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(54) Title: SPLIT OF CONTROL PLANE AND USER PLANE FOR 5G RADIO ACCESS NETWORKS

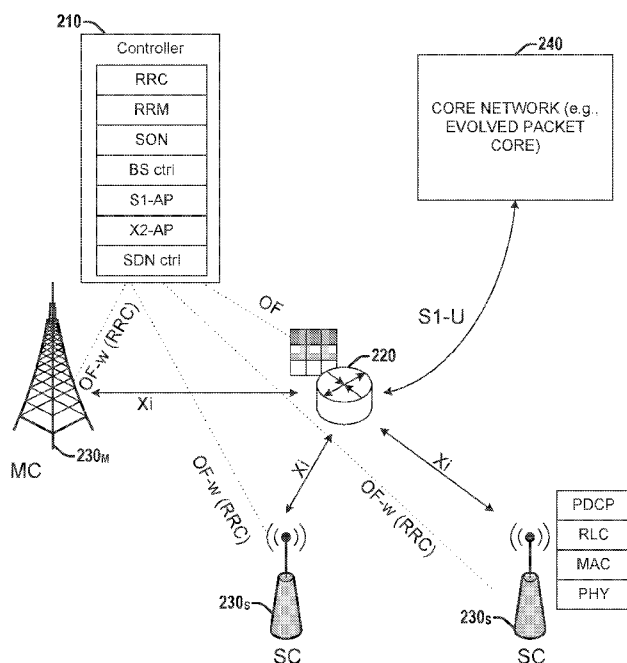


FIG. 2

(57) Abstract: Radio access network (RAN) architectures and associated network entities are discussed. In one example RAN architecture, control plane (CP) and user plane (UP) functionality can be split. The RAN controller can exchange a first set of control messages with the SDN switch via a first interface associated with routing, encapsulation, or decapsulation of user data messages, and can exchange a second set of control messages with one or more base stations (BSs) via a second interface associated with control of an air interface. The SDN switch can also route uplink and downlink user data between the one or more BSs and the core network via third and fourth interfaces. The BSs can facilitate exchange of control messaging between the RAN controller and one or more user equipments (UEs), and exchange of uplink and downlink user data between the UE(s) and the core network via the SDN switch.



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SPLIT OF CONTROL PLANE AND USER PLANE FOR 5G RADIO ACCESS NETWORKS

REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of Patent Cooperation Treaty International Application No. PCT/CN2015/093588 filed November 2, 2015, entitled "SPLIT OF CONTROL PLANE AND USER PLANE FOR 5G RADIO ACCESS NETWORKS", the contents of which are herein incorporated by reference in their entirety.

FIELD

[0002] The present disclosure relates to wireless technology, and more specifically to techniques to facilitate communications in a radio access network (RAN) based on a split of the control plane and user plane.

BACKGROUND

[0003] Multiple architectures have been employed or considered in connection with 4G (fourth generation) and/or 5G (fifth generation) RANs (radio access networks).

[0004] Cloud RAN (CRAN) centralizes the baseband unit (BBU) of base stations (BSs) in a central office and utilizes cloud computing technologies to consolidate BBU resources, thereby providing noticeable pooling gain (i.e., saving of computing resources) as well as performance gain thanks to the capability of enabling advanced algorithms (e.g., CoMP (coordinated multi-point)) JT (joint transmission) and JR (joint reception).

[0005] Stanford proposed SoftRAN to only centralize the control plane (CP) of underlying BSs from RRC (radio resource control), RRM (radio resource management) down to PHY (the physical layer), in a software defined central controller that owns a global view of users and radio resources, and is therefore able to provision optimal performance in theory when performing load balance, interference management, etc.

[0006] EU (European Union) FP7 (seventh frame program) project CROWD (Connectivity management for eneRgy Optimised Wireless Dense networks) put forward an architecture with two-tier controllers for DenseNets based on Software Defined Networking (SDN), which facilitates air interface coordination, including eICIC (enhanced InterCell Interference Coordination).

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] **FIG. 1** is a block diagram illustrating an example user equipment (UE) useable in connection with various aspects described herein.

[0008] **FIG. 2** illustrates a diagram of an example embodiment of a radio access network (RAN) architecture according to various aspects described herein.

[0009] **FIG. 3** illustrates a block diagram of a system that can facilitate generation of control messages in a RAN architecture at a RAN controller according to various aspects described herein.

[0010] **FIG. 4** illustrates a block diagram of a system that can facilitate routing of data messages in a RAN architecture at a software defined network (SDN) switch according to various aspects described herein.

[0011] **FIG. 5** illustrates a block diagram of a system that can facilitate communication of control and data messages between a RAN and one or more user equipments (UEs) by a BS (base station) according to various aspects described herein.

[0012] **FIG. 6** illustrates a diagram of an example embodiment of the Xi interface introduced herein based on IP (Internet Protocol) or Ethernet according to various aspects discussed herein.

[0013] **FIG. 7** illustrates a diagram of an example procedure for initial attachment of a UE to a network implementing a RAN architecture according to various aspects described herein.

[0014] **FIG. 8** illustrates a diagram of an example embodiment of a scalable RAN architecture according to various aspects described herein.

[0015] **FIG. 9** illustrates a pair of diagrams showing two example topologies, star and ring, for embodiments where a macro cell (MC) can be the aggregation point according to various aspects described herein.

[0016] **FIG. 10** illustrates a pair of diagrams showing function splits of the radio and backhaul when the MC is the aggregation point in the star or ring topologies shown in FIG. 9, according to various aspects described herein.

[0017] **FIG. 11** illustrates a diagram of an example embodiment of a RAN architecture with RRC (radio resource control) functions divided between a RAN controller and one or more BSs according to various aspects described herein.

[0018] FIG. 12 illustrates a flow diagram of a method that facilitates communication of control messages to and from a RAN controller according to various aspects described herein.

[0019] FIG. 13 illustrates a flow diagram of a method that facilitates routing of user data messages between a core network and one or more base stations by a SDN switch according to various aspects described herein.

[0020] FIG. 14 illustrates a flow diagram of a method that facilitates transfer of control and data messaging between one or more UEs and a RAN by a BS according to various aspects described herein.

DETAILED DESCRIPTION

[0021] The present disclosure will now be described with reference to the attached drawing figures, wherein like reference numerals are used to refer to like elements throughout, and wherein the illustrated structures and devices are not necessarily drawn to scale. As utilized herein, terms “component,” “system,” “interface,” and the like are intended to refer to a computer-related entity, hardware, software (e.g., in execution), and/or firmware. For example, a component can be a processor (e.g., a microprocessor, a controller, or other processing device), a process running on a processor, a controller, an object, an executable, a program, a storage device, a computer, a tablet PC and/or a user equipment (e.g., mobile phone, etc.) with a processing device. By way of illustration, an application running on a server and the server can also be a component. One or more components can reside within a process, and a component can be localized on one computer and/or distributed between two or more computers. A set of elements or a set of other components can be described herein, in which the term “set” can be interpreted as “one or more.”

[0022] Further, these components can execute from various computer readable storage media having various data structures stored thereon such as with a module, for example. The components can communicate via local and/or remote processes such as in accordance with a signal having one or more data packets (e.g., data from one component interacting with another component in a local system, distributed system, and/or across a network, such as, the Internet, a local area network, a wide area network, or similar network with other systems via the signal).

[0023] As another example, a component can be an apparatus with specific functionality provided by mechanical parts operated by electric or electronic circuitry, in

which the electric or electronic circuitry can be operated by a software application or a firmware application executed by one or more processors. The one or more processors can be internal or external to the apparatus and can execute at least a part of the software or firmware application. As yet another example, a component can be an apparatus that provides specific functionality through electronic components without mechanical parts; the electronic components can include one or more processors therein to execute software and/or firmware that confer(s), at least in part, the functionality of the electronic components.

[0024] Use of the word exemplary is intended to present concepts in a concrete fashion. As used in this application, the term “or” is intended to mean an inclusive “or” rather than an exclusive “or”. That is, unless specified otherwise, or clear from context, “X employs A or B” is intended to mean any of the natural inclusive permutations. That is, if X employs A; X employs B; or X employs both A and B, then “X employs A or B” is satisfied under any of the foregoing instances. In addition, the articles “a” and “an” as used in this application and the appended claims should generally be construed to mean “one or more” unless specified otherwise or clear from context to be directed to a singular form. Furthermore, to the extent that the terms “including”, “includes”, “having”, “has”, “with”, or variants thereof are used in either the detailed description and the claims, such terms are intended to be inclusive in a manner similar to the term “comprising.”

[0025] As used herein, the term “circuitry” may refer to, be part of, or include an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group), and/or memory (shared, dedicated, or group) that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable hardware components that provide the described functionality. In some embodiments, the circuitry may be implemented in, or functions associated with the circuitry may be implemented by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware.

[0026] Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. **FIG. 1** illustrates, for one embodiment, example components of a User Equipment (UE) device 100. In some embodiments, the UE device 100 may include application circuitry 102, baseband circuitry 104, Radio Frequency (RF) circuitry 106, front-end module (FEM) circuitry 108 and one or more antennas 110, coupled together at least as shown.

[0027] The application circuitry 102 may include one or more application processors. For example, the application circuitry 102 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The processor(s) may include any combination of general-purpose processors and dedicated processors (e.g., graphics processors, application processors, etc.). The processors may be coupled with and/or may include memory/storage and may be configured to execute instructions stored in the memory/storage to enable various applications and/or operating systems to run on the system.

[0028] The baseband circuitry 104 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 104 may include one or more baseband processors and/or control logic to process baseband signals received from a receive signal path of the RF circuitry 106 and to generate baseband signals for a transmit signal path of the RF circuitry 106. Baseband processing circuitry 104 may interface with the application circuitry 102 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 106. For example, in some embodiments, the baseband circuitry 104 may include a second generation (2G) baseband processor 104a, third generation (3G) baseband processor 104b, fourth generation (4G) baseband processor 104c, and/or other baseband processor(s) 104d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 6G, etc.). The baseband circuitry 104 (e.g., one or more of baseband processors 104a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 106. The radio control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some embodiments, modulation/demodulation circuitry of the baseband circuitry 104 may include Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 104 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity Check (LDPC) 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.

[0029] In some embodiments, the baseband circuitry 104 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) 104e of the baseband circuitry 104 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) 104f. The audio DSP(s) 104f may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments. Components of the baseband circuitry may be suitably combined in a single chip, a single chipset, or disposed on a same circuit board in some embodiments. In some embodiments, some or all of the constituent components of the baseband circuitry 104 and the application circuitry 102 may be implemented together such as, for example, on a system on a chip (SOC).

[0030] In some embodiments, the baseband circuitry 104 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 104 may support communication with an evolved universal terrestrial radio access network (EUTRAN) and/or other wireless metropolitan area networks (WMAN), a wireless local area network (WLAN), a wireless personal area network (WPAN). Embodiments in which the baseband circuitry 104 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[0031] RF circuitry 106 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 106 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 106 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 108 and provide baseband signals to the baseband circuitry 104. RF circuitry 106 may also include a transmit signal path which may include circuitry to up-convert baseband signals provided by the baseband circuitry 104 and provide RF output signals to the FEM circuitry 108 for transmission.

[0032] In some embodiments, the RF circuitry 106 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 106 may include mixer circuitry 106a, amplifier circuitry 106b and filter circuitry 106c. The transmit signal path of the RF circuitry 106 may include filter circuitry 106c and mixer circuitry 106a. RF

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

[0033] In some embodiments, the mixer circuitry 106a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 106d to generate RF output signals for the FEM circuitry 108. The baseband signals may be provided by the baseband circuitry 104 and may be filtered by filter circuitry 106c. The filter circuitry 106c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

[0034] In some embodiments, the mixer circuitry 106a of the receive signal path and the mixer circuitry 106a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and/or upconversion respectively. In some embodiments, the mixer circuitry 106a of the receive signal path and the mixer circuitry 106a of the transmit signal path may include two or more mixers and may be arranged for image rejection (e.g., Hartley image rejection). In some embodiments, the mixer circuitry 106a of the receive signal path and the mixer circuitry 106a may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 106a of the receive signal path and the mixer circuitry 106a of the transmit signal path may be configured for super-heterodyne operation.

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

[0036] 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.

[0037] In some embodiments, the synthesizer circuitry 106d may be a fractional-N synthesizer or a fractional $N/N+1$ synthesizer, although the scope of the embodiments is not limited in this respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 106d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[0038] The synthesizer circuitry 106d may be configured to synthesize an output frequency for use by the mixer circuitry 106a of the RF circuitry 106 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 106d may be a fractional $N/N+1$ synthesizer.

[0039] In some embodiments, frequency input may be provided by a voltage controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry 104 or the applications processor 102 depending on the desired output frequency. In some embodiments, a divider control input (e.g., N) may be determined from a look-up table based on a channel indicated by the applications processor 102.

[0040] Synthesizer circuitry 106d of the RF circuitry 106 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or $N+1$ (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these 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.

[0041] In some embodiments, synthesizer circuitry 106d may be configured to generate a carrier frequency as the output frequency, while in other embodiments, the

output frequency may be a multiple of the carrier frequency (e.g., twice the carrier frequency, four times the carrier frequency) and used in conjunction with quadrature generator and divider circuitry to generate multiple signals at the carrier frequency with multiple different phases with respect to each other. In some embodiments, the output frequency may be a LO frequency (fLO). In some embodiments, the RF circuitry 106 may include an IQ/polar converter.

[0042] FEM circuitry 108 may include a receive signal path which may include circuitry configured to operate on RF signals received from one or more antennas 110, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 106 for further processing. FEM circuitry 108 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 106 for transmission by one or more of the one or more antennas 110.

[0043] In some embodiments, the FEM circuitry 108 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry may include a low-noise amplifier (LNA) to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 106). The transmit signal path of the FEM circuitry 108 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 106), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 110).

[0044] In various embodiments, network interface controller (NIC) circuitry 112 may include one or more transmission and reception (TX/RX) signal paths, which may connect to one or more data packet networks via network interface circuitry 114. In some embodiments, NIC circuitry 112 may connect to the data packet networks via multiple network interface circuitries 114. The NIC circuitry 112 may support one or more data link layer standards, such as Ethernet, Fiber, Token Ring, asynchronous transfer mode (ATM), and/or any other suitable data link layer standard(s). In some embodiments, each network element that the electronic device 100 may connect to (for example, a base station, network controller, S-GW, SDN switch, MME, P-GW, and the like) may contain a same or similar network interface circuitry 114. Furthermore, The NIC circuitry 112 may include, or may be associated with processing circuitry, such as one or more single-core or multi-core processors and/or logic circuits, to provide

processing techniques suitable to carry out communications according to the one or more data link layer standards used by the NIC circuitry.

