PDCP and/or RRC layers. In some embodiments, the baseband circuitry may include one or more audio digital signal processor(s) (DSP) 204f. The audio DSP(s) 204f may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments. Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the baseband circuitry 204 and the application circuitry 202 may be implemented together such as, for example, on a system on a chip (SOC).

[0031] 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) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 204 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[0032] 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.

[0033] 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
5 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
10 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
15 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
20 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.

[0034] In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a of the transmit signal path may include
25 two or more mixers and may be arranged for quadrature downconversion and/or upconversion respectively. In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 206a of the
30 receive signal path and the mixer circuitry 206a may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 206a of the receive signal path and the mixer circuitry 206a of the transmit signal path may be configured for super-heterodyne operation.

[0035] 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.

[0036] 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 be determined from a look-up table based on a channel indicated by the applications processor 202.

[0037] Synthesizer circuitry 206d of the RF circuitry 206 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or N+1 (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these

embodiments, the delay elements may be configured to break a VCO period up into N_d equal packets of phase, where N_d is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

5 **[0038]** In some embodiments, synthesizer circuitry 206d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple
10 signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency may be a LO frequency (f_{LO}). In some embodiments, the RF circuitry 206 may include an IQ/polar converter.

[0039] FEM circuitry 208 may include a receive signal path which may
15 include circuitry configured to operate on RF signals received from one or more antennas 210, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 206 for further processing. FEM circuitry 208 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 206
20 for transmission by one or more of the one or more antennas 210.

[0040] In some embodiments, the FEM circuitry 208 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier
25 (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 206). The transmit signal path of the FEM circuitry 208 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 206), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more
30 antennas 210. In some embodiments, the UE 200 may include additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface.

[0041] FIG. 3 is a block diagram of an Evolved Node-B (eNB) in accordance with some embodiments. It should be noted that in some embodiments, the eNB 300 may be a stationary non-mobile device. The eNB 300 may be suitable for use as an eNB 104 as depicted in FIG. 1. In some
5 embodiments, the eNB 300 may be configured to operate as a Master eNB (MeNB) and/or a Secondary eNB (SeNB). The eNB 300 may include physical layer circuitry 302 and a transceiver 305, one or both of which may enable transmission and reception of signals to and from the UE 200, other eNBs, other UEs or other devices using one or more antennas 301. As an example, the
10 physical layer circuitry 302 may perform various encoding and decoding functions that may include formation of baseband signals for transmission and decoding of received signals. As another example, the transceiver 305 may perform various transmission and reception functions such as conversion of signals between a baseband range and a Radio Frequency (RF) range.
15 Accordingly, the physical layer circuitry 302 and the transceiver 305 may be separate components or may be part of a combined component. In addition, some of the described functionality related to transmission and reception of signals may be performed by a combination that may include one, any or all of the physical layer circuitry 302, the transceiver 305, and other components or
20 layers. The eNB 300 may also include medium access control layer (MAC) circuitry 304 for controlling access to the wireless medium. The eNB 300 may also include processing circuitry 306 and memory 308 arranged to perform the operations described herein. The eNB 300 may also include one or more interfaces 310, which may enable communication with other components,
25 including other eNBs 104 (FIG. 1), the SDN switch 115, 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 external to the network. The interfaces 310 may be wired or wireless or a combination thereof.

30 [0042] The antennas 210, 301 may comprise one or more directional or omnidirectional antennas, including, for example, dipole antennas, monopole antennas, patch antennas, loop antennas, microstrip antennas or other types of antennas suitable for transmission of RF signals. In some multiple-input

multiple-output (MIMO) embodiments, the antennas 210, 301 may be effectively separated to take advantage of spatial diversity and the different channel characteristics that may result.

[0043] 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 access point, a television, a wearable device such as a medical device (e.g., a heart rate monitor, a blood pressure monitor, etc.), or other device that may receive and/or transmit information wirelessly. In some embodiments, the UE 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 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.

[0044] FIG. 4 is a block diagram of a software-defined network (SDN) switch 115 in accordance with some embodiments. It should be noted that in some embodiments, the SDN switch 400 may be a stationary non-mobile device. The SDN switch 400 may be suitable for use as an SDN switch 115 as depicted in FIG. 1. The SDN switch 400 may include processing circuitry 406 and memory 408 arranged to perform the operations described herein. The SDN switch 400 may also include one or more interfaces 410, which may enable communication with other components, including eNBs 104 (FIG. 1), components in the EPC 120 (FIG. 1) or other network components. In addition, the interfaces 410 may enable communication with other components that may not be shown in FIG. 1, including components external to the network. The interfaces 410 may be wired or wireless or a combination thereof.

[0045] In some embodiments, the SDN switch 400 may be co-located with an MeNB 104 (such as 300). Accordingly, one or more of the components, such as the processing circuitry 406, memory 408 and/or interfaces 410, may be shared with similar components of the eNB 300. In addition, one or more

5 techniques and/or operations performed by the SDN switch 400 may utilize components included in the eNB 300, such as the processing circuitry 306, memory 308, interfaces 310 and/or others. These embodiments are not limiting, however. As an example, the SDN switch 400 may be a stand-alone component in some embodiments.

10 **[0046]** Although the UE 200, the eNB 300, and the SDN switch 400 are each illustrated as having several separate functional elements, one or more of the functional elements may be combined and may be implemented by combinations of software-configured elements, such as processing elements including digital signal processors (DSPs), and/or other hardware elements. For

15 example, some elements may comprise one or more microprocessors, DSPs, field-programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), radio-frequency integrated circuits (RFICs) and combinations of various hardware and logic circuitry for performing at least the functions described herein. In some embodiments, the functional elements may refer to

20 one or more processes operating on one or more processing elements.

[0047] 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

25 herein. A computer-readable storage device may include any non-transitory mechanism for storing information in a form readable by a machine (e.g., a computer). For example, a computer-readable storage device may include read-only memory (ROM), random-access memory (RAM), magnetic disk storage media, optical storage media, flash-memory devices, and other storage devices

30 and media. Some embodiments may include one or more processors and may be configured with instructions stored on a computer-readable storage device.

[0048] It should be noted that in some embodiments, an apparatus used by the UE 200 and/or eNB 300 and/or SDN switch 400 may include various

components of the UE 200 and/or the eNB 300 and/or the SDN switch 400 as shown in FIGs. 2-4. 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. In addition, techniques and operations described herein that refer to the SDN switch 400 (or 115) may be applicable to an apparatus for a SDN switch.

[0049] In accordance with some embodiments, a first eNB 104 may be configured to operate as an MeNB 104 and a second eNB 104 may be configured to operate as an SeNB 104. The MeNB 104 may receive, from the SDN switch 115, a data packet to be forwarded to the UE 102 as part of a first EPS bearer between the S-GW 124 and the UE 102. The MeNB 104 may transmit the data packet to the UE 102 on a first radio bearer included in the first EPS bearer. The MeNB 104 may further transmit, to the SDN switch 115, a configuration message to identify a second EPS bearer between the S-GW 124 and the UE 102. The second EPS bearer may include a second radio bearer between the UE 102 and the SeNB 104, and may exclude radio bearers between the UE 102 and the MeNB 104. These embodiments are described in more detail below.

[0050] FIG. 5 illustrates the operation of a method of communication according to multiple bearer connectivity in accordance with some embodiments. It is important to note that embodiments of the method 500 may include additional or even fewer operations or processes in comparison to what is illustrated in FIG. 5. In addition, embodiments of the method 500 are not necessarily limited to the chronological order that is shown in FIG. 5. In describing the method 500, reference may be made to FIGs. 1-4 and 6-10, although it is understood that the method 500 may be practiced with any other suitable systems, interfaces and components. The method 500 may be practiced by an eNB 104 configured to operate as a Master eNB (MeNB) 104 in some embodiments, although the scope of embodiments is not limited in this respect. It should be noted that such a configuration may or may not be temporary, in some cases. As an example, an eNB 104 may be configured to operate

according to any number of configurations in different cases, which may include MeNB 104, Secondary eNB (SeNB) 104 and/or others.

[0051] In addition, while the method 500 and other methods described herein may refer to eNBs 104 or UEs 102 operating in accordance with 3GPP or other standards, embodiments of those methods are not limited to just those eNBs 104 or UEs 102 and may also be practiced on other devices, such as a Wi-Fi access point (AP) or user station (STA). The method 500 and other methods described herein may also refer to an SDN switch 115, but embodiments of those methods are not limited to just SDN switches 115 and may also be practiced on other devices. In addition, the method 500 and other methods described herein may be practiced by wireless devices configured to operate in other suitable types of wireless communication systems, including systems configured to operate according to various IEEE standards such as IEEE 802.11. The method 500 may also refer to an apparatus for a UE 102 and/or eNB 104 and/or SDN switch 115 and/or other device described above.

[0052] At operation 505 of the method 500, the MeNB 104 may exchange one or more configuration messages with an SDN switch 115 to identify a first EPS bearer between a UE 102 and an S-GW 124. At operation 510, the MeNB 104 may exchange one or more radio bearer setup messages with the UE 102 for an establishment of a first radio bearer included in the first EPS bearer. In some embodiments, the first radio bearer may enable exchanging of data packets and various signals between the UE 102 and the MeNB 104 over one or more wireless links using an air interface.

[0053] At operation 515, the MeNB 104 may receive, from the SDN switch 115, one or more data packets to be forwarded to the UE 102 as part of the first EPS bearer. In some embodiments, the data packets may be received, at the MeNB 104, from the SDN switch 115 operating as a relay for the S-GW 124 as part of the first EPS bearer. At operation 520, the MeNB 104 may transmit the data packets to the UE 102 on the first radio bearer. In some embodiments, the MeNB 104 may also receive one or more uplink data packets from the UE 102 on the first radio bearer as part of the first EPS bearer, and may forward the uplink data packets to the SDN switch 115. In addition, embodiments are not

limited to exchanging of data packets in these and other operations, as control data and/or other data may also be exchanged.

[0054] At operation 525, the MeNB 104 may receive, from the UE 102, link quality information for a wireless link between the UE and a secondary eNB (SeNB) 104. As an example, a signal quality measurement related to a reception of signals at the UE 102 from the SeNB 104 may be used. For instance, a signal-to-noise ratio (SNR), received signal strength indicator (RSSI), reference signal received power (RSRP), reference signal received quality (RSRQ) and/or other suitable measurement may be used.

[0055] At operation 530, the network and/or the UE 102 may determine that a second EPS bearer is to be established between the UE 102 and the S-GW 124. In some embodiments, the second EPS bearer may include a second radio bearer between the UE 102 and the SeNB 104. In addition, the second EPS bearer may exclude radio bearers between the UE 102 and the MeNB 104 in some embodiments. Accordingly, the MeNB 104 may initiate the establishment of the second EPS bearer, although data packets exchanged as part of the second EPS bearer may be routed through a different eNB 104 (the SeNB 104 in this case). As such, the second EPS bearer may further include an interface between the SDN switch 115 and the SeNB 104 for forwarding, by the SDN switch 115, of data packets from the S-GW 124 to the SeNB 104 as part of the second EPS bearer.

[0056] In some embodiments, the determination that the second EPS bearer is to be established may be based at least partly on factors such as the received signal quality measurement, a data throughput between the S-GW 124 and the UE 102 on the first EPS bearer and/or other suitable factors. As an example, the establishment of the second EPS bearer may be for augmenting a combined data throughput between the UE 102 and the S-GW 124 in comparison to a data throughput between the UE 102 and the S-GW 124 on the first EPS bearer. That is, the second EPS bearer may be established to provide additional data throughput between the S-GW 124 and the UE 102 in addition to a data throughput provided by the first EPS bearer. In some cases, the first EPS bearer may remain operational after the second EPS bearer is established. For

instance, a dual connectivity arrangement may be established in which the first and second EPS bearers provide data throughput.

[0057] It should be noted that embodiments are not limited to the usage of a single SeNB 104. In some cases, multiple SeNBs 104 may be monitored by the MeNB 104 as possible candidates that may be used in an establishment of one or more additional EPS bearers. In addition, the MeNB 104 may determine that multiple EPS bearers are to be established, in some cases.