[0045] In some embodiments, the UE device 100 may include additional elements such as, for example, memory/storage, display, camera, sensor, and/or input/output (I/O) interface.

[0046] Additionally, although the above example discussion of device 100 is in the context of a UE device, in various aspects, a similar device can be employed in connection with a base station (BS) such as a NodeB or an Evolved NodeB (eNB), or other components of a Radio Access Network (RAN), such as a RAN controller, software defined network (SDN) switch, etc.

[0047] In various aspects, any of a RAN controller, SDN switch, or BS as discussed herein can employ a device such as electronic device 100.

[0048] In embodiments where the electronic device 100 is, implements, is incorporated into, or is otherwise part of a RAN controller, baseband circuitry 104 and/or NIC circuitry 112 may be to generate and/or control transfer of one or more first messages to/from a software defined network (SDN) switch, wherein the one or more first messages can configure the encapsulation, decapsulation, and/or routing of GTP-U packets; generate and/or control transfer of one or more second messages to/from a base station (BS), wherein the one or more second messages can configure the BS, set up/modify/delete wireless pipes and/or perform aerial coordination; generate and/or control transfer of one or more third messages between the BS and the SDN switch, wherein the one or more third messages can include an S1-U payload that includes GTP-U and/or connectionless IP/Ethernet (IP/Eth) packets or data messages; and control conveyance of the GTP-U packets or data messages between a core network (e.g., an evolved packet core (EPC)) entity and the SDN switch.

[0049] In embodiments where the electronic device 100 is, implements, is incorporated into, or is otherwise part of a base station (BS), such as an eNB, NIC circuitry 112 can transmit and receive one or more second messages to and from a RAN controller over an interface configured to control an air interface (e.g., the example OpenFlow-wireless (OF-w) interface discussed herein); transmit and receive one or more third messages to and from a SDN switch over an interface that provides a relay of GTP-U packets of GTP-U data messages between BSs and a core network (e.g., the example Xi interface discussed herein, etc.); wherein one or more first messages are to be transmitted and received between the RAN controller and the SDN switch over an

OpenFlow (OF) interface, and wherein one or more fourth messages are to be transmitted and received between an evolved packet core (EPC) entity and the SDN switch over an S1-U interface. Baseband circuitry 104 can configure the BS to set up/modify/delete one or more wireless pipes and/or perform aerial coordination; wherein the one or more first messages can configure the encapsulation, decapsulation, and/or routing of GTP-U packets, and the one or more third messages can include an S1-U payload including GTP-U and/or connectionless IP/Ethernet (IP/Eth) packets.

[0050] In embodiments where the electronic device 100 is, implements, is incorporated into, or is otherwise part of an SDN switch, baseband circuitry 104 and/or NIC circuitry 112 can transmit and receive one or more first messages to and from a controller over an OpenFlow (OF) interface; wherein one or more second messages are to be transmitted and received between the controller and a base station (BS) over an interface configured to control an air interface (e.g., the example OpenFlow-wireless (OF-w) interface discussed herein); transmit and receive one or more third messages to and from the BS over an interface that provides a relay of GTP-U packets of GTP-U data messages between BSs and a core network (e.g., the example Xi interface discussed herein, etc.); and can transmit and receive one or more fourth messages to and from an evolved packet core (EPC) entity over an S1-U interface; and second circuitry to configure the SDN switch, based on the one or more first messages, encapsulation, decapsulation, and/or routing of GTP-U packets; wherein the BS can set up/modify/delete one or more wireless pipes and/or perform aerial coordination based on the one or more second messages; wherein the one or more third messages include an S1-U payload including GTP-U and/or connectionless IP/Ethernet (IP/Eth) packets or data messages, and wherein the one or more fourth messages can include one or more GTP-U packets or data messages.

[0051] Various embodiments discussed herein relate to RAN architectures and apparatuses employable in such RAN architectures to meet 5G requirements. Multiple challenges arise in designing an architecture for a 5G network.

[0052] First, the RAN can become ultra-dense and heterogeneous, as a significant number of small cells (SC) are likely to be added to boost the peak data rate up to 10Gbps. This presents a challenge for network configuration, management and interoperability.

[0053] Second, limited coverage of a single SC and large numbers of SCs can pose a challenge to mobility management, leaving the single MME (mobility management entity) approach currently employed insufficient to provision robust mobility in 5G.

[0054] Third, if the paradigm of 3GPP (third generation partnership project) Dual Connectivity (DC) is followed, traffic of DC enabled UEs within the coverage of a macro cell (MC) that can be up to several hundred Gbps will be aggregated at the macro cell, posing a challenge to the transport network and processing capacity. Moreover, as the traffic finally terminated in the SC has to traverse the MC, extra end-to-end latency can be introduced due to the round trip between the MC and the last hop router, which runs contrary to the goal of ultra-low latency, one of the key objectives of 5G.

[0055] Fourth, a standalone deployment of mmWave SCs without assistance from MC poses a challenge in terms of mobility and air interface coordination, if the only medium that can be relied on to exchange signaling between SCs is the X2 interface, as in conventional systems.

[0056] The various conventional architectures—CRAN, SoftRAN, and the CROWD architecture—are all insufficient to meet the design challenges for 5G discussed above.

[0057] For CRAN, the ultra-high bandwidth required for the fronthaul, the interface between the central office and the remote radio head (RRH), suggest that CRAN is not suitable for deployment anywhere, particularly in the 5G scenario where the throughput of mmWave is anticipated to be up to 10Gbps.

[0058] For SoftRAN, the requirement on fronthaul bandwidth is relieved as compared with CRAN. However, on the one hand, SoftRAN depends on an interface with transmission latency down to 1ms for LTE and roughly 0.1ms for 5G, and on the other, SoftRAN will use a RAT (radio access technology)-specific interface to control a BS which could be either 3GPP or WLAN, therefore the approach is neither efficient for a multi-RAT scenario (a typical 5G use case), nor applicable for a deployment where transport of low latency is hard to acquire.

[0059] For CROWD, due to the relatively loose coupling between the controller and the underlying BS, issues like how to efficiently support mobility among SCs and multi-RAT deployment are not solved.

[0060] Various embodiments discussed herein relate to RAN architectures, associated network entities, and techniques that can address the design challenges of 5G networks discussed above.

[0061] In a first set of aspects, the control plane (CP) of a BS can be split at an appropriate level, centralizing part of the CP (e.g., RRM, etc.) in a central controller (e.g., a RAN controller such as that described herein), while leaving other portions of the CP (e.g., MAC (medium access control)) and the user plane (UP) on BSs that are distributed. This C/U split can relieve the requirement on latency of the signaling interface, can facilitate mobility among SCs, and can guarantee low latency for critical data.

[0062] In a second set of aspects, both 3GPP (third generation partnership project) and non-3GPP BSs (e.g., NodeBs (NBs), Evolved NodeBs (eNBs), WiFi routers, etc.) can be abstracted as wireless pipes, and an open interface can be defined comprising common messages to LTE (long term evolution), Wifi, etc., that can manipulate setup, modification, and takedown of connections toward UEs.

[0063] In a third set of aspects, the control and the data of the backhauls (e.g., via the S1-U application protocol for LTE) can be separated, centralizing the control in a central controller (e.g., a RAN controller as described herein), while implementing the data plane on software defined network (SDN) switch(es) (e.g., such as a SDN switch as described herein), which can terminate backhauls toward the core network (e.g., toward an evolved packet core (EPC)), while connecting to one or more BSs via connectionless transport such as Internet Protocol (IP) or Ethernet (Eth) or other interfaces.

[0064] Various embodiments discussed herein can better meet the 5G design goals than conventional RAN architectures. Compared with CRAN and SoftRAN, embodiments discussed herein neither need a fronthaul of ultra-high bandwidth (which CRAN requires) nor requires a signaling interface with latency no more than 1ms for LTE or 0.1 ms for 5G (which SoftRAN requires) as a prerequisite for the controller-BS system to work properly. Compared with CROWD, a RAN controller as discussed herein has a tighter relation with the underlying BS, and is therefore able to provide better performance.

[0065] The abstraction of the BS(s) as wireless pipes and the termination of backhauls at the SDN switch can make unified control interface and common connectionless transport a reality, and can thus readily support multi-RAT deployment. Meanwhile, the SDN switch can avoid aggregation of traffic and thereby reduce latency.

[0066] Referring to **FIG. 2**, illustrated is an example embodiment of a radio access network (RAN) architecture according to various aspects described herein. In the

example embodiment of FIG. 2, the control plane (CP) of the underlying 3GPP BS, including RRC (radio resource control), RRM (radio resource management), S1-AP (the S1 application protocol), X2-AP (the X2 application protocol), etc., and the CP of the backhaul (e.g., S1-U) can be split and centralized in a central controller (as shown in FIG. 2, functionality at the RAN controller 210 can also comprise SON (self-organized networking), BS (base station) 230 control, and control of SDN switch 220). The RAN of the example embodiment shown in FIG. 2 can be re-architected from a conventional 3GPP architecture, with interfaces and network elements as described herein.

[0067] The following interfaces can be employed in the RAN architecture of FIG. 2. A first interface shown in FIG. 2 (labeled as “OF”) can be an embodiment of an OpenFlow interface (e.g., which can be configured with one or more extensions as described herein to handle GTP-U packets) that can convey messages between an SDN switch 220 and RAN controller 210 associated with configuration of the encapsulation, decapsulation, and/or routing of GTP-U packets. A second interface shown in FIG. 2 (labeled as “OF-W”) can be an interface configured to control an air interface, such as the example interface introduced herein and referred to as OpenFlow-wireless, and can convey messages between one or more BSs 230 and a RAN controller 210 for one or more of configuration of the underlying BS, setup/modification/deletion of wireless pipes, or performing aerial coordination. A third interface shown in FIG. 2 (labeled as “Xi”) can be an interface configured to relay GTP-U packets or data messages between the one or more BSs 230 (e.g., one or more macro cells (MCs) 230_M or small cells (SCs) 230_S, which can be 3GPP or non-3GPP BSs, etc.) and a core network 240, such as the example interface introduced herein and referred to as Xi, and can transfer S1-U payload between BS(s) 230 and the SDN switch 220, which can be GTP-U (GPRS (general packet radio service) tunneling protocol user) or connectionless IP (Internet Protocol)/Eth (Ethernet). A fourth interface shown in FIG. 2 (labeled as “S1-U”) can be an S1-U interface that can facilitate transferring GTP-U data messages between an EPC (evolved packet core) 240 and the SDN switch 220.

[0068] The network elements shown in FIG. 2 include a RAN controller 210, one or more BSs 230, a SDN switch 230, and an EPC 240. The RAN controller 210 can host most control functions of the air interface, BS and backhaul. For example, RRC (or at least a portion of RRC) and S1-AP of all UEs can be processed by RAN controller 210, as well as inter-macro/controller X2-AP. Functionality related to access/mobility management and performance optimization, which can include RRM and SON (self-

organized networking) can be implemented in a central manner in the RAN controller 210, which can have a global view of the network. The RAN controller 210 can also take care of SDN control (e.g., via OpenFlow, etc.). The BS(s) 230 (e.g., MC(s) 230_M and/or SC(s) 230_S) can host wireless pipes which can be further divided into signaling pipes (e.g., signaling radio bearers (SRBs) in 3GPP, etc.) and data pipes (e.g., data radio bearers (DRBs) in 3GPP) to facilitate direct transfer of control messages and data messages between UE(s) and various other entities of the RAN architecture. The SDN switch 220 can terminate S1-U towards the EPC 240 and can terminate Xi towards the BS(s) 230. Functionality implemented at the BSs 230 can include PDCP (Packet Data Convergence Protocol), RLC (radio link control), MAC (medium access control), and PHY (the physical layer). The EPC 240 can act as the mobility anchor and gateway for Internet access.

[0069] Referring to **FIG. 3**, illustrated is a block diagram of a system 300 that can facilitate generation of control messages in a RAN architecture at a RAN controller (e.g., such as RAN controller 210) according to various aspects described herein. System 300 can include a processor 310 (e.g., a baseband processor such as one of the baseband processors discussed in connection with FIG. 1), network interface controller (NIC) circuitry 320 (which can comprise one or more NICs for communication via one or more interfaces such as those described herein), and memory 330 (which can comprise any of a variety of storage mediums and can store instructions and/or data associated with one or more of processor 310 or NIC circuitry 320). In various aspects, system 300 can be included within a RAN controller such as the example RAN controllers discussed herein. As described in greater detail below, system 300 can facilitate at least a portion of control messaging in a RAN architecture.

[0070] Processor 310 can send and receive multiple types of control messages to and from one or more SDN switches (e.g., SDN switch 220) over a first interface (e.g., an OpenFlow interface, which can be modified as discussed herein) and to and from one or more BSs (e.g., BS(s) 230) over a second interface that can be configured to control an air interface (e.g., such as the interface introduced herein and referred to as OpenFlow-wireless, etc.).

[0071] In connection with this first interface, processor 310 can generate a first subset of a first set of messages (e.g., OpenFlow messages) that can be associated with one or more of encapsulation, decapsulation, or routing of one or more GTP-U data messages by SDN switch(es) such as SDN switch 220. In some aspects, one or more

of these messages can indicate a BS for an SDN switch to route GTP-U data messages associated with a given UE. In the same or other aspects, one or more of these messages can indicate whether a SDN switch should route GTP-U data messages based on a GTP-U encapsulation, or a connectionless IP or Eth encapsulation. In some such aspects, an encapsulation can be indicated to apply to all BSs, or for one or more BSs (e.g., indicating specific BSs, categories of BSs, etc.). Processor 310 can output the first subset of the first set of messages for transmission to one or more SDN switches via network interface controller (NIC) circuitry 320 for communication via the first interface (e.g., an OpenFlow interface, such as an OpenFlow interface configured with one or more extensions associated with GTP-U data messages). Additionally, processor 310 can also receive other messages of the first set of messages (e.g., a second subset of the first set) from the NIC circuitry 320 that were sent by the one or more SDN switches via the first interface.

[0072] In connection with this second interface, processor 310 can generate a first subset of a second set of messages that can be associated with configuration of one or more BSs, configuration of connections between the one or more BSs and one or more UEs communicating with the one or more BSs over the air interface, or a combination thereof. Processor 310 can output the first subset of the second set of messages for transmission to one or more BSs via NIC circuitry 320 for communication via the second interface (e.g., which can be an interface for control of the air interface between the BS(s) and the UE(s), such as the OpenFlow-wireless interface introduced herein). Processor 310 can also receive from the NIC circuitry 320 a second subset of messages of the second set, which can include messages the BS(s) received from the UE(s) and directly transferred to the NIC circuitry 320, or messages originating from the BSs. Examples of messages of the second set that are associated with configuration of the one or more BSs can be messages associated with one or more of self-organized networking, cell configuration, paging, handover control, or with any of setup, modification, or deletion of UE context. Examples of such messages associated with configuration of connections between the one or more BSs and the one or more UEs include messages associated with one or more of setup, modification, or deletion of a wireless pipe (e.g., a signaling pipe such as a SRB or a data pipe such as a DRB, etc.), or radio resource control (RRC) messaging to be directly transferred by a BS to a UE. In some aspects, all downlink (DL) RRC messages can be generated by processor 310, with processor 310 responding to all uplink (UL) RRC messaging from the one or more

UEs. In other aspects, a first set of RRC messages can be generated by processor 310, and a second set of RRC messages can be generated at the one or more BSs, for example, with the one or more BSs generating RRC messaging that is more time sensitive, and processor 310 generating RRC messaging that need not occur in real time.

[0073] Referring to **FIG. 4**, illustrated is a block diagram of a system 400 that can facilitate routing of data messages in a RAN architecture at a software defined network (SDN) switch (e.g., such as SDN switch 220) according to various aspects described herein. System 400 can include a processor 410 (e.g., a baseband processor such as one of the baseband processors discussed in connection with FIG. 1), NIC circuitry 420 (which can comprise one or more NICs for communication via one or more interfaces such as those described herein), and memory 430 (which can comprise any of a variety of storage mediums and can store instructions and/or data associated with one or more of processor 410 or NIC circuitry 420). In various aspects, system 400 can be included within a SDN switch such as the example RAN controllers discussed herein. As described in greater detail below, system 400 can facilitate routing of data messaging in a RAN architecture.

[0074] Processor 410 can communicate data messages to and from a core network (e.g., such as EPC 240) over a first interface (e.g., an S1-U interface) via NIC circuitry 420, can receive and respond to control signaling from a RAN controller (e.g., such as RAN controller 210) over a second interface (e.g., an OpenFlow interface that can be modified with one or more extensions associated with GTP-U packets) via NIC circuitry 420, and can communicate data messages to and from one or more BSs (e.g., such as any of BSs 230) over a third interface (e.g., an interface for relaying GTP-U packets between the core network and the one or more BSs, such as the Xi interface introduced herein) via NIC circuitry 420. In general, processor 410 can route data messages between the core network and the one or more BSs over the first and third networks, and the encapsulation, decapsulation and routing of those data messages can be based on control messages received via the second interface.

[0075] In connection with the first interface, processor 410 can receive (via NIC circuitry 420) a first subset of a first set of messages (e.g., DL GTP-U data messages for one or more UEs) from a core network (e.g., core network 240) over the first interface (e.g., an S1-U interface employing the S1 application protocol). Additionally, processor 410 can generate a second subset of the first set of messages (e.g., UL

GTP-U data messages comprising UL data from the one or more UEs), which can comprise packets (e.g., UL user data packets) received from one or more BSs (e.g., BS(s) 230) via messages over the third interface, and can output the second subset of the first set of messages (e.g., GTP-U data messages) for transmission by NIC circuitry 420 to the core network over the first interface. Thus, processor 410 (via NIC circuitry 420) can receive DL user data from the core network and can output UL user data to the core network over the first interface.

[0076] In connection with this second interface, processor 420 can receive (via NIC circuitry 420) a first subset of a second set of messages (e.g., OpenFlow control messages) over the second interface (e.g., an OpenFlow interface, such as one modified with extensions to handle GTP-U data messages, such as by adding the GTP-U message type and TEID to Match Fields and/or adding encapsulation and/or decapsulation of GTP-U packets to Instruction/Action). In aspects, processor 420 can also generate and output to NIC circuitry 420 a second subset of the second set of messages for transmission to the RAN controller in response to control messages received from the RAN controller. The second set of messages can comprise OpenFlow control messages associated with one or more of routing, encapsulation, or decapsulation of GTP-U data messages (e.g., the first set of messages, messages comprising GTP-U packets received over the first interface and resent over the third interface (e.g., via GTP-U, IP, Ethernet, etc.) to one or more BSs, etc.). In some aspects, one or more messages of the second set of messages can be associated with encapsulation or decapsulation of GTP-U data messages, and can indicate, for example, what encapsulation processor 410 can apply to messages sent to the one or more BSs over the third interface (e.g., GTP-U, IP, Ethernet, etc.), either for all of the BSs, or for a subset thereof (e.g., indicated BS(s), indicated type(s) of BSs, etc.). In the same or other aspects, one or more messages of the second set of messages can be associated with routing GTP-U data messages, and can indicate a UE and an associated BS. For GTP-U data packets received by processor 410 via the first interface that are associated with the indicated UE, processor 420 can generate and output a data message (e.g., a GTP-U, IP, or Ethernet data message, etc.), over the third interface comprising those data packets for subsequent transmission by NIC circuitry 420 to the associated BS. In one example scenario, the associated BS can be indicated via a mapping of a TEID (tunneling endpoint identity) associated with the GTP-U data packets to a VLAN (virtual local area network) ID associated with that base

station, and the corresponding message can be output over the third interface for a transmission based on the IEEE (Institute of Electrical and Electronics Engineers) 802.1Q standard or the IEEE 802.1ad standard. In another example scenario, GTP-U can be used for the third interface, and processor 410 can change a destination IP or TEID of a GTP-U data message received via the first interface to a final destination IP or TEID when generating a GTP-U data message to output via the third interface, while leaving other optional fields of the GTP-U data message unchanged.

[0077] In connection with this third interface, processor 410 can generate a first subset of a third set of messages (e.g., DL user data messages) to output to NIC circuitry 420 for transmission to the one or more BSs via the third interface. In various embodiments, the third interface can be configured to relay GTP-U data packets between the one or more BSs and the core network, and can be, for example, the Xi interface introduced herein. In some aspects, the third interface can employ GTP-U encapsulation, while in other aspects, connectionless IP or Ethernet can be employed. Processor 410 can also receive, via NIC circuitry 420, a second set of the third set of messages (e.g., UL user data messages) from the one or more BSs via the third interface. Messages of the first subset of the third set of messages generated by processor 410 can comprise DL user data packets received from GTP-U data messages via the first interface. Additionally, GTP-U data messages of the second subset of the first set of messages generated by processor 410 can comprise UL user data packets received from BSs. Thus, processor 410 can facilitate encapsulation, decapsulation and routing of UL and DL user data packets between the one or more BSs and the core network over the first and third interfaces based on control messages received from the RAN controller over the second interface.

[0078] In some embodiments, an SDN switch comprising system 400 can be collocated with the RAN controller and one of the BSs of the one or more BSs, for example, incorporated into a single entity as a macro cell. In such aspects, the second interface can be entirely internal to that entity, and the third interface can comprise both some internal messaging (e.g., to the BS collocated with system 400) and messaging to one or more other (remote) BSs.

[0079] Referring to **FIG. 5**, illustrated is a block diagram of a system 500 that can facilitate communication of control and data messages between a RAN and one or more user equipments (UEs) by a BS (e.g., such as any of BSs 230) according to various aspects described herein. System 500 can include a processor 510 (e.g., a baseband

processor such as one of the baseband processors discussed in connection with FIG. 1), network interface controller (NIC) circuitry 520 (which can comprise one or more NICs for communication via one or more interfaces such as those described herein), transmitter circuitry 530, receiver circuitry 540, and memory 550 (which can comprise any of a variety of storage mediums and can store instructions and/or data associated with one or more of processor 510, NIC circuitry 520, transmitter circuitry 530, or receiver circuitry 540). In various aspects, system 500 can be included within a BS such as the example BSs discussed herein. In some aspects, the processor 510, the NIC circuitry 520, the transmitter circuitry 530, the receiver circuitry 540, and the memory 550 can be included in a single device, while in other aspects, they can be included in different devices, such as part of a distributed architecture. As described in greater detail below, system 500 can facilitate an air interface between the one or more UEs and a RAN to transfer control messaging and data messaging to and from the RAN and the one or more UEs.

[0080] Processor 510 can receive and respond to control signaling from a RAN controller (e.g., such as RAN controller 210) over a first interface (e.g., an interface configured to control an air interface, such as the OpenFlow-wireless interface introduced herein) via NIC circuitry 520; can receive DL user data messages from and output UL user data messages (e.g., via NIC circuitry 520) to a SDN switch (e.g., such as SDN switch 220) over a second interface configured to route user data messages between the BS and a core network (e.g., such as the Xi interface introduced herein); and can communicate with one or more UEs via an air interface, directly transferring at least a subset of RRC messages between the first interface and the air interface (in some aspects, another subset of RRC messages can be responded to by processor 510), output DL user data received over the second interface for transmission (via transmitter circuitry 530) to the one or more UEs via the air interface, and receiving (via receiver circuitry 540) UL user data via the air interface (based on which processor 510 can generate data messages UL user data messages for transmission over the second interface).

[0081] In connection with the first interface, processor 510 can receive (e.g., via NIC circuitry 520) a first subset of a first set of messages (e.g., a set of control messages) from a RAN controller over a first interface, which can be configured to control the air interface (e.g., such as the OpenFlow-wireless interface introduced herein, etc.). Messages of the first subset of the first set of messages can be associated with

configuration of a BS employing system 500, or of one or more connections between processor 510 and one or more UEs. One or more control messages of the first subset of the first set of messages can be RRC messages composed by the RAN controller for direct transfer to a UE. Processor 510 can also output a second subset of the first set of messages for transmission (e.g., via NIC circuitry 520) to the RAN controller via the first interface. In various aspects, one or more of the second subset of the first set of messages output by processor 510 can be an RRC message received from a UE and directly transferred for transmission (e.g., via NIC circuitry 520) to the RAN controller via the first interface. In the same or other aspects, one or more of the second subset of the first set of messages output by processor 510 can be a message generated by processor 510 in response to a message associated with configuration of a BS employing system 500.

[0082] One or more messages of the first set of messages (e.g., control messages) received by processor 510 can be associated with configuration of the BS employing system 500. In such aspects, processor 510 can configure or reconfigure the BS in one or more ways based on those one or more messages, such as reconfiguration based on messages associated with self-organized networking, with cell configuration, with paging, with handover control, with setup/modification/deletion of UE context, etc.

[0083] In the same or other aspects, based on one or more messages of the first set of messages, processor 510 can setup, modify, or delete a wireless connection (e.g., a wireless pipe such as a signaling pipe or data pipe) with a UE of the one or more UEs.

[0084] In connection with the second interface, processor 510 can receive (e.g., via NIC circuitry 520), a first subset of a second set of messages (e.g., a set of data messages comprising DL user data) from an SDN switch over the second interface. Based on the received messages of the second set of messages, processor 510 can generate a set of downlink radio frames comprising the DL user data and output the set of DL radio frames to transmitter circuitry 530 for transmission to the one or more UEs via the air interface. Additionally, UL user data received by processor 510 (e.g., from receiver circuitry 540 via the air interface) from the one or more UEs can be output by processor 510 for transmission (e.g., via NIC circuitry 520) over the second interface to the SDN switch. In various aspects, the second set of messages can be GTP-U, IP, or Ethernet data messages.

[0085] In connection with the air interface, processor 510 can directly transfer RRC messages received from the RAN controller to transmitter circuitry 530 for transmission

over the air interface, and processor 510 can output the generated set of DL radio frames to the transmitter circuitry 530 for transmission over the air interface.

Additionally, processor 510 can receive (e.g., via receiver circuit 540) one or more uplink RRC messages from the one or more UEs. In a first set of embodiments, processor 510 can either directly transfer all RRC messages to be sent via the first interface to the RAN controller. In a second set of embodiments, processor 510 can directly transfer a first set of RRC messages (e.g., RRC messages that need not be responded to in real time) to be sent via the first interface to the RAN controller, and can generate and output (for transmission via the air interface by transmitter circuitry 530) one or more additional RRC messages in response to a second set of RRC messages (e.g., RRC messages that are time sensitive).

[0086] In various aspects, example embodiments of interfaces are provided herein, such as for: (1) the interface between the RAN controller (e.g., RAN controller 210) and the SDN switch (e.g., SDN switch 220), which can be, for example, an OpenFlow (OF) interface modified with extensions to support GTP-U packets; (2) the interface between the RAN controller and the one or more BSs (e.g., BS(s) 230), which can be, for example, the OpenFlow-wireless (OF-w) interface introduced herein; (3) the interface between the SDN switch and the one or more BSs, which can be, for example, the Xi interface introduced herein; and (4) the interface between the SDN switch and the core network, which can be, for example, the S1-U interface.

[0087] An example embodiment of OF-w can comprise the following messages listed in Table 1:

Table 1: example messages for OF-w

<u>Message Name</u>	<u>Main fields included</u>
Cell configure	Radio frame structure (including scheduling of SIB), antenna installation, intra-frequency /inter-frequency neighbor cells, etc.
Paging configure	Paging message from MME to UE, including UE Paging Identity chosen from S-TMSI or IMSI
Wireless pipe configure	UE Identity, signaling radio bearer (SRB) configure including setup/modify/release a particular signaling pipe, data radio bearer (DRB) configure including set up/modify/release a particular data pipe, L1/L2 configure, MAC CE (used for

	Msg. 4)
UE context setup	UE identity, AS Security info, UE AMBR, DRB configure, L1/L2 configure, RACH configure (used for HO), SN status (used for HO), SRB configure (used for HO)
UE context modify	UE identity, AS security info, UE AMBR
UE context release	UE Identity
UE HO command	UE Identity, RRC-PDU
UE status report	UE Identity, SN status
UL RRC Msg. trans.	UE Identity, RRC-PDU
DL RRC Msg. trans.	UE Identity, RRC-PDU
Control & Anchor Switch	UE Identity, New Controller Identity, New SDN Switch Identity

[0088] Referring to **FIG. 6**, illustrated is an example embodiment of the Xi interface based on IP or Ethernet according to various aspects discussed herein. To support EPS (evolved packet system) session management or bearer differentiation, 802.1Q VLAN or 802.1ad stacked VLANs can be used to carry the information contained in the TEID. The management of VLAN_ID (i.e. mapping of TEID, which can have a length of 32 bits, to VLAN ID, which can have a length of 12 bits or its multiples) can be performed by an S1-AP entity (e.g., which can be part of a RAN controller such as RAN controller 210), and configuration of the SDN switch (e.g., SDN switch 220) and the MC(s)/SC(s) (e.g., BSs 230) can be respectively handled by SDN ctrl and BS ctrl (e.g., which can be implemented by a RAN controller such as RAN controller 210). IP/Eth could reduce the redundancy brought by GTP-U header, while unifying and simplifying the processing of Xi at MC/SC, regardless of LTE, WLAN or other emerging RATs such as mmWave.