[0058] At operation 535, the MeNB 104 may transmit, to the SDN switch 115, one or more configuration messages to identify the second EPS bearer. In some cases, the MeNB 104 may initiate the establishment of the second EPS bearer by the transmission of the configuration messages. In some cases, the first and second EPS bearers may operate simultaneously and/or in overlapping time periods, although the scope of embodiments is not limited in this respect. As an example, the first EPS bearer may remain operational even after the second EPS bearer has been established. As another example, the first EPS bearer may remain operational even after the one or more setup messages for the establishment of the second EPS bearer have been transmitted. As another example, the first EPS bearer may remain operational even after it has been determined that the second EPS bearer is to be established. For instance, in any of these examples, the MeNB 104 may transmit, receive and/or forward data packets as part of the first EPS bearer.

[0059] At operation 540, the MeNB 104 may transmit, to the SDN switch 115, one or more bearer splitting messages for the second EPS bearer. In some embodiments, the bearer splitting messages may indicate that the second EPS bearer is to be split into a master portion and a secondary portion. The master portion may include a master radio bearer between the MeNB 104 and the UE 102 and the secondary portion may include the second radio bearer included in the second EPS bearer (previously established, between the UE 102 and the SeNB 104). Although not limited as such, the master radio bearer and the first radio bearer (included in the first EPS bearer, between the MeNB 104 and the UE 102) may utilize similar techniques. The two radio bearers between the MeNB 104 and the UE 102 may also utilize common frequency resources and/or time resources in some embodiments. In some cases, the splitting of the

second EPS bearer may enable the MeNB 104 to increase overall throughput between the UE 102 and the S-GW 124 and/or to perform load balancing between the MeNB 104 and the SeNB 104.

[0060] It should be noted that the second EPS bearer may exclude radio bearers between the MeNB 104 and the UE 102 before such a splitting of the second EPS bearer and/or when the second EPS bearer is a non-split EPS bearer. Accordingly, after the splitting of the second EPS bearer, a radio bearer (the master radio bearer previously described) may be established between the MeNB 104 and the UE 102 for the second EPS bearer.

5 [0061] The SDN switch 115 may receive additional data packets for the split second EPS bearer. The SDN switch 115 may forward a first portion of the additional data packets to the MeNB 104 for forwarding to the UE 102 on the master radio bearer. The SDN switch 115 may also forward a second portion of the additional data packets to the SeNB 104 for forwarding to the UE 102 on the second radio bearer (previously established) included in the second EPS bearer.

15 [0062] In some embodiments, the MeNB 104 may indicate to the SDN switch 115 a traffic splitting rule to be used, by the SDN switch 115, to route data packets intended for the UE 102 as part of the second EPS bearer. As an example, the traffic splitting rule may be used to determine a first number of packets that are to be forwarded to the MeNB 104 as part of the second EPS bearer and a second number of packets that are to be forwarded to the SeNB 104 as part of the second EPS bearer. As another example, the traffic splitting rule may indicate a ratio, a minimum, a maximum and/or other number related to throughputs routed through the MeNB 104 and the SeNB 104 for the second EPS bearer. It should also be noted that in some cases, the one or more bearer splitting messages may indicate the traffic splitting rule, although embodiments are not limited as such, and separate messages may be used for this purpose in some cases.

25 [0063] At operation 545, the MeNB 104 may determine whether or not a third radio bearer is to be established between a second SeNB 104 and the UE 102. In some embodiments, the determination may be performed by the network and/or the UE 102.

[0064] At operation 555, the MeNB 104 may transmit, to the SDN switch 115, one or more hand-off messages that may indicate a hand-off of the second EPS bearer for the UE 102 between the SeNB (a second radio bearer) and a second SeNB (a third radio bearer). Accordingly, the hand-off may be indicated by the MeNB 104 after the third radio bearer has been established, in some cases. However, it should be noted that in some embodiments, such a hand-off may be indicated by the one or more setup messages transmitted at operation 540.

[0065] As described previously regarding the second EPS bearer, the third radio bearer may be established to provide additional throughput between the UE 102 and the S-GW 124. A determination that the third radio bearer is to be established may be performed using similar techniques to those used for the determination that the second radio bearer is to be established.

[0066] FIG. 6 illustrates the operation of another method of communication according to multiple bearer connectivity in accordance with some embodiments. As mentioned previously regarding the method 500, embodiments of the method 600 may include additional or even fewer operations or processes in comparison to what is illustrated in FIG. 6 and embodiments of the method 600 are not necessarily limited to the chronological order that is shown in FIG. 6. In describing the method 600, reference may be made to FIGs. 1-5 and 7-10, although it is understood that the method 600 may be practiced with any other suitable systems, interfaces and components. In addition, embodiments of the method 600 may refer to UEs 102, eNBs 104, MeNBs 104, SeNBs 104, SDN switches 115, APs, STAs or other wireless or mobile devices. The method 600 may also refer to an apparatus for an SDN switch 115, eNB 104 and/or UE 102 or other device described above. It should be noted that the method 600 may be practiced at an SDN switch 115 and may include exchanging of signals or messages with an MeNB 104. Similarly, the method 500 may be practiced at an MeNB 104 and may include exchanging of signals or messages with an SDN switch 115. In some cases, operations and techniques described as part of the method 500 may be relevant to the method 600. In addition, embodiments may include operations performed at the SDN switch 115 that are reciprocal or similar to other operations described herein performed at

the MeNB 104. For instance, an operation of the method 600 may include reception of a message by the SDN server 115 while an operation of the method 600 may include transmission of the same message or similar message by the MeNB 104. In addition, previous discussion of various techniques and concepts may be applicable to the method 600 in some cases, including the establishment of EPS bearers, radio bearers, interfaces between the SDN 115 and the MeNB 104 and/or SeNB 104, technique to determine whether a second EPS bearer is to be established, bearer splitting, traffic splitting techniques, and others.

5 [0067] At operation 605, the SDN switch 115 may receive one or more configuration messages from an MeNB 104 to identify a first EPS bearer between a UE 102 and an S-GW 124. In some embodiments, the first EPS bearer may include a first radio bearer between the MeNB 104 and the UE 102. At operation 610, the SDN switch 115 may receive, from the S-GW 124, a first data packet intended for the UE 102. At operation 615, the SDN switch 115 may forward the first data packet to the MeNB 104 for forwarding to the UE 102 as part of the first EPS bearer. In some embodiments, the SDN switch 115 may operate as a relay between the S-GW 124 and the MeNB 104 as part of the first EPS bearer. In addition, the SDN switch 115 may also receive uplink data packets from the MeNB 104 and may forward them to the S-GW 124. Such operation may be performed as part of the first EPS bearer in some cases. In some embodiments, the first EPS bearer may include an interface between the SDN switch 115 and the MeNB 104 for forwarding, by the SDN switch 115, of data packets from the S-GW 124 to the MeNB 104 as part of the first EPS bearer.

25 [0068] At operation 620, the SDN switch 115 may exchange one or more configuration messages with the MeNB 104 to identify a second EPS bearer between the UE 102 and the S-GW 124. In some cases, the second EPS bearer may include a second radio bearer between an SeNB 104 and the UE 102. In addition, the second EPS bearer may exclude radio bearers between the MeNB 104 and the UE 102, although the MeNB 104 may perform operations related to the establishment of the second EPS bearer.

30 [0069] At operation 625, the SDN switch 115 may receive, from the S-GW 124, a second data packet intended for the UE 102. At operation 630, the

SDN switch may forward the second data packet to the MeNB 104 for forwarding to the UE 102 as part of the second EPS bearer. In some embodiments, the SDN switch 115 may operate as a relay between the S-GW 124 and the SeNB 104 as part of the second EPS bearer. In addition, the SDN switch 115 may also receive uplink data packets from the SeNB 104 and may forward them to the S-GW 124. Such operation may be performed as part of the second EPS bearer in some cases. In some embodiments, the second EPS bearer may include an interface between the SDN switch 115 and the SeNB 104 for forwarding, by the SDN switch 115, of data packets from the S-GW 124 to the SeNB 104 as part of the second EPS bearer.

[0070] At operation 635, the SDN switch 115 may receive, from the MeNB 104, one or more bearer splitting message for the second EPS bearer. As previously described, the second EPS bearer may be split into a master portion and a secondary portion, in some cases. It should also be noted that the bearer splitting messages and/or other messages transmitted from the MeNB 104 as part of the method 600 may indicate traffic splitting rules to be used, by the SDN switch 115, in some embodiments. Although not limited as such, previously described techniques may be used in some cases. At operation 640, the SDN switch 115 may receive, from the S-GW 124, one or more additional data packets intended for the UE 102. At operation 645, the SDN switch 115 may forward at least a first portion of the additional data packets to the MeNB 104 as part of the master portion of the second EPS bearer and may forward at least a second portion of the additional data packets to the SeNB 104 as part of the secondary portion of the second EPS bearer. In some cases, the first and second portions may be determined based at least partly on a traffic splitting rule received from the MeNB 104.

[0071] As another example, the SDN switch 115 may determine, based at least partly on EPS bearer identifiers included in the additional data packets, that the additional data packets are to be forwarded as part of either the first EPS bearer or the second EPS bearer. The SDN switch 115 may reframe some or all of the packets in some cases. For instance, data packets to be forwarded to the MeNB 104 may include an identifier of the MeNB 104 and data packets to be forwarded to the SeNB 104 may include an identifier of the SeNB 104.

[0072] At operation 655, the SDN switch may exchange one or more hand-off messages with the MeNB 104 for a hand-off of the second bearer for the UE 102 between the SeNB 104 (the second radio bearer) and a second SeNB 104 (a third radio bearer). A determination that the third radio bearer is to be established may be performed using similar techniques to those used for the determination that the second radio bearer is to be established, in some cases. The third radio bearer may be between the second SeNB 104 and the UE 102 in some cases. The third radio bearer may be established, in some cases, to augment a data throughput between the UE 102 and the S-GW 124. As an example, the hand-off may be performed after the third radio bearer is established and while the second radio bearer is still operational. As another example, the hand-off may be indicated as part of the setup messages for the establishment of the third radio bearer.

[0073] At operation 660, the SDN switch 115 may forward a data packet to the second SeNB 104 as part of the second EPS bearer. At operation 665, the SDN switch 115 may refrain from forwarding data packets to the SeNB 104 as part of the second EPS bearer. As a non-limiting example, the refraining may be performed after a hand-off is made.

[0074] FIG. 7 illustrates example scenarios in which multiple Evolved Packet System (EPS) bearers may be supported in accordance with some embodiments. FIG. 8 illustrates example scenarios in which multiple EPS bearers may be supported in accordance with some embodiments. It should be noted that the example scenarios 700, 710, 720, 800, 810 and/or 820 may illustrate some or all of the techniques and/or operations described herein, but embodiments are not limited by those example scenarios. In some embodiments, operations and/or techniques included in the example scenarios 700, 710, 720, 800, 810, and/or 820 may be similar to or the same as operations and/or techniques described for other methods disclosed herein.

[0075] Embodiments are not limited by the number, type or arrangement of the components and/or messages as shown in FIGs. 7-8. As an example, embodiments are not limited to usage of the UE 102, as other mobile devices may be used in some cases. For instance, a station (STA) arranged to communicate using a wireless local area network (WLAN) protocol (or other

protocol) may be used. As another example, embodiments are not limited to usage of the eNB 104, as other base station devices may be used in some cases. For instance, an access point (AP) arranged to communicate using a WLAN protocol (or other protocol) may be used. As another example, embodiments are not limited to usage of the SDN switch 115, as other components arranged to support operations for connectivity with multiple bearers may be used in some cases.