[0089] In other example embodiments, the Xi interface can reuse GTP-U. The SDN switch (e.g., SDN switch 220) can change the destination IP (e.g., the IP of the controller or MC) to the IP of its 'real' destination (e.g., the SC that will deliver the GTP-U packet(s) to the relevant UE) while keeping unchanged the optional fields, such as sequence number. The relationship between the 'real' destination IP and the TEID can be provided by the S1-AP (e.g., by RAN controller 220), and configuration of the SDN switch and MC/SC can be respectively handled by SDN ctrl and BS ctrl.

[0090] The OF (OpenFlow) interface can be based on the OF indicated via the technical specification specified by the Open Network Foundation (ONF), with

extensions to handle GTP-U, which can include respectively adding GTP-U message type and TEID to Match Fields, and adding encapsulation and decapsulation of GTP-U packets to Instruction/Action.

[0091] Referring to **FIG. 7**, illustrated is a diagram of an example procedure for initial attachment of a UE to a network implementing a RAN architecture according to various aspects described herein. In the example procedure illustrated in FIG. 7, messages exchanged between the BS and controller can comprise messages defined in Table 1.

[0092] Referring to **FIG. 8**, illustrated is a diagram of an example embodiment of a scalable RAN architecture according to various aspects described herein. The example embodiment in FIG. 8 is similar to that of FIG. 2, but in the example shown in FIG. 8, the RAN controller 210 can control more than one SDN switch 220. Because of the split of the CP and the UP for the BS(s) 230 and the termination of the backhaul at the SDN switch 220, the number of SDN switches 220 can be scaled up to accommodate a very large number of BS(s) 230, which can satisfy the demand of ever-increasing data rates within a particular geographic area in an incremental manner. The capacity of the RAN controller 210 can be upgraded as well, which can be readily accomplished if NFV (network function virtualization) is employed.

[0093] Referring to **FIG. 9**, illustrated is a pair of diagrams showing two example topologies, star and ring, for embodiments where a macro cell 230_M can be the aggregation point according to various aspects described herein. Referring to **FIG. 10**, illustrated is a pair of diagrams showing function splits of the radio and backhaul when the MC 230_M is the aggregation point in the star and ring topologies shown in FIG. 9, according to various aspects described herein. For the two deployments shown in FIGS. 9 and 10, the MC 230_M rather than the SDN switch 220 (not shown in FIGS. 9 or 10) can be the aggregation point toward the core network (e.g., via SGW (serving gateway) 250). For such embodiments, the function splits discussed herein can still apply; however, as seen in FIG. 10, the OF interface can become an internal interface of MC 230_M. In the ring topology, individual BSs can communicate with one another via the Xi (or other similar) interface in a manner similar to that described herein in connection with communications between a BS and SDN switch via the Xi (or other similar) interface. Compared with a conventional MC, the proposed architecture described above can be superior both in terms of efficiency and scalability.

[0094] Referring to **FIG. 11**, illustrated is an example embodiment of a RAN architecture with RRC functions divided between a RAN controller 210 and one or more

BSs 230 according to various aspects described herein. In one set of embodiments associated with the example illustrated in FIG. 10, RRC can be further split into real-time (RT) and non-RT parts, and the former can reside at the BS(s) 230 to reduce signaling latency, while the latter can be centralized in the RAN controller 210.

[0095] An example of an RRC RT portion is the functionality that handles RRC connection establishment. An example of an RRC non-RT portion is the functionality that handles RRC connection reconfiguration, measurement, and inter-RAT mobility.

[0096] Referring to **FIG. 12**, illustrated is a flow diagram of a method 1200 that facilitates communication of control messages to and from a RAN controller according to various aspects described herein. In some aspects, method 1200 can be performed at a RAN controller. In other aspects, a machine readable medium can store instructions associated with method 1200 that, when executed, can cause a RAN controller to perform the acts of method 1200.

[0097] At 1210, one or more control messages of a first set of control messages can be generated. Control messages of the first set can be associated with GTP-U data messages, such as routing of GTP-U data messages (e.g., indicating target BS(s) for GTP-U data messages associated with a given UE, etc.), or encapsulation or decapsulation of GTP-U data messages (e.g., as IP, Eth, or GTP-U, etc.).

[0098] At 1220, the one or more generated control messages of the first set can be output to a SDN switch via a first interface (e.g., an OF interface).

[0099] At 1230, one or more additional control messages of the first set can be received from the SDN switch via the first interface.

[00100] At 1240, one or more control messages of a second set can be received from one or more BSs via a second interface associated with configuration of an air interface (e.g., the OF-w interface introduced herein). Control messages of the second type can be associated with configuration of the one or more BSs, or configuration of connections between the one or more BSs and one or more UEs.

[00101] At 1250, one or more additional control messages of the second set can be generated. At least one of the additional control messages of the second set can be a RRC message generated in response to a RRC message directly transferred from a UE to the RAN controller by a BS via the second interface.

[00102] At 1260, the one or more additional control messages of the second set can be output to the one or more BS(s) via the second interface.

[00103] Referring to **FIG. 13**, illustrated is a flow diagram of a method 1300 that facilitates routing of user data messages between a core network and one or more base stations by a SDN switch according to various aspects described herein. In some aspects, method 1300 can be performed at a SDN switch. In other aspects, a machine readable medium can store instructions associated with method 1300 that, when executed, can cause a SDN switch to perform the acts of method 1300.

[00104] At 1310, a first set of UL and DL user data messages can be exchanged with a core network via a first interface (e.g., a S1-U interface, etc.). In aspects, this can comprise one or more of receiving DL user data messages from the core network (e.g., GTP-U data messages), or generating and outputting UL user data messages (e.g., GTP-U data messages) based on UL packets received from one or more BSs (e.g., at 1330).

[00105] At 1320, control messages can be exchanged with a RAN controller via a second interface (e.g., an OF interface, which can be modified with extensions associated with GTP-U data messages). In aspects, this can comprise one or more of receiving control messages from the RAN controller, or generating and outputting control messages (e.g., in response to received control messages) to the RAN controller. The exchanged control messages can be associated with GTP-U data messages, and can configure one or more of the routing, encapsulation, or decapsulation of GTP-U data messages or IP or Ethernet messages based thereupon.

[00106] At 1330, a second set of UL and DL user data messages can be exchanged with one or more BSs via a third interface (e.g., the Xi interface introduced herein). In aspects, one or more of the routing, encapsulation or decapsulation of messages of the second set of UL and DL messages can be based at least in part on control messages exchanged at 1320. In various aspects, GTP-U, IP, or Ethernet can be employed for the exchange of the second set of UL and DL user data messages.

[00107] Referring to **FIG. 14**, illustrated is a flow diagram of a method 1400 that facilitates transfer of control and data messaging between one or more UEs and a RAN by a BS according to various aspects described herein. In some aspects, method 1400 can be performed at a BS (e.g., a NB, an eNB, a WiFi router, etc.). In other aspects, a machine readable medium can store instructions associated with method 1400 that, when executed, can cause a BS to perform the acts of method 1400.

[00108] At 1410, one or more control messages can be received from a RAN controller via a first interface (e.g., the OF-w interface introduced herein, etc.). In

aspects, one or more of the received control messages can be an RRC message that can be directly transferred for output and subsequent transmission to an associated UE at 1440. In the same or other aspects, one or more of the received control messages can be associated with configuration of a BS employing method 1400, such as control messages associated with self-organized networking, cell configuration, handover control, setup/modification/deletion of UE context, etc.

[00109] At 1420, one or more DL user data messages can be received from a SDN switch via a second interface (e.g., the Xi interface introduced herein, etc.). In various aspects, the one or more received DL user data messages can be IP, Ethernet, or GTP-U data messages.

[00110] At 1430, one or more DL radio frames can be generated, which can comprise one or more DL payloads received via the one or more DL user data messages.

[00111] At 1440, one or more DL RRC messages and the one or more DL radio frames can be output for transmission to one or more UEs via an air interface. In some aspects, each of the one or more DL RRC messages can be an RRC message received from the RAN controller via the first interface and directly transferred for output and transmission to the one or more UEs. In other aspects, at least one of the RRC messages (e.g., a RT RRC message, etc.) can be a RRC message generated by a BS employing method 1400.

[00112] At 1450, PUSCH can be received via the air interface from the one or more UEs, comprising one or more UL user data messages and one or more UL RRC messages.

[00113] At 1460, the one or more UL user data can be output via the second interface to the SDN switch, and some or all of the one or more UL RRC messages can be output via the first interface to the RAN controller. In some aspects, all of the UL RRC messages can be output to the RAN controller. In other aspects, a first set of the UL RRC messages can be output to the RAN controller (e.g., non-RT RRC, etc.), while a second set can be responded to by a BS employing method 1400 (e.g., RT RRC).

[00114] Examples herein can include subject matter such as a method, means for performing acts or blocks of the method, at least one machine-readable medium including executable instructions that, when performed by a machine (e.g., a processor with memory, an application-specific integrated circuit (ASIC), a field programmable gate array (FPGA), or the like) cause the machine to perform acts of the method or of

an apparatus or system for concurrent communication using multiple communication technologies according to embodiments and examples described.

[00115] Example 1 is an apparatus for use in a radio access network (RAN) controller, comprising a processor configured to: generate a first subset of a first set of messages, wherein each message of the first set of messages is associated with one or more of an encapsulation, a decapsulation, or a routing of one or more general packet radio service (GPRS) tunneling protocol (GTP) user (GTP-U) data messages at one or more software defined network (SDN) switches; output the first subset of the first set of messages for transmission to the one or more SDN switches via a first interface; receive a second subset of the first set of messages from the one or more SDN switches via the first interface; receive a first subset of a second set of messages from one or more base stations (BSs) via a second interface, wherein each message of the second set of messages is associated with a configuration of a BS of the one or more BSs or a configuration of a connection between that BS and one or more user equipments (UEs); generate a second subset of the second set of messages, wherein at least one message of the second subset of the second set of messages is generated in response to at least one message of the first subset of the second set of messages; and output the second subset of the second set of messages for transmission to the one or more BSs via the second interface.

[00116] Example 2 comprises the subject matter of any variation of example 1, wherein at least one message of the first subset of the first set of messages is associated with a first UE of the one or more UEs, and designates a first BS of the one or more BSs for routing GTP-U data messages associated with the first UE.

[00117] Example 3 comprises the subject matter of any variation of example 1, wherein at least one message of the first subset of the first set of messages designates whether to route GTP-U data messages to a first BS of the one or more BSs via a GTP-U encapsulation, an Internet Protocol (IP) encapsulation, or an Ethernet encapsulation.

[00118] Example 4 comprises the subject matter of any variation of any of examples 1-3, wherein at least one message of the first subset of the second set of messages comprises a radio resource control (RRC) message for a first UE of the one or more UEs.

[00119] Example 5 comprises the subject matter of any variation of example 4, wherein the RRC message is an RRC message of a first set of RRC messages for the

first UE, wherein each RRC message of the first set of RRC messages is distinct from RRC messages of a second set of RRC messages generated at the one or more BSs.

[00120] Example 6 comprises the subject matter of any variation of any of examples 1-3, wherein at least one message of the first subset of the second set of messages is associated with a setup, a modification, or a deletion of a wireless connection between a first UE of the one or more UEs and a first BS of the one or more BSs.

[00121] Example 7 comprises the subject matter of any variation of example 6, wherein the wireless connection between the first UE of the one or more UEs and the first BS of the one or more BSs is one of a signaling radio bearer (SRB) or a data radio bearer (DRB).

[00122] Example 8 comprises the subject matter of any variation of any of examples 1-3, wherein at least one message of the first subset of the second set of messages is associated with one or more of a cell configuration, a paging configuration, a handover control, or a setup, a modification, or a deletion of a UE context.

[00123] Example 9 comprises the subject matter of any variation of any of examples 1-3, wherein at least one message of the first subset of the second set of messages is associated with self-organized networking.

[00124] Example 10 comprises the subject matter of any variation of any of examples 1-3, wherein the second interface is an interface configured to control an air interface.

[00125] Example 11 comprises the subject matter of any variation of any of examples 1-5, wherein at least one message of the first subset of the second set of messages is associated with a setup, a modification, or a deletion of a wireless connection between a first UE of the one or more UEs and a first BS of the one or more BSs.

[00126] Example 12 comprises the subject matter of any variation of example 11, wherein the wireless connection between the first UE of the one or more UEs and the first BS of the one or more BSs is one of a signaling radio bearer (SRB) or a data radio bearer (DRB).

[00127] Example 13 comprises the subject matter of any variation of any of examples 1-12, wherein at least one message of the first subset of the second set of messages is associated with one or more of self-organized networking, a cell configuration, a paging configuration, a handover control, or a setup, a modification, or a deletion of a UE context.

[00128] Example 14 comprises the subject matter of any variation of example 1, wherein at least one message of the first subset of the second set of messages

comprises a radio resource control (RRC) message for a first UE of the one or more UEs.

[00129] Example 15 comprises the subject matter of any variation of example 14, wherein the RRC message is an RRC message of a first set of RRC messages for the first UE, wherein each RRC message of the first set of RRC messages is distinct from RRC messages of a second set of RRC messages generated at the one or more BSs.

[00130] Example 16 comprises the subject matter of any variation of example 1, wherein at least one message of the first subset of the second set of messages is associated with a setup, a modification, or a deletion of a wireless connection between a first UE of the one or more UEs and a first BS of the one or more BSs.

[00131] Example 17 comprises the subject matter of any variation of example 16, wherein the wireless connection between the first UE of the one or more UEs and the first BS of the one or more BSs is one of a signaling radio bearer (SRB) or a data radio bearer (DRB).

[00132] Example 18 comprises the subject matter of any variation of example 1, wherein at least one message of the first subset of the second set of messages is associated with one or more of a cell configuration, a paging configuration, a handover control, or a setup, a modification, or a deletion of a UE context.

[00133] Example 19 comprises the subject matter of any variation of example 1, wherein at least one message of the first subset of the second set of messages is associated with self-organized networking.

[00134] Example 20 comprises the subject matter of any variation of example 1, wherein the second interface is an interface configured to control an air interface.

[00135] Example 21 is an apparatus for use in a software defined network (SDN) switch, comprising a processor configured to: receive a first subset of a first set of messages from a core network via a first interface, wherein each message of the first set of messages is a general packet radio service (GPRS) tunneling protocol (GTP) user (GTP-U) data message; generate a second subset of the first set of messages; output the second subset of the first set of messages for transmission to the core network via the first interface; receive a first subset of a second set of messages from a radio access network (RAN) controller via a second interface, wherein each message of the second set of messages is associated with one or more of an encapsulation, a decapsulation, or a routing of one or more GTP-U data messages of the first set of messages; generate a second subset of the second set of messages; output the second

subset of the second set of messages for transmission to the RAN controller via the second interface; generate a first subset of a third set of messages, wherein each message of the third set of messages comprises a payload of a message of the first set of messages, and wherein each message of the first subset of the third set of messages is output based at least in part on one or more messages of the second set of messages; output the first subset of a third set of messages for transmission to one or more Base Stations (BSs) via a third interface; and receive a second subset of the third set of messages from the one or more BSs via the third interface.

[00136] Example 22 comprises the subject matter of any variation of example 21, wherein at least one message of the first subset of the second set of messages indicates a first BS of the one or more BS associated with a first user equipment (UE) of one or more UEs, wherein, for each message of the first subset of the third set of messages that comprises a payload associated with the first UE, the processor is configured to output that message for transmission to the first BS.

[00137] Example 23 comprises the subject matter of any variation of example 21, wherein a first message of the first subset of the third set of messages is an Internet Protocol (IP) message or an Ethernet message.

[00138] Example 24 comprises the subject matter of any variation of example 23, wherein a first message of the first subset of the second set of messages indicates a mapping of a tunneling endpoint identity (TEID) of a first message of the first subset of the first set of messages to a virtual local area network (VLAN) identity (VLAN ID) of the first message of the first subset of the third set of messages.

[00139] Example 25 comprises the subject matter of any variation of example 21, wherein a first message of the first subset of the third set of messages is a GTP-U data message.

[00140] Example 26 comprises the subject matter of any variation of example 25, wherein a first message of the first subset of the second set of messages indicates a mapping of a tunneling endpoint identity (TEID) of a first message of the first subset of the first set of messages to a TEID of the first message of the first subset of the third set of messages.

[00141] Example 27 comprises the subject matter of any variation of any of examples 21-26, wherein the first interface employs an S1 application protocol.

[00142] Example 28 comprises the subject matter of any variation of any of examples 21-26, wherein the second interface comprises an OpenFlow interface configured with one or more extensions associated with GTP-U data messages.

[00143] Example 29 comprises the subject matter of any variation of any of examples 21-26, wherein the third interface is configured to relay of GTP-U packets of GTP-U data messages between the one or more BSs and the core network.

[00144] Example 30 comprises the subject matter of any variation of any of examples 21-26, wherein the one or more BSs comprise at least two BSs, and the SDN switch is collocated with the RAN controller and a first BS of the at least two BSs.

[00145] Example 31 comprises the subject matter of any variation of any of examples 21-22, wherein a first message of the first subset of the third set of messages is an Internet Protocol (IP) message or an Ethernet message.

[00146] Example 32 comprises the subject matter of any variation of example 31, wherein a first message of the first subset of the second set of messages indicates a mapping of a tunneling endpoint identity (TEID) of a first message of the first subset of the first set of messages to a virtual local area network (VLAN) identity (VLAN ID) of the first message of the first subset of the third set of messages.

[00147] Example 33 comprises the subject matter of any variation of any of examples 21-22, wherein a first message of the first subset of the third set of messages is a GTP-U data message.

[00148] Example 34 comprises the subject matter of any variation of example 33, wherein a first message of the first subset of the second set of messages indicates a mapping of a tunneling endpoint identity (TEID) of a first message of the first subset of the first set of messages to a TEID of the first message of the first subset of the third set of messages.

[00149] Example 35 comprises the subject matter of any variation of any of examples 21-34, wherein the one or more BSs comprise at least two BSs, and the SDN switch is collocated with the RAN controller and a first BS of the at least two BSs.

[00150] Example 36 comprises the subject matter of any variation of example 21, wherein the first interface employs an S1 application protocol.

[00151] Example 37 comprises the subject matter of any variation of example 21, wherein the second interface comprises an OpenFlow interface configured with one or more extensions associated with GTP-U data messages.

[00152] Example 38 comprises the subject matter of any variation of example 21, wherein the third interface is configured to relay of GTP-U packets of GTP-U data messages between the one or more BSs and the core network.

[00153] Example 39 comprises the subject matter of any variation of example 21, wherein the one or more BSs comprise at least two BSs, and the SDN switch is collocated with the RAN controller and a first BS of the at least two BSs.

[00154] Example 40 is an apparatus for use in a Base Station (BS), comprising a processor configured to: receive a first subset of a set of control messages from a radio access network (RAN) controller via a first interface and a first subset of a set of data messages from a software defined network (SDN) switch via a second interface, wherein the first subset of the set of control messages comprises a first set of downlink radio resource control (RRC) messages; directly transfer the first set of downlink radio resource control (RRC) messages to transmitter circuitry for transmission to one or more user equipments (UEs); generate a set of downlink radio frames based on the first subset of the set of data messages; output the set of downlink radio frames to the transmitter circuitry for transmission to the one or more UEs; receive at least one uplink RRC message and at least one uplink data message from the one or more UEs via a physical uplink shared channel (PUSCH); directly transfer the at least one uplink RRC message to the transmitter circuitry for transmission to the RAN controller; generate a second subset of the set of data messages, wherein at least one message of the second subset of the set of data messages comprises data received from the at least one uplink data message; and output the second subset of the set of control messages for transmission to the RAN controller via the first interface and the second subset of the set of data messages for transmission to the SDN switch via the second interface.

[00155] Example 41 comprises the subject matter of any variation of example 40, wherein the processor is further configured to one of setup, modify, or delete a wireless connection to a first UE of the one or more UEs based on at least one message of the first subset of the set of control messages.

[00156] Example 42 comprises the subject matter of any variation of example 40, wherein the processor is further configured to: generate a second set of downlink RRC messages independent of the first subset of the set of control messages; and output the second set of downlink RRC messages for transmission to the one or more UEs.

[00157] Example 43 comprises the subject matter of any variation of example 40, wherein at least one message of the first subset of the set of control messages is

associated with one or more of a cell configuration, a paging configuration, a handover control, or a setup, a modification, or a deletion of a UE context, and wherein the processor is further configured to reconfigure the BS based on the at least one message of the subset of the set of control messages.

[00158] Example 44 comprises the subject matter of any variation of example 40, wherein at least one message of the first subset of the set of control messages is associated with self-organized networking, and wherein the processor is further configured to reconfigure the BS based on the at least one message of the subset of the set of control messages.

[00159] Example 45 comprises the subject matter of any variation of any of examples 40-44, wherein the set of data messages comprise one or more of an Internet Protocol (IP) message or an Ethernet message.

[00160] Example 46 comprises the subject matter of any variation of any of examples 40-44, wherein the set of data messages comprise a general packet radio service (GPRS) tunneling protocol (GTP) user (GTP-U) data message.

[00161] Example 47 comprises the subject matter of any variation of example 40, wherein the set of data messages comprise one or more of an Internet Protocol (IP) message or an Ethernet message.

[00162] Example 48 comprises the subject matter of any variation of example 40, wherein the set of data messages comprise a general packet radio service (GPRS) tunneling protocol (GTP) user (GTP-U) data message.

[00163] Example 49 is a machine readable medium comprising instructions that, when executed, cause a Base Station (BS) to: receive a set of downlink radio resource control (RRC) messages from a radio access network (RAN) controller; receive a set of downlink user data messages from a software defined network (SDN) switch, wherein each downlink user data message comprises a downlink payload; generate a set of downlink radio frames comprising the downlink payloads; output the set of downlink RRC messages and the set of downlink radio frames for transmission to at least one user equipment (UE); receive, from the at least one UE, at least one uplink RRC message and one or more uplink payloads via a physical uplink shared channel (PUSCH); and output the at least one uplink RRC message for transmission to the RAN controller and a set of uplink user data messages comprising the uplink payloads for transmission to the SDN switch.

[00164] Example 50 comprises the subject matter of any variation of example 49, wherein the instructions further cause the BS to receive one or more BS configuration messages from the RAN controller, wherein the instructions further cause the BS to reconfigure the BS in connection with one or more of a cell configuration, a paging configuration, a handover control, or a setup, a modification, or a deletion of a UE context.

[00165] Example 51 comprises the subject matter of any variation of any of examples 49-51, wherein the instructions further cause the BS to generate each uplink user data message of the set of uplink user data messages as one of an Internet Protocol (IP) message, an Ethernet message, or a general packet radio service (GPRS) tunneling protocol (GTP) user (GTP-U) data message.

[00166] Example 52 comprises the subject matter of any variation of example 49, wherein the instructions further cause the BS to generate each uplink user data message of the set of uplink user data messages as one of an Internet Protocol (IP) message, an Ethernet message, or a general packet radio service (GPRS) tunneling protocol (GTP) user (GTP-U) data message.

[00167] Example 53 is an apparatus for use in a radio access network (RAN) controller, comprising means for processing and means for interfacing via one or more networks. The means for processing is configured to generate a first subset of a first set of messages, wherein each message of the first set of messages is associated with one or more of an encapsulation, a decapsulation, or a routing of one or more general packet radio service (GPRS) tunneling protocol (GTP) user (GTP-U) data messages at one or more software defined network (SDN) switches. The means for interfacing via one or more networks is configured to: output the first subset of the first set of messages for transmission to the one or more SDN switches via a first interface; receive a second subset of the first set of messages from the one or more SDN switches via the first interface; and receive a first subset of a second set of messages from one or more base stations (BSs) via a second interface, wherein each message of the second set of messages is associated with a configuration of a BS of the one or more BSs or a configuration of a connection between that BS and one or more user equipments (UEs). The means for processing is further configured to generate a second subset of the second set of messages, wherein at least one message of the second subset of the second set of messages is generated in response to at least one message of the first subset of the second set of messages. The means for interfacing is further

configured to output the second subset of the second set of messages for transmission to the one or more BSs via the second interface.

[00168] Example 54 comprises the subject matter of any variation of example 53, wherein at least one message of the first subset of the first set of messages is associated with a first UE of the one or more UEs, and designates a first BS of the one or more BSs for routing GTP-U data messages associated with the first UE.

[00169] Example 55 comprises the subject matter of any variation of any of examples 53-54, wherein at least one message of the first subset of the first set of messages designates whether to route GTP-U data messages to a first BS of the one or more BSs via a GTP-U encapsulation, an Internet Protocol (IP) encapsulation, or an Ethernet encapsulation.

[00170] Example 56 is an apparatus for use in a software defined network (SDN) switch, comprising means for interfacing via one or more networks and means for processing. The means for interfacing via one or more networks is configured to receive a first subset of a first set of messages from a core network via a first interface, wherein each message of the first set of messages is a general packet radio service (GPRS) tunneling protocol (GTP) user (GTP-U) data message. The means for processing is configured to generate a second subset of the first set of messages. The means for interfacing is further configured to output the second subset of the first set of messages for transmission to the core network via the first interface. The means for interfacing is further configured to receive a first subset of a second set of messages from a radio access network (RAN) controller via a second interface, wherein each message of the second set of messages is associated with one or more of an encapsulation, a decapsulation, or a routing of one or more GTP-U data messages of the first set of messages. The means for processing is further configured to generate a second subset of the second set of messages. The means for interfacing is further configured to output the second subset of the second set of messages for transmission to the RAN controller via the second interface. The means for processing is further configured to generate a first subset of a third set of messages, wherein each message of the third set of messages comprises a payload of a message of the first set of messages, and wherein each message of the first subset of the third set of messages is output based at least in part on one or more messages of the second set of messages. The means for interfacing is further configured to output the first subset of a third set of messages for transmission to one or more Base Stations (BSs) via a third interface, and to receive a

second subset of the third set of messages from the one or more BSs via the third interface.

[00171] Example 57 is an apparatus for use in a Base Station (BS), comprising means for interfacing via one or more networks, means for processing, means for transmitting, and means for receiving. The means for interfacing via one or more networks is configured to receive a first subset of a set of control messages from a radio access network (RAN) controller via a first interface and a first subset of a set of data messages from a software defined network (SDN) switch via a second interface, wherein the first subset of the set of control messages comprises a first set of downlink radio resource control (RRC) messages. The means for processing is configured to: directly transfer the first set of downlink radio resource control (RRC) messages to transmitter circuitry for transmission to one or more user equipments (UEs); and generate a set of downlink radio frames based on the first subset of the set of data messages. The means for transmitting is configured to transmit the set of downlink radio frames to the one or more UEs. The means for receiving configured to receive at least one uplink RRC message and at least one uplink data message from the one or more UEs via a physical uplink shared channel (PUSCH). The means for processing is further configured to directly transfer the at least one uplink RRC message to the means for transmitting for transmission to the RAN controller, and to generate a second subset of the set of data messages, wherein at least one message of the second subset of the set of data messages comprises data received from the at least one uplink data message. The means for interfacing is further configured to transmit the second subset of the set of control messages to the RAN controller via the first interface and the second subset of the set of data messages for transmission to the SDN switch via the second interface.

[00172] Example 58 comprises the subject matter of any variation of any of examples 1-39 or 53-56, wherein at least one of the one or more BSs is an Evolved NodeB (eNB).

[00173] Example 59 comprises the subject matter of any variation of any of examples 40-48 or 57, wherein the BS is an Evolved NodeB (eNB).