[0076] In the example scenario 700, the MeNB 104 may manage dual connectivity for the SeNB 104 without a bearer split of a second EPS bearer between the SeNB 104 and the UE 102. As an example, a concatenation of interfaces 1a, 2a, and 3 (701, 702, 705) as shown in FIG. 7 may be part of a first EPS bearer (bearer 1) that may be established when the UE 102 is attached to the MeNB 104. As another example, a concatenation of interfaces 1a, 4, and 5 (701, 703, 707) as shown in FIG. 7 may be part of the second EPS bearer (bearer 2) for which the SeNB 104 may route packets between the UE 102 and the SDN switch 115. In some embodiments, the interface 1a may logically connect the S-GW 124 and the SDN switch 115, wherein a physical link between the two components may include other components such as other routers. The interface 2a may connect the SDN switch 115 to the MeNB 104 and the interface 3 may be a radio bearer between the UE 102 and the MeNB 104.

[0077] As a non-limiting example, packets exchanged on interfaces 1a and 2a may differ in some layers of a protocol stack and may be the same or similar in other layers of the protocol stack. For instance, in terms of an Open Systems Interconnection (OSI) protocol stack, the packets may differ in terms of Layer 2 and below but may be the same or similar in terms of Layer 3 and above. It should be noted that the S-GW 124 may terminate an interface toward an EUTRAN network and may act as a mobility anchor point for inter-MeNB 104 handover in some embodiments.

[0078] Referring to FIG. 8, some or all of the operations shown in the example scenario 800 may be performed in accordance with the example scenario 700, in some cases. At operation 801, the MeNB 104 may add new rules on packet processing and forwarding, and may send the rules to the SDN switch on interface 2b. At operation 802, packets of the second EPS bearer may

arrive at the SDN switch 115 on the interface 1b and may be processed by the SDN switch 115. The packets may be forwarded to the SeNB 104 on the interface 4 at operation 803.

[0079] In the example scenario 710, the MeNB 104 may manage dual
5 connectivity for the SeNB 104 with a bearer split of the second EPS bearer. In contrast to the example scenario 700, the second EPS bearer (bearer 2) may be split in a manner in which a first portion of data packets may be routed to the SeNB 104 over the interface 4 (713) for forwarding to the UE 102 on interface 5 (717) and a second portion may be routed to the MeNB 104 over the interface 2c
10 (712) for forwarding to the UE 102 on interface 6 (716). In some cases, the splitting of bearer 2 may be controlled by the MeNB 104 over the interface 2b. Accordingly, such a split may be performed in order to increase throughput and/or to maintain a load balance between the MeNB 104 and the SeNB 104.

[0080] Referring to FIG. 8, some or all of the operations shown in the
15 example scenario 810 may be performed in accordance with the example scenario 710, in some cases. At operation 811, the MeNB 104 may add new rules on packet splitting, processing and forwarding, and may send the rules to the SDN switch on interface 2b. At operation 812, packets of the second EPS bearer may arrive at the SDN switch 115 on interface 1b and may be processed
20 by the SDN switch 115. A portion of the packets may be reframed and may be forwarded to the SeNB 104 on the interface 4 at operation 813. Another portion of the packets may be reframed and may be forwarded to the MeNB 104 at operation 814.

[0081] In the example scenario 720, the MeNB 104 may manage inter-
25 SeNB handover. As shown, the handover is performed in accordance with dual connectivity for the SeNBs 104 with a bearer split of the second EPS bearer. However, embodiments are not so limited, as such handovers (or handoffs) may be performed in the absence of a split EPS bearer in some embodiments. In contrast to the example scenario 710, a second SeNB 104 (labeled SeNB 2) is
30 supported in addition to the first SeNB 104 (labeled SeNB 1). The SDN switch 115 may communicate with the second SeNB 104 over the interface 7 (labeled 724).

[0082] Referring to FIG. 8, some or all of the operations shown in the example scenario 820 may be performed in accordance with the example scenario 720, in some cases. At operation 821, the MeNB 104 may add new rules on packet splitting, processing and forwarding, and may send the rules to the SDN switch on interface 2b. At operation 822, packets of the second EPS bearer may arrive at the SDN switch 115 on interface 1b and may be processed by the SDN switch 115. A portion of the packets may be reframed and may be forwarded to the SeNB 104 on the interface 4 at operation 823. Another portion of the packets may be reframed and may be forwarded to the MeNB 104 at operation 824.

[0083] At operation 825, the MeNB 104 may change the rules to stop packet forwarding, by the SDN switch 115, to the first SeNB 104 (SeNB 1) and may add the second SeNB 104 (SeNB 2) as a new destination for such packets. The new rules or updates to the rules may be sent to the SDN switch on interface 2b. At operation 826, a portion of packets arriving at the SDN switch may be reframed and forwarded to the second SeNB 104 via interface 7.

[0084] It should also be noted that in some embodiments, a handover to a second SeNB 104 may also include a handover to a different SDN switch 115. Accordingly, some or all techniques and/or operations described herein may be applicable in those embodiments, in some cases.

[0085] FIG. 9 illustrates an example of a control/data packet in accordance with some embodiments. It should be noted that embodiments are not limited to the arrangement and/or elements shown in the control/data packet 900. For instance, all parameters and/or information shown in FIG. 9 for the example control packet 900 may not necessarily be included in some embodiments. In addition, the organization of the parameters and/or information shown in the example control/data packet 900 is not limiting.

[0086] In some embodiments, an S1-U packet may be used, although the scope of embodiments is not limited in this respect. The GTP-U header 920 may be used, in some cases, to represent the second EPS bearer (bearer 2). As an example, the SDN switch 115 may examine received packets from the S-GW 124 to match the TEID 930 assigned to the second EPS bearer (bearer 2).

[0087] In some embodiments, the SDN switch 115 may use one or more flow tables to perform packet lookups and forwarding, and may communicate on one or more control channels to an external controller. As an example, an application programming interface (API) such as OpenFlow or other may provide an interface (which may or may not be part of a standard) for programming of data plane switches. Using the OpenFlow switch protocol, the controller may add, update and/or delete flow entries in flow tables. As an example, a flow table may include a set of flow entries, each of which may comprise any or all of match fields, counters, a set of instructions to apply to matching packets and/or other related information. In some embodiments, OpenFlow may support Ethernet, MPLS, IP, TCP, UDP and/or SCTP. In some embodiments, GTP-U may be supported with one or more extensions to the SDN framework. As an example, the SDN switch 115 may be configured to understand and/or process a mapping of TEID and MeNB/SeNB 104 via S1-AP. As another example, a Message Type 925 and/or TEID 930, as shown in FIG. 9, may be included in the Match Fields. In some cases, GTP-U destined for a specific SeNB 104 may be properly processed.

[0088] FIG. 10 illustrates example software layers for an SDN switch in accordance with some embodiments. In some embodiments, one or more of the layers shown may be included in and/or supported by the processing circuitry 406 of the SDN switch 400 as shown in FIG. 4. In the example 1000, when radio sub-layers are not included in the SDN switch 400 and/or not supported by the SDN switch 400, a GTP-U entity 1010 and a data forwarding layer 1020 may be included in the SDN switch 400. In the example 1050, when one or more radio sub-layers are included in the SDN switch 400 and/or supported by the SDN switch 400, a GTP-U entity 1060, a PDCP entity 1070, and a data forwarding layer 1080 may be included in the SDN switch 400.

[0089] FIG. 11 illustrates a block diagram of an example machine in accordance with some embodiments. The machine 1100 is an example machine upon which any one or more of the techniques and/or methodologies discussed herein may be performed. In alternative embodiments, the machine 1100 may operate as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine 1100 may operate in the

capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine 1100 may act as a peer machine in peer-to-peer (P2P) (or other distributed) network environment. The machine 1100 may be a UE 102, eNB 104, access point (AP), station (STA), mobile
5 device, base station, personal computer (PC), a tablet PC, a set-top box (STB), a personal digital assistant (PDA), a mobile telephone, a smart phone, a web appliance, a network router, switch or bridge, SDN switch, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine. It should be noted that in some embodiments, an eNB
10 or other base station may include some or all of the components shown in either FIG. 3 or FIG. 11 or both. It should be noted that in some embodiments, a UE or other mobile device may include some or all of the components shown in either FIG. 2 or FIG. 11 or both. Further, while only a single machine is illustrated, the term “machine” shall also be taken to include any collection of machines that
15 individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein, such as cloud computing, software as a service (SaaS), other computer cluster configurations.

[0090] Examples as described herein, may include, or may operate on, logic or a number of components, modules, or mechanisms. Modules are
20 tangible entities (e.g., hardware) capable of performing specified operations and may be configured or arranged in a certain manner. In an example, circuits may be arranged (e.g., internally or with respect to external entities such as other circuits) in a specified manner as a module. In an example, the whole or part of one or more computer systems (e.g., a standalone, client or server computer
25 system) or one or more hardware processors may be configured by firmware or software (e.g., instructions, an application portion, or an application) as a module that operates to perform specified operations. In an example, the software may reside on a machine readable medium. In an example, the software, when executed by the underlying hardware of the module, causes the hardware to
30 perform the specified operations.

[0091] Accordingly, the term “module” is understood to encompass a tangible entity, be that an entity that is physically constructed, specifically configured (e.g., hardwired), or temporarily (e.g., transitorily) configured (e.g.,

programmed) to operate in a specified manner or to perform part or all of any operation described herein. Considering examples in which modules are temporarily configured, each of the modules need not be instantiated at any one moment in time. For example, where the modules comprise a general-purpose

5 hardware processor configured using software, the general-purpose hardware processor may be configured as respective different modules at different times. Software may accordingly configure a hardware processor, for example, to constitute a particular module at one instance of time and to constitute a different module at a different instance of time.

10 **[0092]** The machine (e.g., computer system) 1100 may include a hardware processor 1102 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof), a main memory 1104 and a static memory 1106, some or all of which may communicate with each other via an interlink (e.g., bus) 1108. The machine

15 1100 may further include a display unit 1110, an alphanumeric input device 1112 (e.g., a keyboard), and a user interface (UI) navigation device 1114 (e.g., a mouse). In an example, the display unit 1110, input device 1112 and UI navigation device 1114 may be a touch screen display. The machine 1100 may additionally include a storage device (e.g., drive unit) 1116, a signal generation

20 device 1118 (e.g., a speaker), a network interface device 1120, and one or more sensors 1121, such as a global positioning system (GPS) sensor, compass, accelerometer, or other sensor. The machine 1100 may include an output controller 1128, such as a serial (e.g., universal serial bus (USB), parallel, or other wired or wireless (e.g., infrared (IR), near field communication (NFC),

25 etc.) connection to communicate or control one or more peripheral devices (e.g., a printer, card reader, etc.).

[0093] The storage device 1116 may include a machine readable medium 1122 on which is stored one or more sets of data structures or instructions 1124 (e.g., software) embodying or utilized by any one or more of the techniques or

30 functions described herein. The instructions 1124 may also reside, completely or at least partially, within the main memory 1104, within static memory 1106, or within the hardware processor 1102 during execution thereof by the machine 1100. In an example, one or any combination of the hardware processor 1102,

the main memory 1104, the static memory 1106, or the storage device 1116 may constitute machine readable media. In some embodiments, the machine readable medium may be or may include a non-transitory computer-readable storage medium.

5 [0094] Various embodiments may be implemented fully or partially in software and/or firmware. This software and/or firmware may take the form of instructions contained in or on a non-transitory computer-readable storage medium. Those instructions may then be read and executed by one or more processors to enable performance of the operations described herein. The
10 instructions may be in any suitable form, such as but not limited to source code, compiled code, interpreted code, executable code, static code, dynamic code, and the like. Such a computer-readable medium may include any tangible non-transitory medium for storing information in a form readable by one or more computers, such as but not limited to read only memory (ROM); random access
15 memory (RAM); magnetic disk storage media; optical storage media; and/or a flash memory.