[00174] Example 60 comprises the subject matter of any variation of any of examples 49-52, wherein the BS is an Evolved NodeB (eNB).

[00175] The above description of illustrated embodiments of the subject disclosure, including what is described in the Abstract, is not intended to be exhaustive or to limit the disclosed embodiments to the precise forms disclosed. While specific embodiments and examples are described herein for illustrative purposes, various modifications are

possible that are considered within the scope of such embodiments and examples, as those skilled in the relevant art can recognize.

[00176] In this regard, while the disclosed subject matter has been described in connection with various embodiments and corresponding Figures, where applicable, it is to be understood that other similar embodiments can be used or modifications and additions can be made to the described embodiments for performing the same, similar, alternative, or substitute function of the disclosed subject matter without deviating therefrom. Therefore, the disclosed subject matter should not be limited to any single embodiment described herein, but rather should be construed in breadth and scope in accordance with the appended claims below.

[00177] In particular regard to the various functions performed by the above described components or structures (assemblies, devices, circuits, systems, etc.), the terms (including a reference to a "means") used to describe such components are intended to correspond, unless otherwise indicated, to any component or structure which performs the specified function of the described component (e.g., that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the function in the herein illustrated exemplary implementations. In addition, while a particular feature may have been disclosed with respect to only one of several implementations, such feature may be combined with one or more other features of the other implementations as may be desired and advantageous for any given or particular application.

CLAIMS

What is claimed is:

1. An apparatus for use in a radio access network (RAN) controller, comprising:
a processor configured to:
 - generate a first subset of a first set of messages, wherein each message of the first set of messages is associated with one or more of an encapsulation, a decapsulation, or a routing of one or more general packet radio service (GPRS) tunneling protocol (GTP) user (GTP-U) data messages at one or more software defined network (SDN) switches;
 - output the first subset of the first set of messages for transmission to the one or more SDN switches via a first interface;
 - receive a second subset of the first set of messages from the one or more SDN switches via the first interface;
 - receive a first subset of a second set of messages from one or more base stations (BSs) via a second interface, wherein each message of the second set of messages is associated with a configuration of a BS of the one or more BSs or a configuration of a connection between that BS and one or more user equipments (UEs);
 - generate a second subset of the second set of messages, wherein at least one message of the second subset of the second set of messages is generated in response to at least one message of the first subset of the second set of messages; and
 - output the second subset of the second set of messages for transmission to the one or more BSs via the second interface.
2. The apparatus of claim 1, wherein at least one message of the first subset of the first set of messages is associated with a first UE of the one or more UEs, and designates a first BS of the one or more BSs for routing GTP-U data messages associated with the first UE.
3. The apparatus of claim 1, wherein at least one message of the first subset of the first set of messages designates whether to route GTP-U data messages to a first BS of

the one or more BSs via a GTP-U encapsulation, an Internet Protocol (IP) encapsulation, or an Ethernet encapsulation.

4. The apparatus of any of claims 1-3, wherein at least one message of the first subset of the second set of messages comprises a radio resource control (RRC) message for a first UE of the one or more UEs.
5. The apparatus of claim 4, wherein the RRC message is an RRC message of a first set of RRC messages for the first UE, wherein each RRC message of the first set of RRC messages is distinct from RRC messages of a second set of RRC messages generated at the one or more BSs.
6. The apparatus of any of claims 1-3, wherein at least one message of the first subset of the second set of messages is associated with a setup, a modification, or a deletion of a wireless connection between a first UE of the one or more UEs and a first BS of the one or more BSs.
7. The apparatus of claim 6, wherein the wireless connection between the first UE of the one or more UEs and the first BS of the one or more BSs is one of a signaling radio bearer (SRB) or a data radio bearer (DRB).
8. The apparatus of any of claims 1-3, wherein at least one message of the first subset of the second set of messages is associated with one or more of a cell configuration, a paging configuration, a handover control, or a setup, a modification, or a deletion of a UE context.
9. The apparatus of any of claims 1-3, wherein at least one message of the first subset of the second set of messages is associated with self-organized networking.
10. The apparatus of any of claims 1-3, wherein the second interface is an interface configured to control an air interface.
11. An apparatus for use in a software defined network (SDN) switch, comprising:
a processor configured to:

receive a first subset of a first set of messages from a core network via a first interface, wherein each message of the first set of messages is a general packet radio service (GPRS) tunneling protocol (GTP) user (GTP-U) data message;

generate a second subset of the first set of messages;

output the second subset of the first set of messages for transmission to the core network via the first interface;

receive a first subset of a second set of messages from a radio access network (RAN) controller via a second interface, wherein each message of the second set of messages is associated with one or more of an encapsulation, a decapsulation, or a routing of one or more GTP-U data messages of the first set of messages;

generate a second subset of the second set of messages;

output the second subset of the second set of messages for transmission to the RAN controller via the second interface;

generate a first subset of a third set of messages, wherein each message of the third set of messages comprises a payload of a message of the first set of messages, and wherein each message of the first subset of the third set of messages is output based at least in part on one or more messages of the second set of messages;

output the first subset of a third set of messages for transmission to one or more Base Stations (BSs) via a third interface; and

receive a second subset of the third set of messages from the one or more BSs via the third interface.

12. The apparatus of claim 11, wherein at least one message of the first subset of the second set of messages indicates a first BS of the one or more BS associated with a first user equipment (UE) of one or more UEs, wherein, for each message of the first subset of the third set of messages that comprises a payload associated with the first UE, the processor is configured to output that message for transmission to the first BS.

13. The apparatus of claim 11, wherein a first message of the first subset of the third set of messages is an Internet Protocol (IP) message or an Ethernet message.

14. The apparatus of claim 13, wherein a first message of the first subset of the second set of messages indicates a mapping of a tunneling endpoint identity (TEID) of a first message of the first subset of the first set of messages to a virtual local area network (VLAN) identity (VLAN ID) of the first message of the first subset of the third set of messages.
15. The apparatus of claim 11, wherein a first message of the first subset of the third set of messages is a GTP-U data message.
16. The apparatus of claim 15, wherein a first message of the first subset of the second set of messages indicates a mapping of a tunneling endpoint identity (TEID) of a first message of the first subset of the first set of messages to a TEID of the first message of the first subset of the third set of messages.
17. The apparatus of any of claims 11-16, wherein the first interface employs an S1 application protocol.
18. The apparatus of any of claims 11-16, wherein the second interface comprises an OpenFlow interface configured with one or more extensions associated with GTP-U data messages.
19. The apparatus of any of claims 11-16, wherein the third interface is configured to relay of GTP-U packets of GTP-U data messages between the one or more BSs and the core network.
20. The apparatus of any of claims 11-16, wherein the one or more BSs comprise at least two BSs, and the SDN switch is collocated with the RAN controller and a first BS of the at least two BSs.
21. An apparatus for use in a Base Station (BS), comprising:
a processor configured to:
 receive a first subset of a set of control messages from a radio access network (RAN) controller via a first interface and a first subset of a set of data messages from a software defined network (SDN) switch via a second interface,

wherein the first subset of the set of control messages comprises a first set of downlink radio resource control (RRC) messages;

directly transfer the first set of downlink radio resource control (RRC) messages to transmitter circuitry for transmission to one or more user equipments (UEs);

generate a set of downlink radio frames based on the first subset of the set of data messages;

output the set of downlink radio frames to the transmitter circuitry for transmission to the one or more UEs;

receive at least one uplink RRC message and at least one uplink data message from the one or more UEs via a physical uplink shared channel (PUSCH);

directly transfer the at least one uplink RRC message to the transmitter circuitry for transmission to the RAN controller;

generate a second subset of the set of data messages, wherein at least one message of the second subset of the set of data messages comprises data received from the at least one uplink data message; and

output the second subset of the set of control messages for transmission to the RAN controller via the first interface and the second subset of the set of data messages for transmission to the SDN switch via the second interface.

22. The apparatus of claim 21, wherein the processor is further configured to one of setup, modify, or delete a wireless connection to a first UE of the one or more UEs based on at least one message of the first subset of the set of control messages.

23. The apparatus of claim 21, wherein the processor is further configured to:
generate a second set of downlink RRC messages independent of the first subset of the set of control messages; and
output the second set of downlink RRC messages for transmission to the one or more UEs.

24. The apparatus of claim 21, wherein at least one message of the first subset of the set of control messages is associated with one or more of a cell configuration, a paging configuration, a handover control, or a setup, a modification, or a deletion of a

UE context, and wherein the processor is further configured to reconfigure the BS based on the at least one message of the subset of the set of control messages.

25. The apparatus of claim 21, wherein at least one message of the first subset of the set of control messages is associated with self-organized networking, and wherein the processor is further configured to reconfigure the BS based on the at least one message of the subset of the set of control messages.

26. The apparatus of any of claims 21-25, wherein the set of data messages comprise one or more of an Internet Protocol (IP) message or an Ethernet message.

27. The apparatus of any of claims 21-25, wherein the set of data messages comprise a general packet radio service (GPRS) tunneling protocol (GTP) user (GTP-U) data message.

28. A machine readable medium comprising instructions that, when executed, cause a Base Station (BS) to:

- receive a set of downlink radio resource control (RRC) messages from a radio access network (RAN) controller;

- receive a set of downlink user data messages from a software defined network (SDN) switch, wherein each downlink user data message comprises a downlink payload;

- generate a set of downlink radio frames comprising the downlink payloads;

- output the set of downlink RRC messages and the set of downlink radio frames for transmission to at least one user equipment (UE);

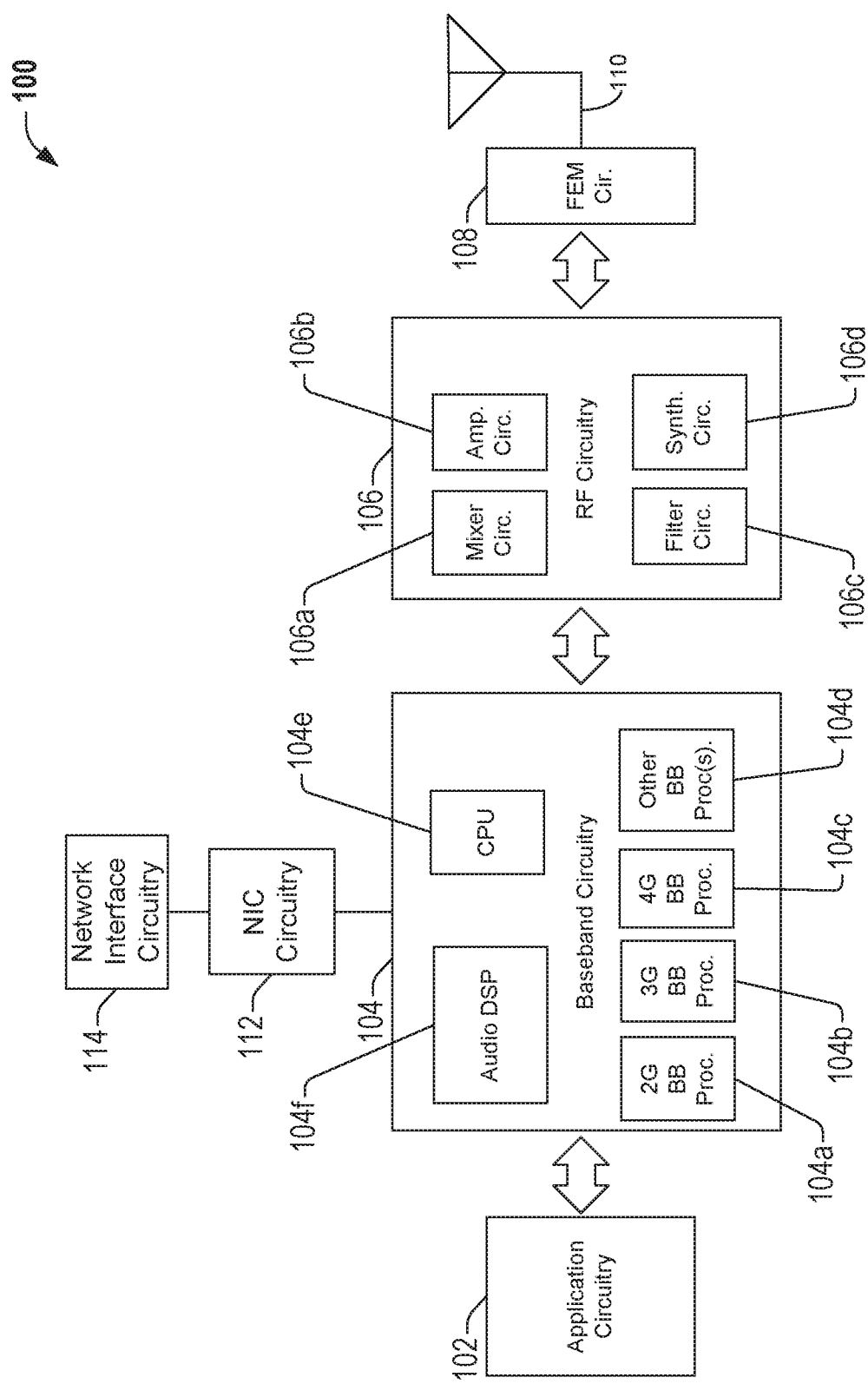
- receive, from the at least one UE, at least one uplink RRC message and one or more uplink payloads via a physical uplink shared channel (PUSCH); and

- output the at least one uplink RRC message for transmission to the RAN controller and a set of uplink user data messages comprising the uplink payloads for transmission to the SDN switch.

29. The machine readable medium of claim 28, wherein the instructions further cause the BS to receive one or more BS configuration messages from the RAN controller, wherein the instructions further cause the BS to reconfigure the BS in

connection with one or more of a cell configuration, a paging configuration, a handover control, or a setup, a modification, or a deletion of a UE context.

30. The machine readable medium of any of claims 28-30, wherein the instructions further cause the BS to generate each uplink user data message of the set of uplink user data messages as one of an Internet Protocol (IP) message, an Ethernet message, or a general packet radio service (GPRS) tunneling protocol (GTP) user (GTP-U) data message.



Example UE, Etc.

FIG. 1

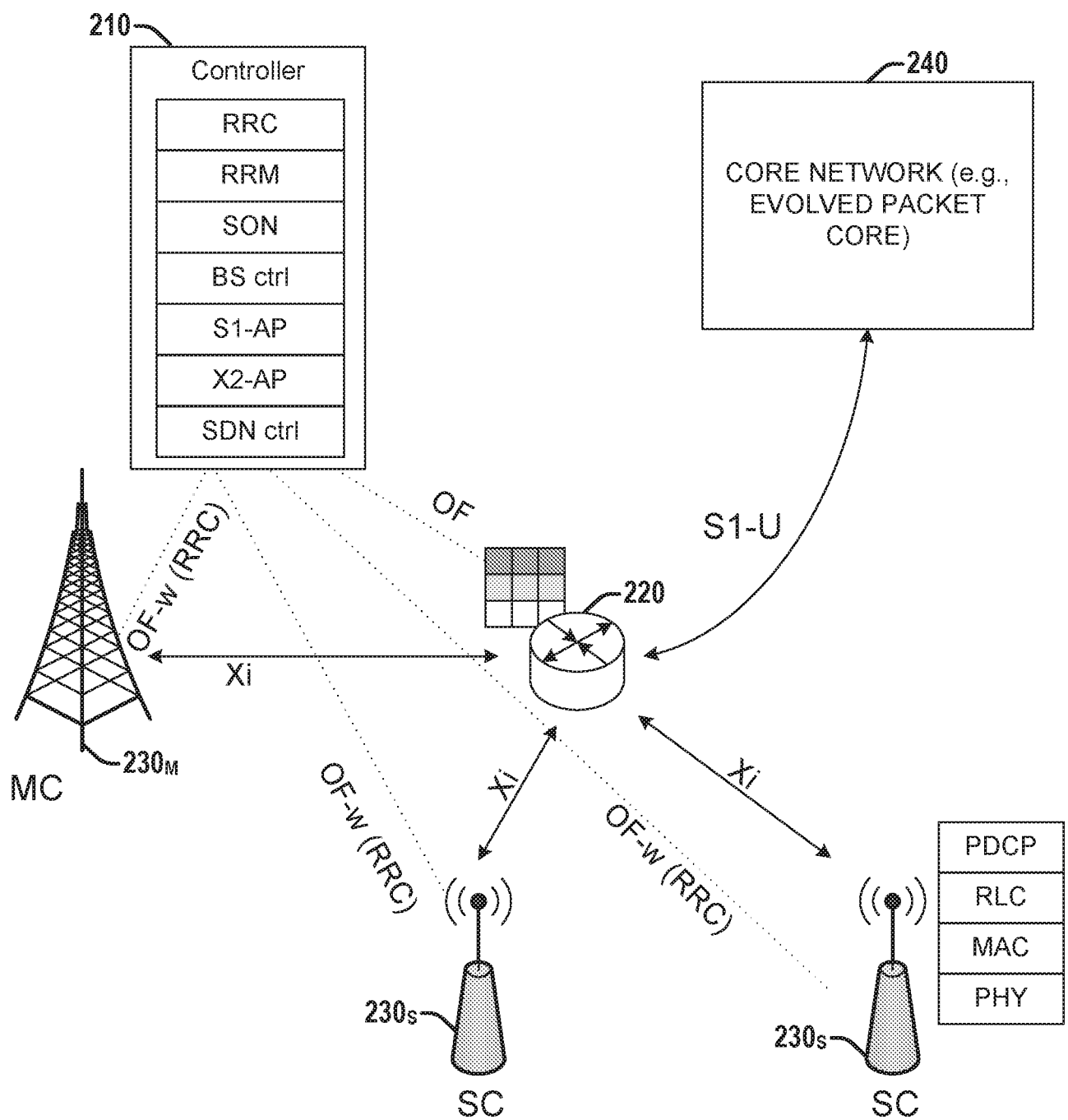


FIG. 2

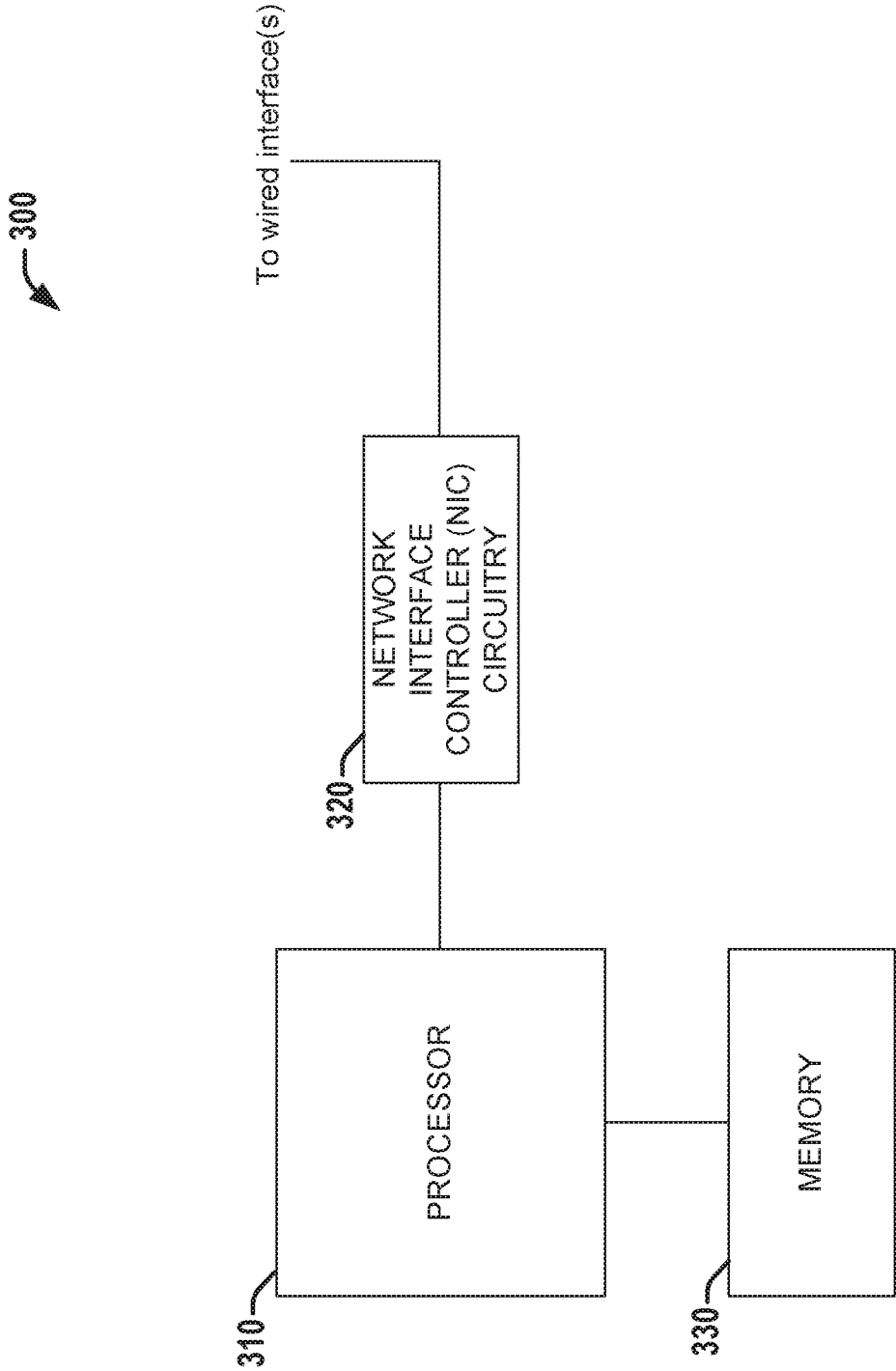


FIG. 3

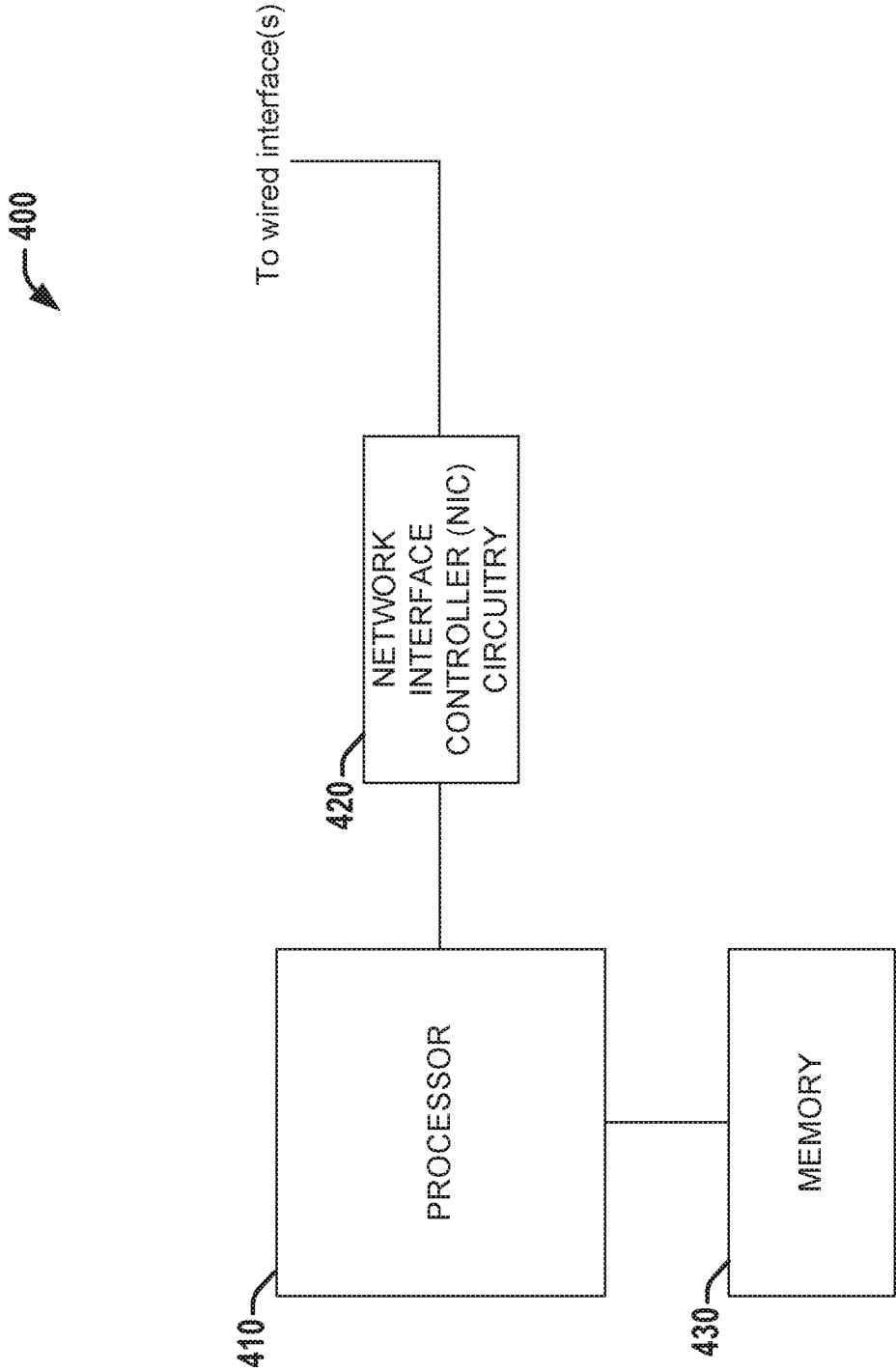


FIG. 4

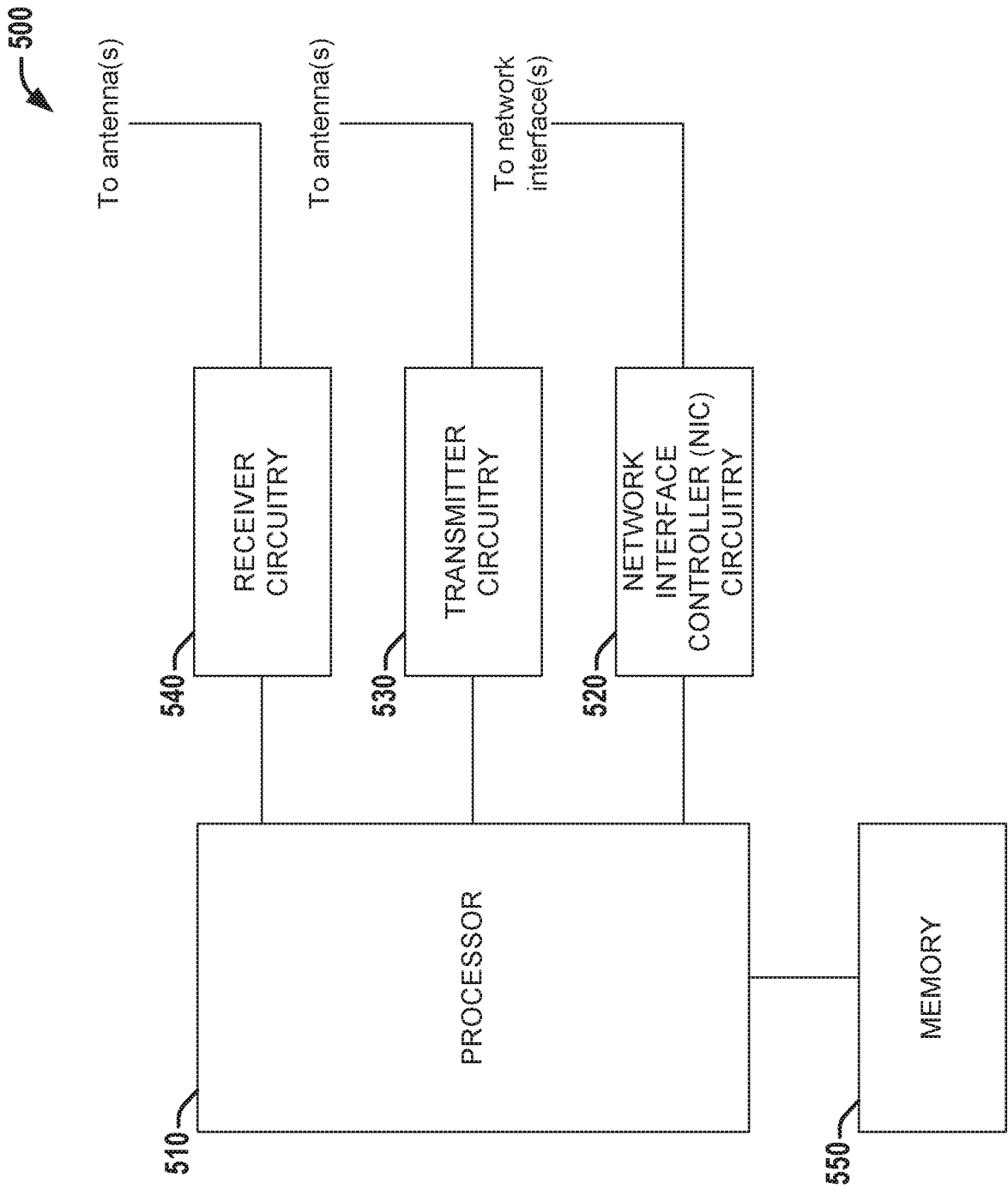