[0095] While the machine readable medium 1122 is illustrated as a single medium, the term "machine readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database, and/or
20 associated caches and servers) configured to store the one or more instructions 1124. The term "machine readable medium" may include any medium that is capable of storing, encoding, or carrying instructions for execution by the machine 1100 and that cause the machine 1100 to perform any one or more of the techniques of the present disclosure, or that is capable of storing, encoding or
25 carrying data structures used by or associated with such instructions. Non-limiting machine readable medium examples may include solid-state memories, and optical and magnetic media. Specific examples of machine readable media may include: non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically Erasable
30 Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; Random Access Memory (RAM); and CD-ROM and DVD-ROM disks. In some examples, machine readable media may include non-transitory

machine readable media. In some examples, machine readable media may include machine readable media that is not a transitory propagating signal.

[0096] The instructions 1124 may further be transmitted or received over a communications network 1126 using a transmission medium via the network interface device 1120 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 1120 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 1126. In an example, the network interface device 1120 may include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), multiple-input multiple-output (MIMO), or multiple-input single-output (MISO) techniques. In some examples, the network interface device 1120 may wirelessly communicate using Multiple User MIMO techniques. The term “transmission medium” shall be taken to include any intangible medium that is capable of storing, encoding or carrying instructions for execution by the machine 1100, and includes digital or analog communications signals or other intangible medium to facilitate communication of such software.

[0097] In Example 1, an apparatus for a master Evolved Node-B (MeNB) may comprise transceiver circuitry and hardware processing circuitry. The hardware processing circuitry may configure the transceiver circuitry to receive a data packet to be forwarded to a User Equipment (UE) as part of a first Evolved Packet System (EPS) bearer between a Serving Gateway (S-GW) and the UE. The hardware processing circuitry may further configure the transceiver

circuitry to transmit the data packet to the UE on a first radio bearer included in the first EPS bearer. The hardware processing circuitry may further configure the transceiver circuitry to transmit, to a software-defined network (SDN) switch, a configuration message to identify a second EPS bearer between the S-GW and the UE. The second EPS bearer may include a second radio bearer between the UE and a secondary Evolved Node-B (SeNB).

[0098] In Example 2, the subject matter of Example 1, wherein the data packet may be received, at the MeNB, from the SDN switch operating as a relay for the S-GW as part of the first EPS bearer.

[0099] In Example 3, the subject matter of one or any combination of Examples 1-2, wherein the second EPS bearer may exclude radio bearers between the UE and the MeNB.

[00100] In Example 4, the subject matter of one or any combination of Examples 1-3, wherein the second EPS bearer may further include an interface between the SDN switch and the SeNB for forwarding, by the SDN switch, of data packets from the S-GW to the SeNB as part of the second EPS bearer.

[00101] In Example 5, the subject matter of one or any combination of Examples 1-4, wherein the establishment of the second EPS bearer may be for augmenting a combined data throughput between the UE and the S-GW in comparison to a data throughput between the UE and the S-GW on the first EPS bearer.

[00102] In Example 6, the subject matter of one or any combination of Examples 1-5, wherein the data packet may be a first data packet and the hardware processing circuitry may further configure the transceiver circuitry to transmit, to the SDN switch, a bearer splitting message that indicates that the second EPS bearer is to be split into a master portion and a secondary portion. The master portion may include a master radio bearer between the MeNB and the UE and the secondary portion may include the second radio bearer. The hardware processing circuitry may further configure the transceiver circuitry to receive, from the SDN switch, a second data packet to be forwarded to the UE as part of the second EPS bearer. The hardware processing circuitry may further configure the transceiver circuitry to transmit the second data packet to the UE on the master radio bearer.

[00103] In Example 7, the subject matter of one or any combination of Examples 1-6, wherein the bearer splitting message may indicate a traffic splitting rule to be used, by the SDN switch, to determine a first number of packets that are to be forwarded to the MeNB as part of the master portion of the second EPS bearer and a second number of packets that are to be forwarded to the SeNB as part of the secondary portion of the second EPS bearer.

[00104] In Example 8, the subject matter of one or any combination of Examples 1-7, wherein the data packet may be a first data packet and the hardware processing circuitry may further configure the transceiver circuitry to receive a second data packet to be forwarded to the UE as part of the first EPS bearer. The hardware processing circuitry may further configure the transceiver circuitry to transmit the second data packet to the UE on the first radio bearer. The reception and the transmission of the second data packet may be performed after the transmission of the setup message for the establishment of the second EPS bearer.

[00105] In Example 9, the subject matter of one or any combination of Examples 1-8, wherein the hardware processing circuitry may further configure the transceiver circuitry to receive, from the UE, a signal quality measurement for a link between the UE and the SeNB. The hardware processing circuitry may be configured to determine that the second EPS bearer is to be established based at least partly on the received signal quality measurement.

[00106] In Example 10, the subject matter of one or any combination of Examples 1-9, wherein the hardware processing circuitry may be configured to determine that the second EPS bearer is to be established based at least partly on a data throughput between the S-GW and the UE on the first EPS bearer.

[00107] In Example 11, the subject matter of one or any combination of Examples 1-10, wherein the SeNB may be a first SeNB and the setup message may be a first setup message. The hardware processing circuitry may further configure the transceiver circuitry to transmit a second setup message for an establishment of a third radio bearer between the UE and a second SeNB.

[00108] In Example 12, the subject matter of one or any combination of Examples 1-11, wherein the second setup message may indicate a hand-off, for the UE, between the first SeNB and the second SeNB.

[00109] In Example 13, the subject matter of one or any combination of Examples 1-12, wherein the apparatus may further include one or more antennas coupled to the transceiver circuitry for the transmission of the data packet to the UE.

5 [00110] In Example 14, a non-transitory computer-readable storage medium may store instructions for execution by one or more processors to perform operations for communication by a master Evolved Node-B (MeNB). The operations may configure the one or more processors to configure the MeNB to forward data packets to a User Equipment (UE) on a first radio bearer
10 included in a first Evolved Packet System (EPS) bearer between a Serving Gateway (S-GW) and the UE. The operations may configure the one or more processors to determine, based at least partly on a data throughput of the first EPS bearer, whether a second EPS bearer is to be established between the S-GW and the UE. The operations may configure the one or more processors to
15 configure the MeNB to, when it is determined that the second EPS bearer is to be established, transmit a configuration message to a software-defined network (SDN) switch to identify the second EPS bearer. The second EPS bearer may include a second radio bearer between the UE and a secondary eNB (SeNB) and may exclude radio bearers between the UE and the MeNB.

20 [00111] In Example 15, the subject matter of Example 14, wherein the data packets may be received at the MeNB from the SDN switch for forwarding to the UE as part of the first EPS bearer.

[00112] In Example 16, the subject matter of one or any combination of Examples 14-15, wherein the second EPS bearer may further include an
25 interface between the SDN switch and the SeNB for forwarding, by the SDN switch, of data packets from the S-GW to the SeNB as part of the second EPS bearer.

[00113] In Example 17, the subject matter of one or any combination of Examples 14-16, wherein the establishment of the second EPS bearer may be for
30 augmenting a combined data throughput between the UE and the S-GW in comparison to a data throughput between the UE and the S-GW on the first EPS bearer.

[00114] In Example 18, a software-defined network (SDN) switch may comprise transceiver circuitry and hardware processing circuitry. The hardware processing circuitry may configure the transceiver circuitry to receive a data packet from a Serving Gateway (S-GW) as part of a first Evolved Packet System (EPS) bearer between the S-GW and a User Equipment (UE). The hardware processing circuitry may further configure the transceiver circuitry to forward the data packet to a Master Evolved Node-B (MeNB) for forwarding to the UE. The hardware processing circuitry may further configure the transceiver circuitry to receive, from the MeNB, a configuration message to identify EPS bearers between the S-GW and the UE. The first EPS bearer may include a first radio bearer between the UE and the MeNB. The second EPS bearer may include a second radio bearer between the UE and a secondary Evolved Node-B (SeNB) and may exclude radio bearers between the UE and the MeNB.

[00115] In Example 19, the subject matter of Example 18, wherein the SDN switch may operate as a relay between the S-GW and the MeNB as part of the first EPS bearer.

[00116] In Example 20, the subject matter of one or any combination of Examples 18-19, wherein the first EPS bearer may further include an interface between the SDN switch and the MeNB for forwarding, by the SDN switch, of data packets from the S-GW to the MeNB as part of the first EPS bearer. The second EPS bearer may further include an interface between the SDN switch and the SeNB for forwarding, by the SDN switch, of data packets from the S-GW to the SeNB as part of the second EPS bearer.

[00117] In Example 21, the subject matter of one or any combination of Examples 18-20, wherein the hardware processing circuitry may further configure the transceiver circuitry to receive, from the MeNB, a bearer splitting message that indicates that the second EPS bearer is to be split into a master portion and a secondary portion. The master portion may include a master radio bearer between the MeNB and the UE. The secondary portion may include the second radio bearer.

[00118] In Example 22, the subject matter of one or any combination of Examples 18-21, wherein the hardware processing circuitry may further configure the transceiver circuitry to receive, from the S-GW, one or more

additional data packets intended for forwarding to the UE as part of the second EPS bearer. The hardware processing circuitry may further configure the transceiver circuitry to forward at least a first portion of the additional data packets to the MeNB as part of the second EPS bearer. The hardware processing
5 circuitry may further configure the transceiver circuitry to forward at least a second portion of the additional data packets to the SeNB as part of the second EPS bearer. The first and second portions may be determined based at least partly on a traffic splitting rule received from the MeNB.

[00119] In Example 23, the subject matter of one or any combination of
10 Examples 18-22, wherein the hardware processing circuitry may be configured to determine, based on EPS bearer identifiers included in the additional data packets, that the data packets are to be forwarded as part of the second EPS bearer. The hardware processing circuitry may be further configured to include an identifier of the MeNB or the SeNB in the additional data packets.

[00120] In Example 24, the subject matter of one or any combination of
15 Examples 18-23, wherein the SeNB may be a first SeNB and the setup message may be a first setup message. The hardware processing circuitry may further configure the transceiver circuitry to receive, from the MeNB, a second setup message for an establishment of a third radio bearer between the UE and a
20 second SeNB.

[00121] In Example 25, the subject matter of one or any combination of Examples 18-24, wherein the second setup message may indicate a hand-off, for the UE, between the first SeNB and the second SeNB.

[00122] In Example 26, the subject matter of one or any combination of
25 Examples 18-25, wherein the data packet may be a first data packet. The hardware processing circuitry may further configure the transceiver circuitry to forward a second data packet to the second SeNB as part of the second EPS bearer. The hardware processing circuitry may further configure the transceiver circuitry to, based on the hand-off indicated by the second setup message, refrain
30 from forwarding of data packets to the first SeNB as part of the second EPS bearer.

[00123] The Abstract is provided to comply with 37 C.F.R. Section 1.72(b) requiring an abstract that will allow the reader to ascertain the nature and

gist of the technical disclosure. It is submitted with the understanding that it will not be used to limit or interpret the scope or meaning of the claims. The following claims are hereby incorporated into the detailed description, with each claim standing on its own as a separate embodiment.

5

CLAIMS

What is claimed is:

- 5 1. An apparatus for a master Evolved Node-B (MeNB), the apparatus comprising transceiver circuitry and hardware processing circuitry, the hardware processing circuitry to configure the transceiver circuitry to:
- receive a data packet to be forwarded to a User Equipment (UE) as part of a first Evolved Packet System (EPS) bearer between a Serving Gateway (S-
- 10 GW) and the UE;
- transmit the data packet to the UE on a first radio bearer included in the first EPS bearer; and
- transmit, to a software-defined network (SDN) switch, a configuration message to identify a second EPS bearer between the S-GW and the UE,
- 15 wherein the second EPS bearer includes a second radio bearer between the UE and a secondary Evolved Node-B (SeNB).
2. The apparatus according to claim 1, wherein the data packet is received, at the MeNB, from the SDN switch operating as a relay for the S-GW
- 20 as part of the first EPS bearer.
3. The apparatus according to claim 1, wherein the second EPS bearer excludes radio bearers between the UE and the MeNB.
- 25 4. The apparatus according to claim 3, wherein the second EPS bearer further includes an interface between the SDN switch and the SeNB for forwarding, by the SDN switch, of data packets from the S-GW to the SeNB as part of the second EPS bearer.
- 30 5. The apparatus according to claim 1, wherein the establishment of the second EPS bearer is for augmenting a combined data throughput between the UE and the S-GW in comparison to a data throughput between the UE and the S-GW on the first EPS bearer.

6. The apparatus according to claim 1, wherein:

the data packet is a first data packet,

the hardware processing circuitry is to further configure the transceiver

5 circuitry to:

transmit, to the SDN switch, a bearer splitting message that indicates that the second EPS bearer is to be split into a master portion and a secondary portion, wherein the master portion includes a master radio bearer between the MeNB and the UE and wherein the secondary portion includes the

10 second radio bearer;

receive, from the SDN switch, a second data packet to be forwarded to the UE as part of the second EPS bearer; and

transmit the second data packet to the UE on the master radio bearer.

15

7. The apparatus according to claim 6, wherein the bearer splitting message indicates a traffic splitting rule to be used, by the SDN switch, to determine a first number of packets that are to be forwarded to the MeNB as part of the master portion of the second EPS bearer and a second number of packets

20 that are to be forwarded to the SeNB as part of the secondary portion of the second EPS bearer.

8. The apparatus according to claim 1, wherein:

the data packet is a first data packet,

25 the hardware processing circuitry is to further configure the transceiver circuitry to:

receive a second data packet to be forwarded to the UE as part of the first EPS bearer; and

transmit the second data packet to the UE on the first radio bearer,

30 wherein the reception and the transmission of the second data packet are performed after the transmission of the setup message for the establishment of the second EPS bearer.

9. The apparatus according to claim 1, the hardware processing circuitry configured to:

configure the transceiver circuitry to receive, from the UE, a signal quality measurement for a link between the UE and the SeNB; and

5 determine that the second EPS bearer is to be established based at least partly on the received signal quality measurement.

10 10. The apparatus according to claim 1, the hardware processing circuitry configured to determine that the second EPS bearer is to be established based at least partly on a data throughput between the S-GW and the UE on the first EPS bearer.

11. The apparatus according to claim 1, wherein:

the SeNB is a first SeNB and the setup message is a first setup message,

15 the hardware processing circuitry is to further configure the transceiver circuitry to transmit, a second setup message for an establishment of a third radio bearer between the UE and a second SeNB.

20 12. The apparatus according to claim 11, wherein the second setup message indicates a hand-off, for the UE, between the first SeNB and the second SeNB.

25 13. The apparatus according to claim 1, wherein the apparatus further includes one or more antennas coupled to the transceiver circuitry for the transmission of the data packet to the UE.

30 14. A computer-readable storage medium that stores instructions for execution by one or more processors to perform operations for communication by a master Evolved Node-B (MeNB), the operations to configure the one or more processors to:

configure the MeNB to forward data packets to a User Equipment (UE) on a first radio bearer included in a first Evolved Packet System (EPS) bearer between a Serving Gateway (S-GW) and the UE;

determine, based at least partly on a data throughput of the first EPS bearer, whether a second EPS bearer is to be established between the S-GW and the UE;

configure the MeNB to, when it is determined that the second EPS bearer
5 is to be established, transmit a configuration message to a software-defined network (SDN) switch to identify the second EPS bearer,

wherein the second EPS bearer includes a second radio bearer between the UE and a secondary eNB (SeNB) and excludes radio bearers between the UE and the MeNB.

10

15. The computer-readable storage medium according to claim 14, wherein the data packets are received at the MeNB from the SDN switch for forwarding to the UE as part of the first EPS bearer.

15

16. The computer-readable storage medium according to claim 14, wherein the second EPS bearer further includes an interface between the SDN switch and the SeNB for forwarding, by the SDN switch, of data packets from the S-GW to the SeNB as part of the second EPS bearer.

20

17. The computer-readable storage medium according to claim 14, wherein the establishment of the second EPS bearer is for augmenting a combined data throughput between the UE and the S-GW in comparison to a data throughput between the UE and the S-GW on the first EPS bearer.

25

18. A software-defined network (SDN) switch comprising transceiver circuitry and hardware processing circuitry, the hardware processing circuitry to configure the transceiver circuitry to:

receive a data packet from a Serving Gateway (S-GW) as part of a first Evolved Packet System (EPS) bearer between the S-GW and a User Equipment
30 (UE);

forward the data packet to a Master Evolved Node-B (MeNB) for forwarding to the UE;

receive, from the MeNB, a configuration message to identify EPS bearers between the S-GW and the UE,

wherein the first EPS bearer includes a first radio bearer between the UE and the MeNB, and

5 wherein the second EPS bearer includes a second radio bearer between the UE and a secondary Evolved Node-B (SeNB) and excludes radio bearers between the UE and the MeNB.

19. The SDN switch according to claim 18, wherein the SDN switch
10 operates as a relay between the S-GW and the MeNB as part of the first EPS bearer.

20. The SDN switch according to claim 18, wherein:
the first EPS bearer further includes an interface between the SDN switch
15 and the MeNB for forwarding, by the SDN switch, of data packets from the S-GW to the MeNB as part of the first EPS bearer, and
the second EPS bearer further includes an interface between the SDN switch and the SeNB for forwarding, by the SDN switch, of data packets from the S-GW to the SeNB as part of the second EPS bearer.

20 21. The SDN switch according to claim 18, the hardware processing circuitry to configure the transceiver circuitry to:
receive, from the MeNB, a bearer splitting message that indicates that the second EPS bearer is to be split into a master portion and a secondary portion,
25 wherein the master portion includes a master radio bearer between the MeNB and the UE and wherein the secondary portion includes the second radio bearer.

22. The SDN switch according to claim 21, the hardware processing
30 circuitry to configure the transceiver circuitry to:
receive, from the S-GW, one or more additional data packets intended for forwarding to the UE as part of the second EPS bearer;

forward at least a first portion of the additional data packets to the MeNB
as part of the second EPS bearer; and

forward at least a second portion of the additional data packets to the
SeNB as part of the second EPS bearer,

5 wherein the first and second portions are determined based at least partly
on a traffic splitting rule received from the MeNB.

23. The SDN switch according to claim 22, the hardware processing
circuitry configured to:

10 determine, based on EPS bearer identifiers included in the additional data
packets, that the data packets are to be forwarded as part of the second EPS
bearer;

include an identifier of the MeNB or the SeNB in the additional data
packets.

15

24. The SDN switch according to claim 18, wherein:

the SeNB is a first SeNB and the setup message is a first setup message,

the hardware processing circuitry is to further configure the transceiver
circuitry to receive, from the MeNB, a second setup message for an

20 establishment of a third radio bearer between the UE and a second SeNB.

25. The SDN switch according to claim 24, wherein the second setup
message indicates a hand-off, for the UE, between the first SeNB and the second
SeNB.

25

26. The SDN switch according to claim 25, wherein:

the data packet is a first data packet;

the hardware processing circuitry is to further configure the transceiver
circuitry to:

30 forward a second data packet to the second SeNB as part of the
second EPS bearer; and

based on the hand-off indicated by the second setup message,
refrain from forwarding of data packets to the first SeNB as part of the second
EPS bearer.

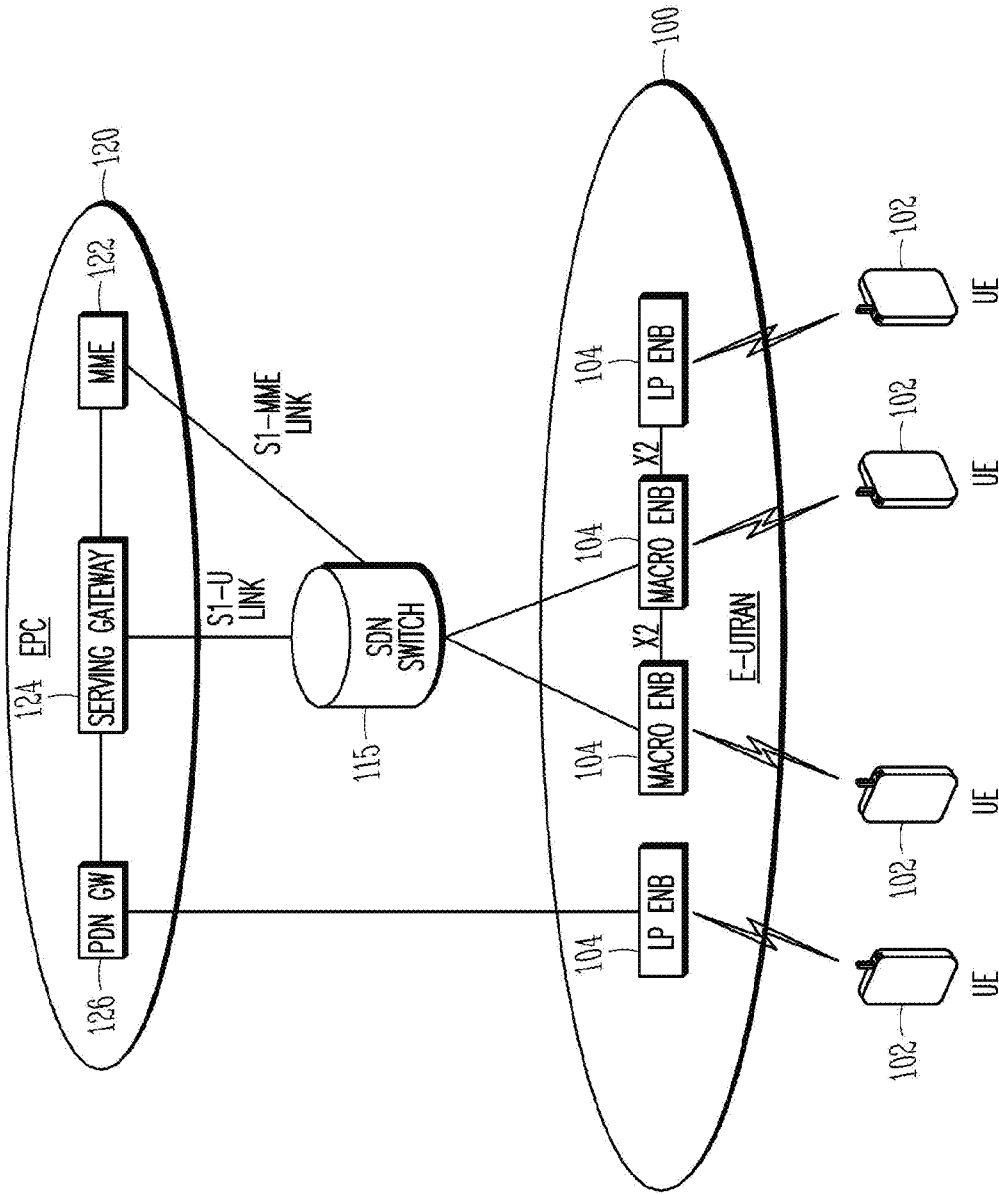


FIG. 1

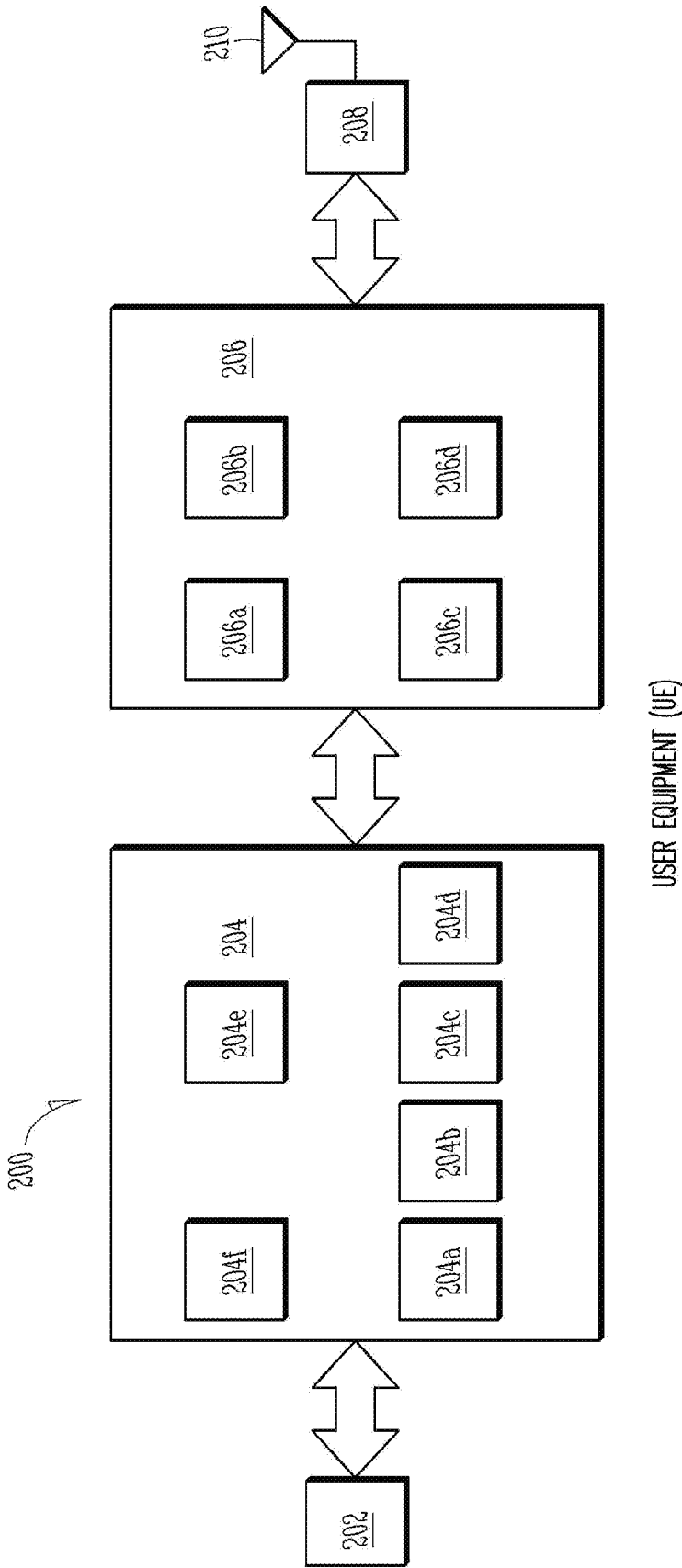


FIG. 2

3/11

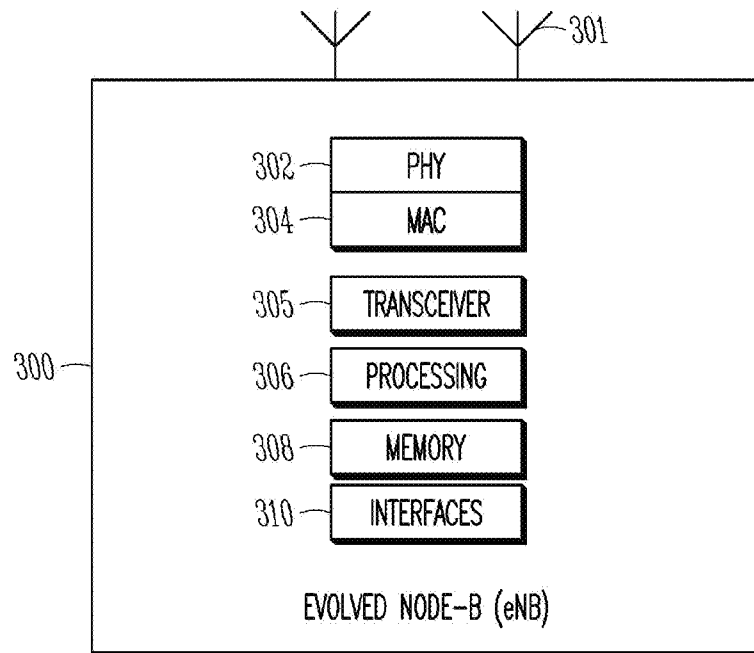


FIG. 3

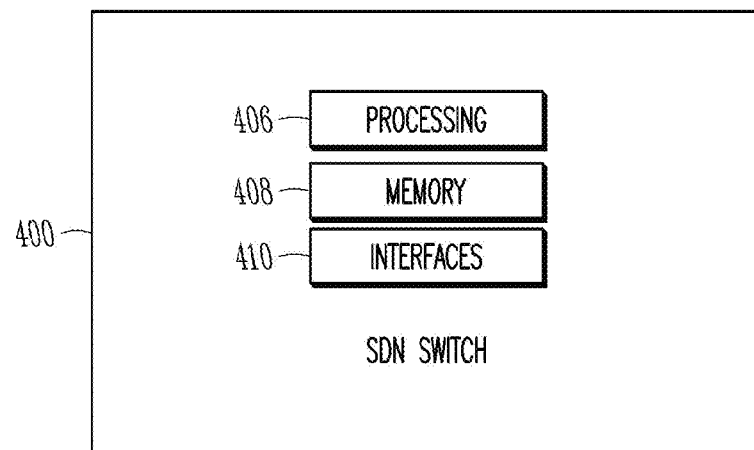


FIG. 4

4/11

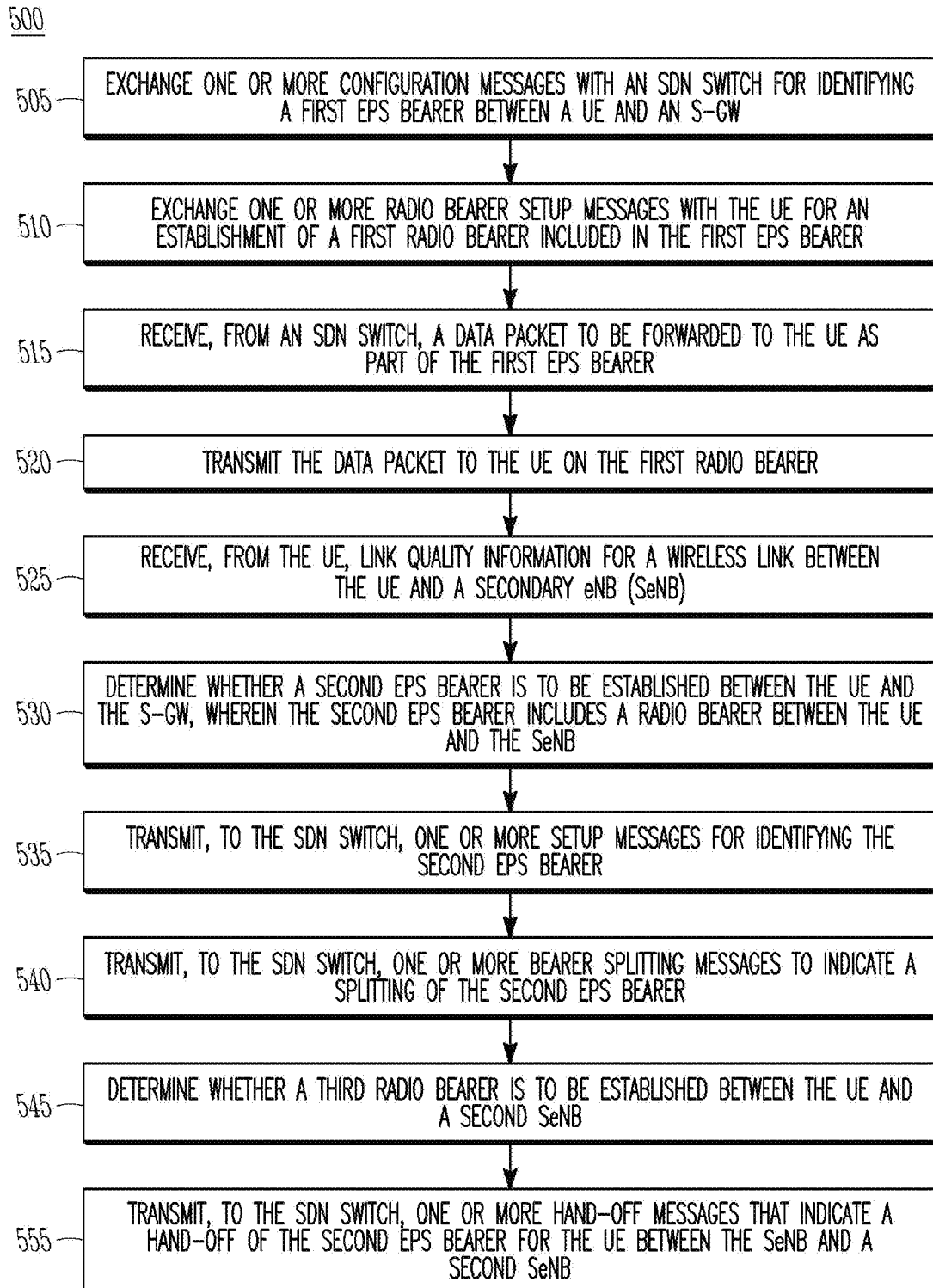


FIG. 5

5/11

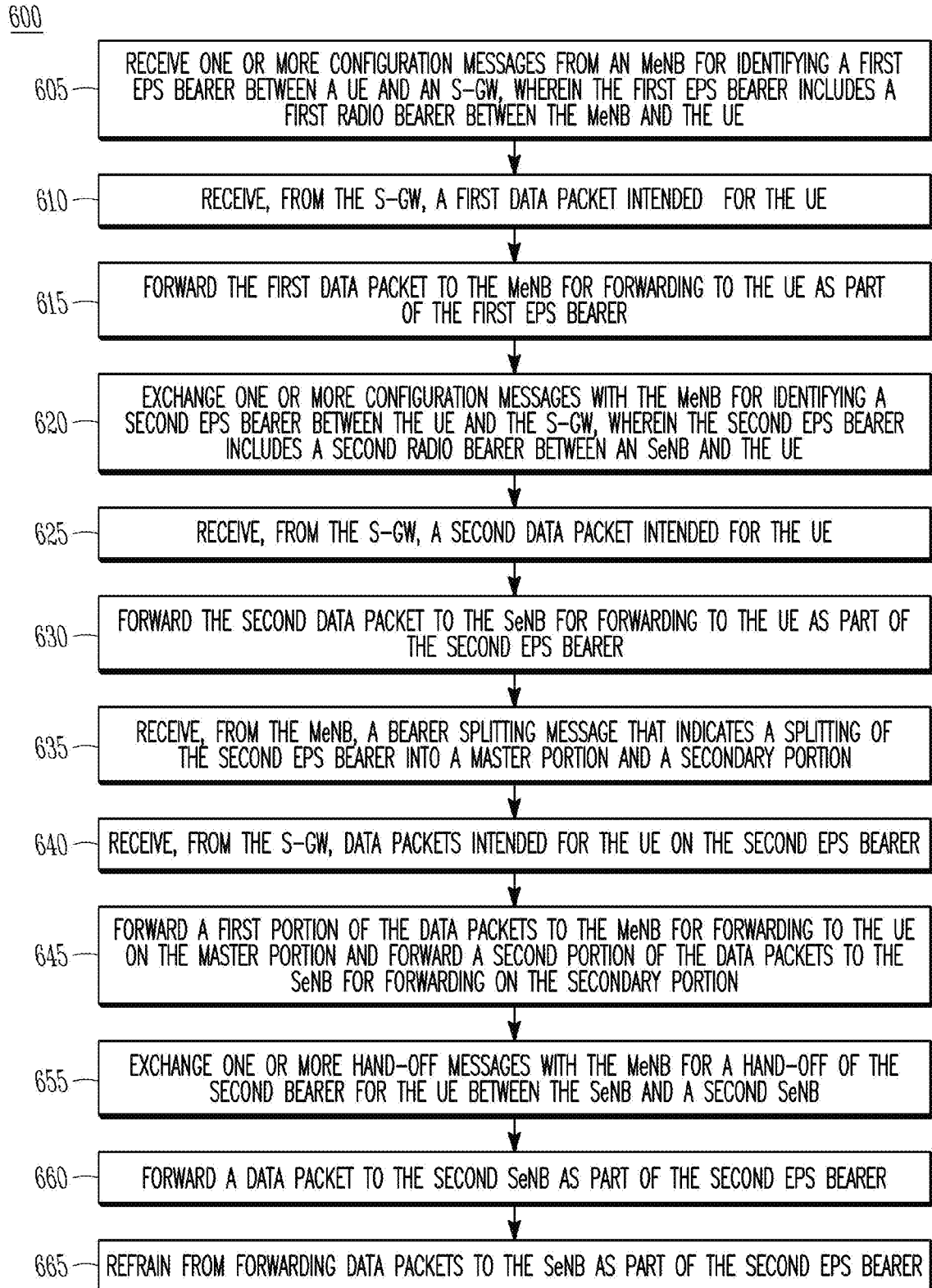


FIG. 6

6/11

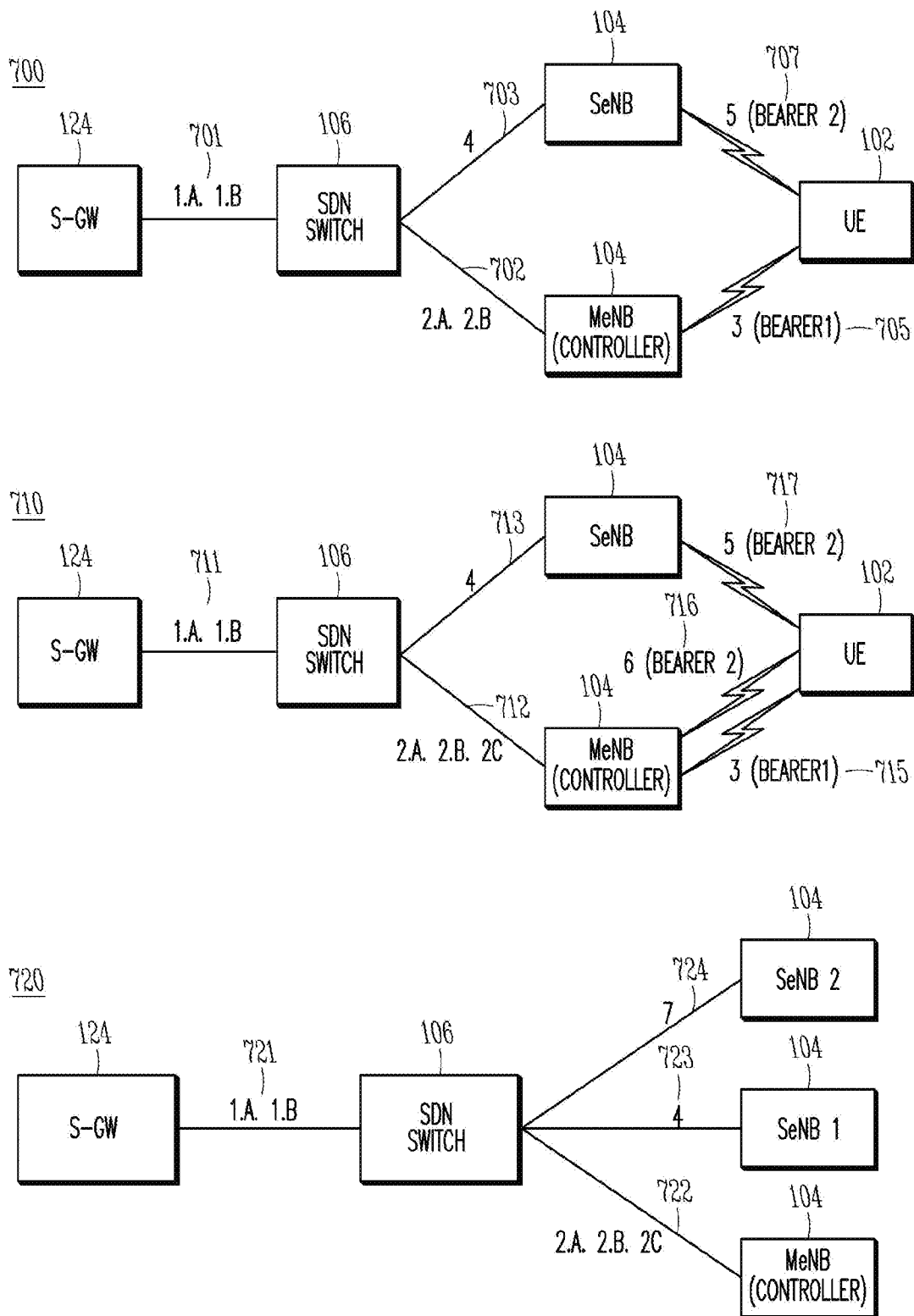


FIG. 7

800

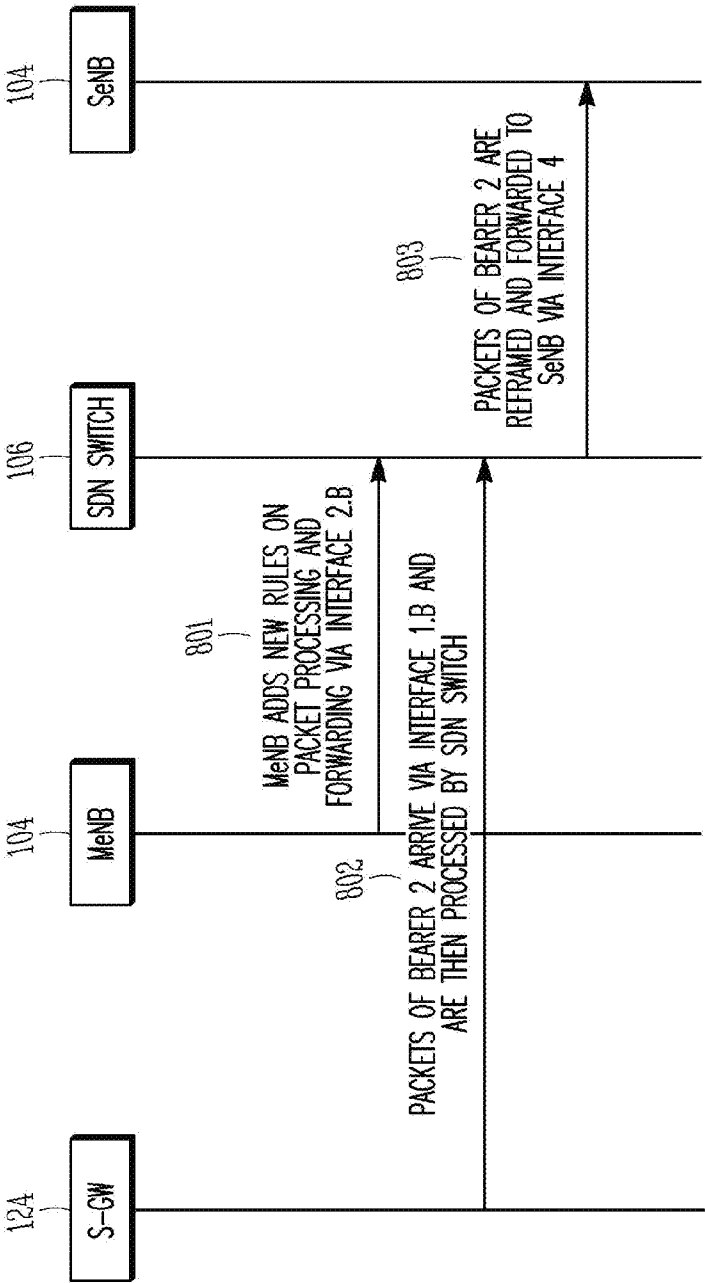


FIG. 8A

810

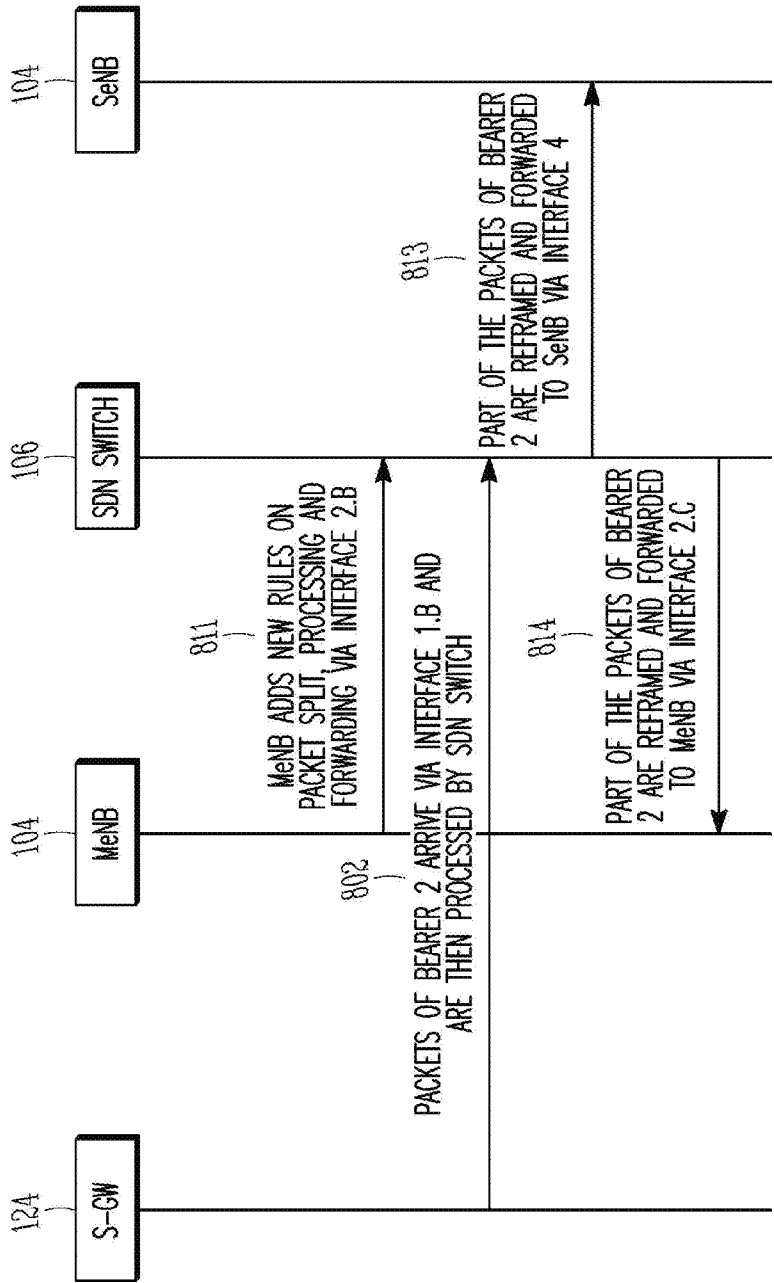


FIG. 8B

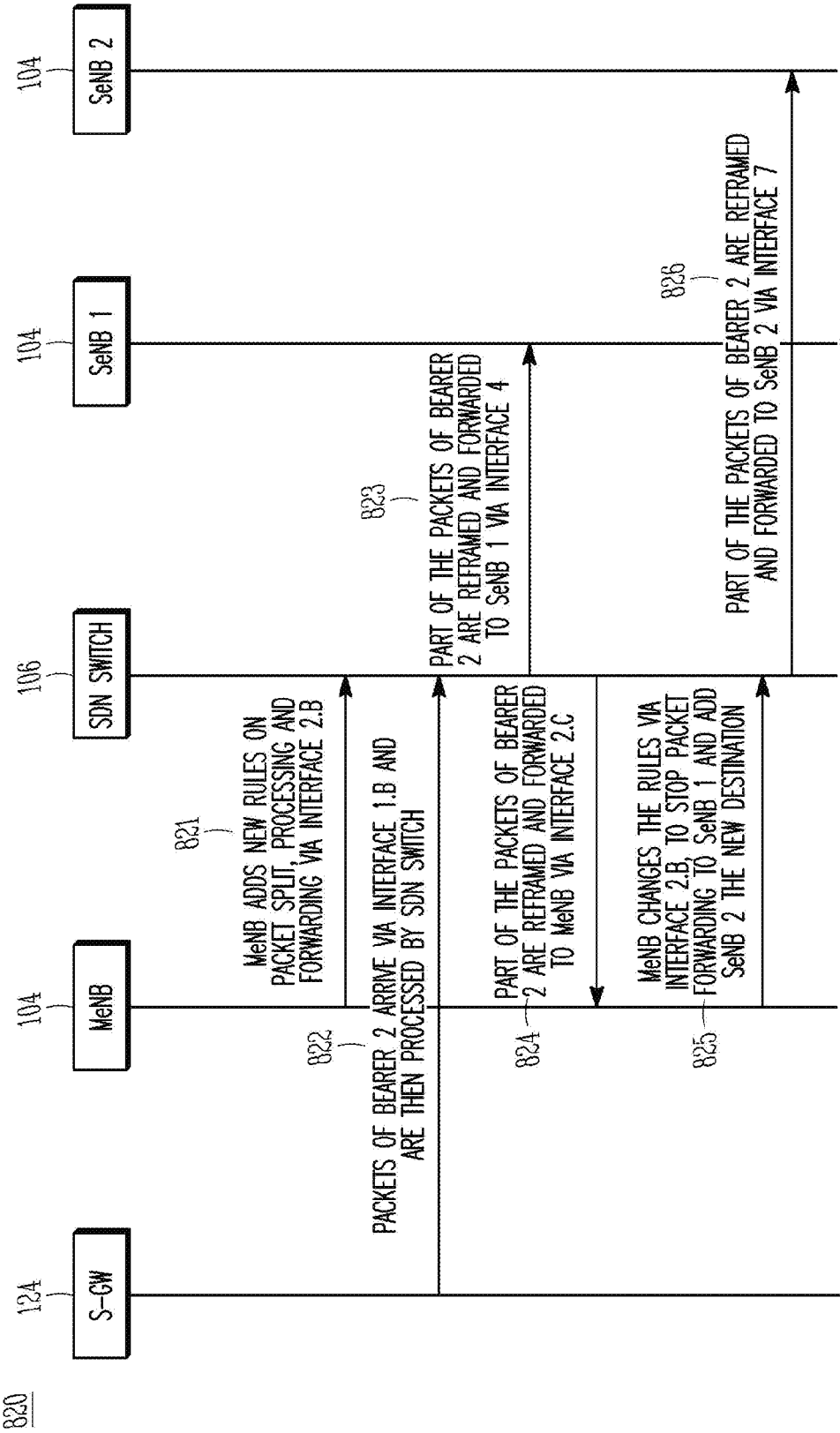


FIG. 8C

10/11

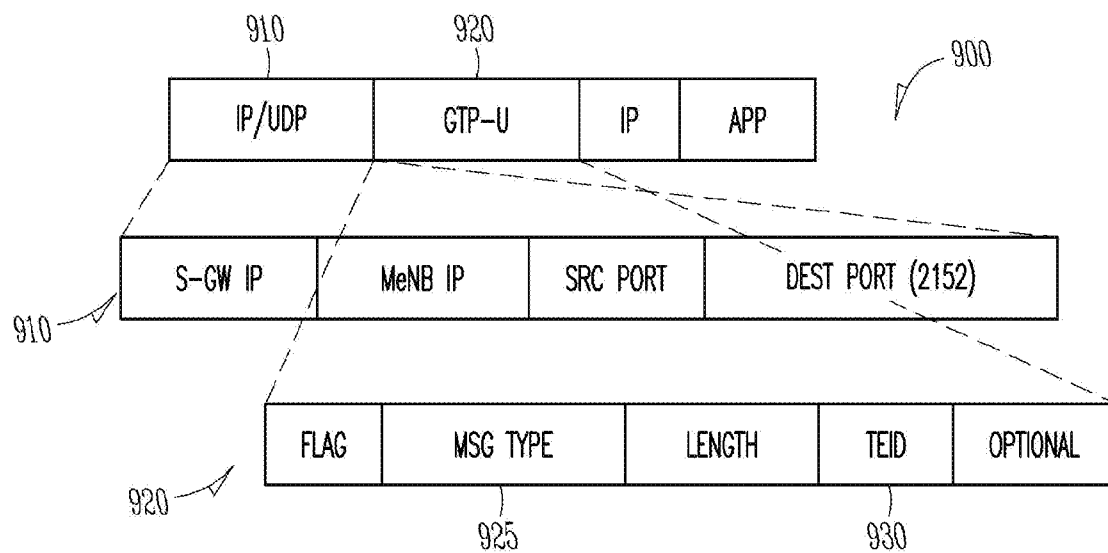


FIG. 9

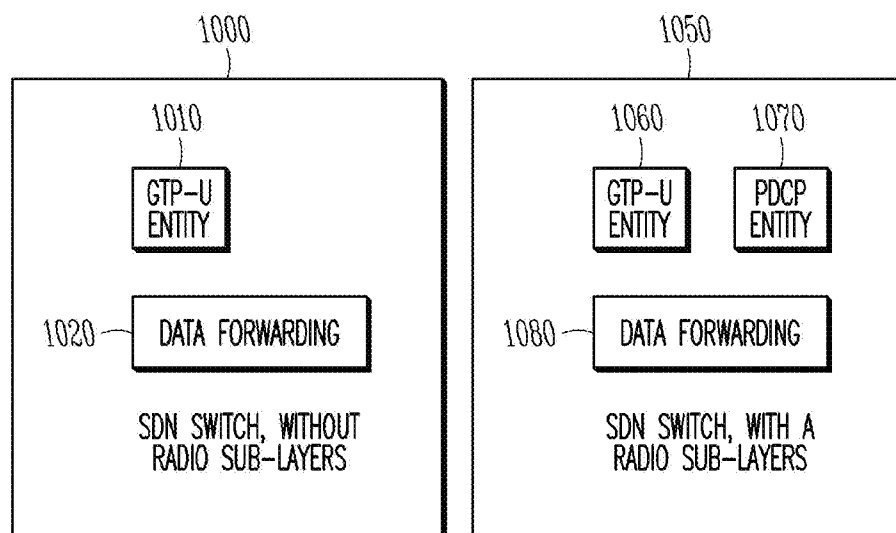


FIG. 10

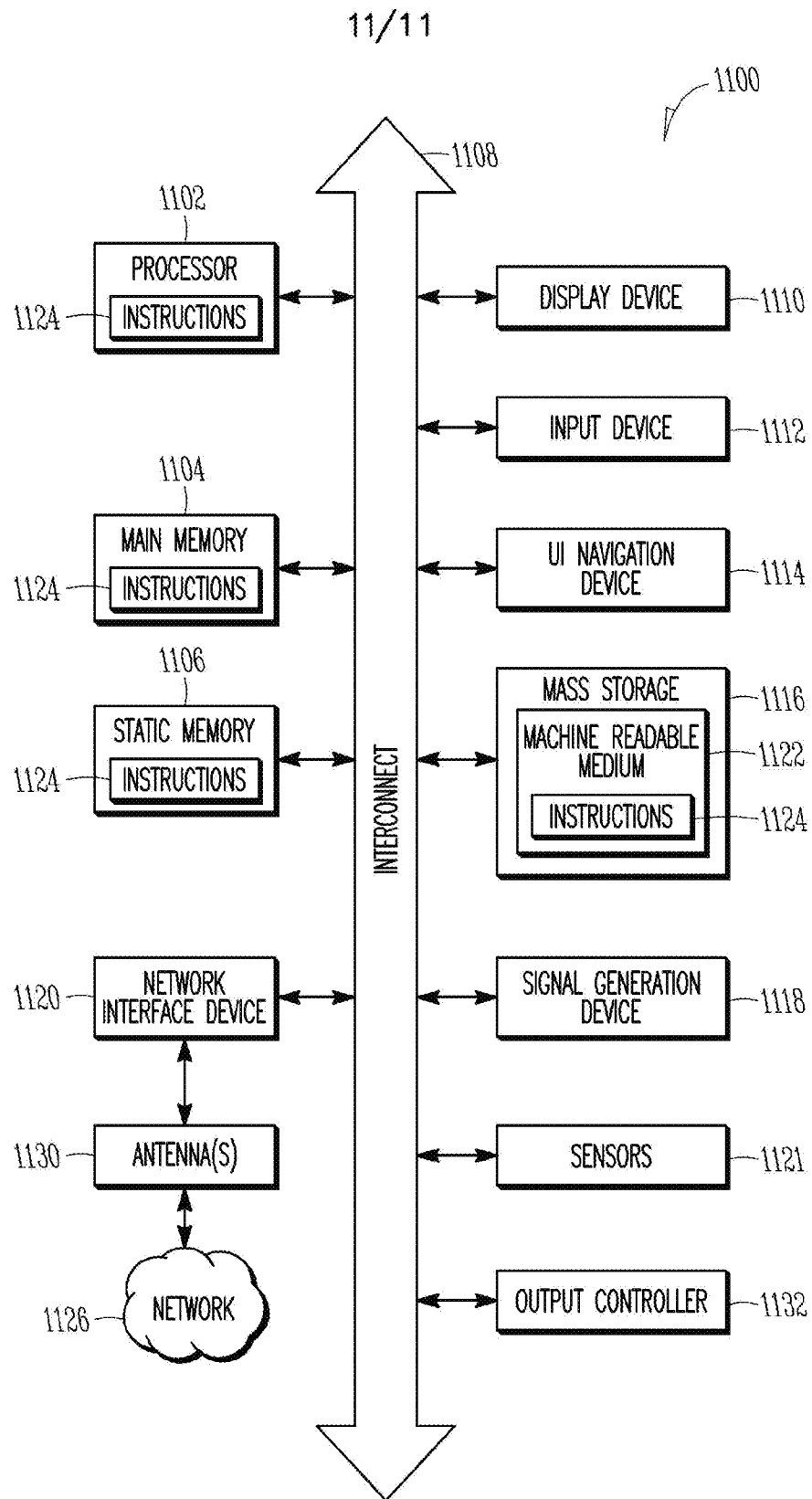


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2015/096691

A. CLASSIFICATION OF SUBJECT MATTER

H04W 88/08(2009.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H04W H04L H04M H04B H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNKI, CNPAT, IEEE, 3GPP, WPI, EPODOC: User Equipment, UE, Evolved Packet System, EPS, serving gateway, SGW, S-GW, Software Defined Network, SDN, master Evolved Node-B, MeNB, secondary Evolved Node-B, SeNB, bearer, MME, switch

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 104219722 A (ZTE CORP.) 17 December 2014 (2014-12-17) description, paragraphs [0006], [0007], [0010], [0011], [0093] and figure 4	1-26
A	CN 104797000 A (POTEVIO INFORMATION TECHNOLOGY CO., LTD.) 22 July 2015 (2015-07-22) the whole document	1-26
A	WO 2015021597 A1 (NOKIA SIEMENS NETWORKS OY) 19 February 2015 (2015-02-19) the whole document	1-26
A	HAMPEL, Georg et al. "Applying Software-Defined Networking to the Telecom Domain" 2013 IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS), 19 April 2013 (2013-04-19), the whole document	1-26
A	3GPP. "Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Study on Small Cell Enhancements for E-UTRA and E-UTRAN – Higher layer aspects" 3GPP TR 36.842 V1.0.0, 30 November 2013 (2013-11-30), the whole document	1-26

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

* Special categories of cited documents:

“A” document defining the general state of the art which is not considered to be of particular relevance
 “E” earlier application or patent but published on or after the international filing date
 “L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
 “O” document referring to an oral disclosure, use, exhibition or other means
 “P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
 “X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
 “Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
 “&” document member of the same patent family

Date of the actual completion of the international search

12 July 2016

Date of mailing of the international search report

19 August 2016

Name and mailing address of the ISA/CN

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2015/096691

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
CN	104219722	A	17 December 2014	WO	2015176462	A1	26 November 2015
CN	104797000	A	22 July 2015	None			
WO	2015021597	A1	19 February 2015	None			