FIG. 5

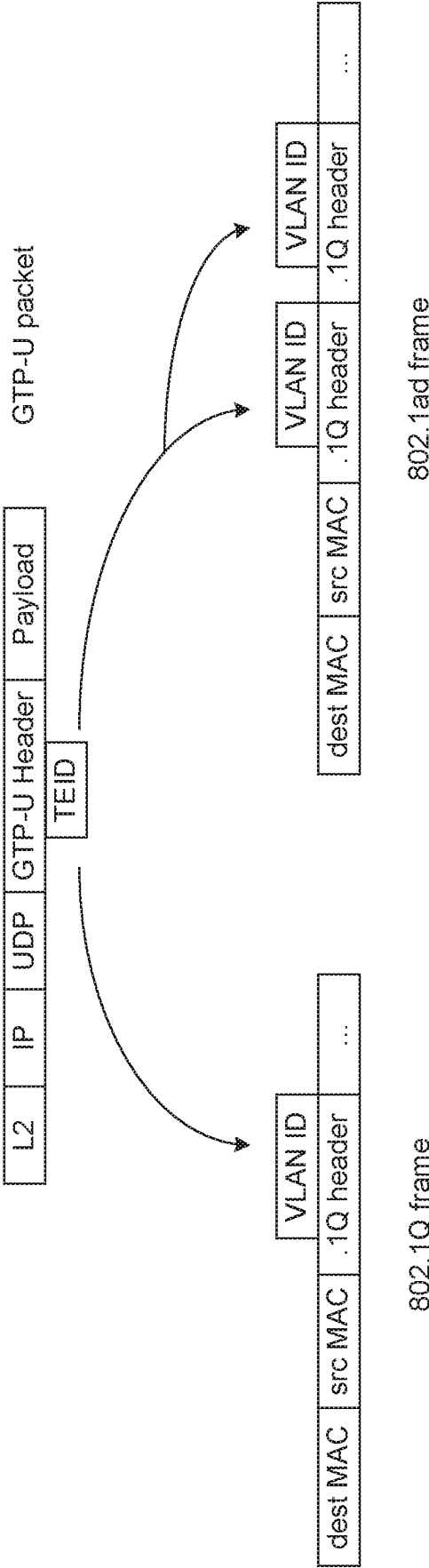


FIG. 6

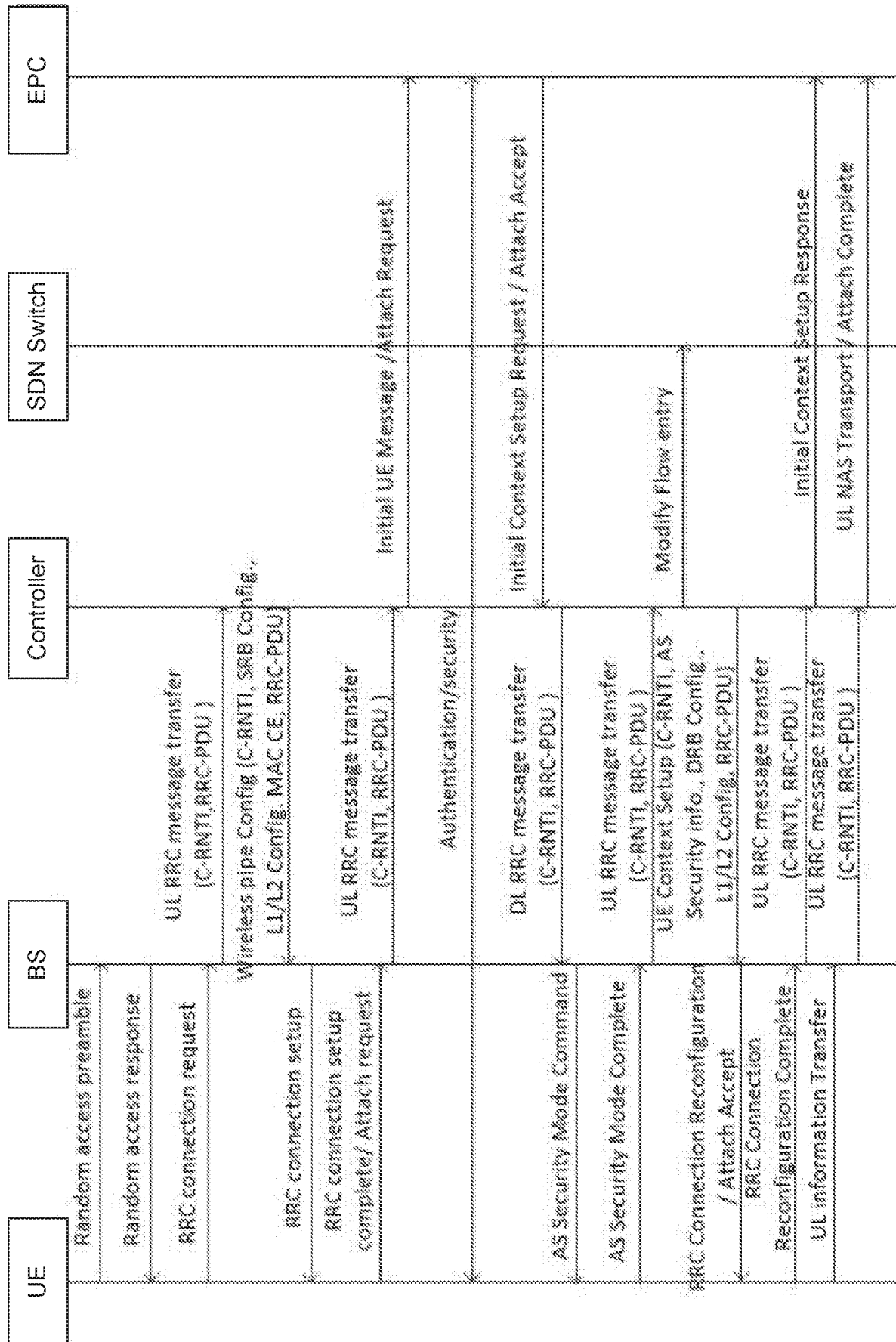


FIG. 7

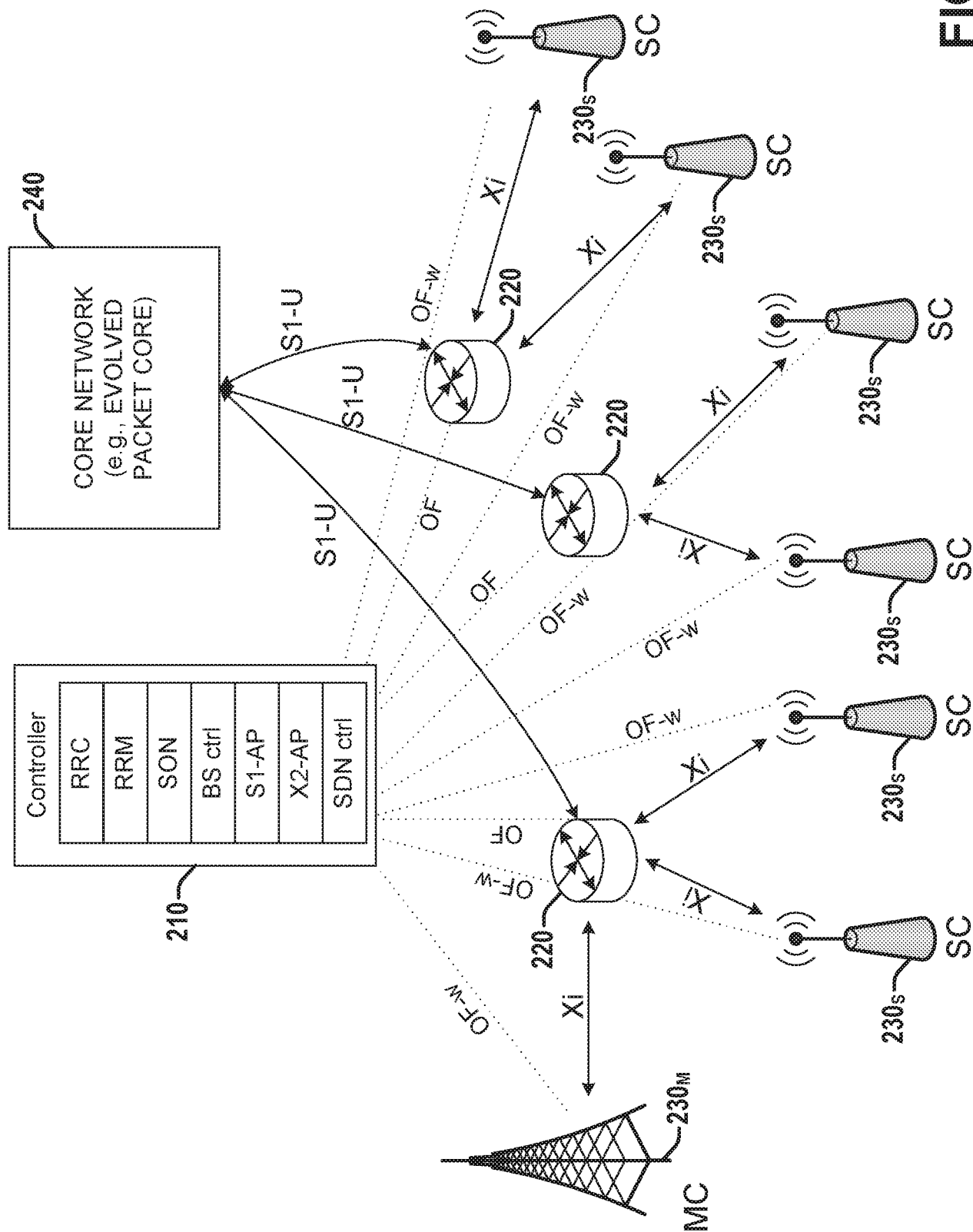


FIG. 8

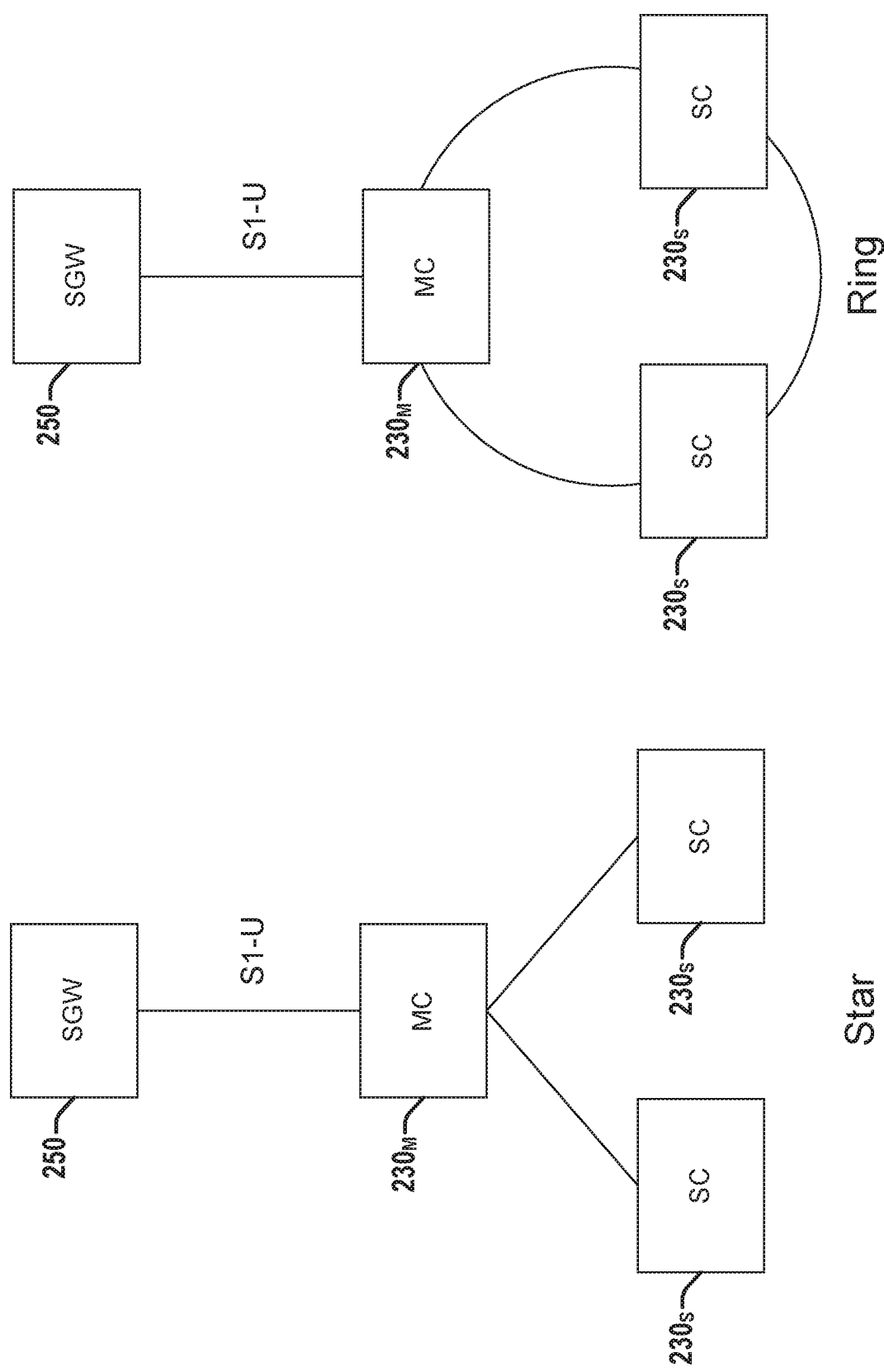


FIG. 9

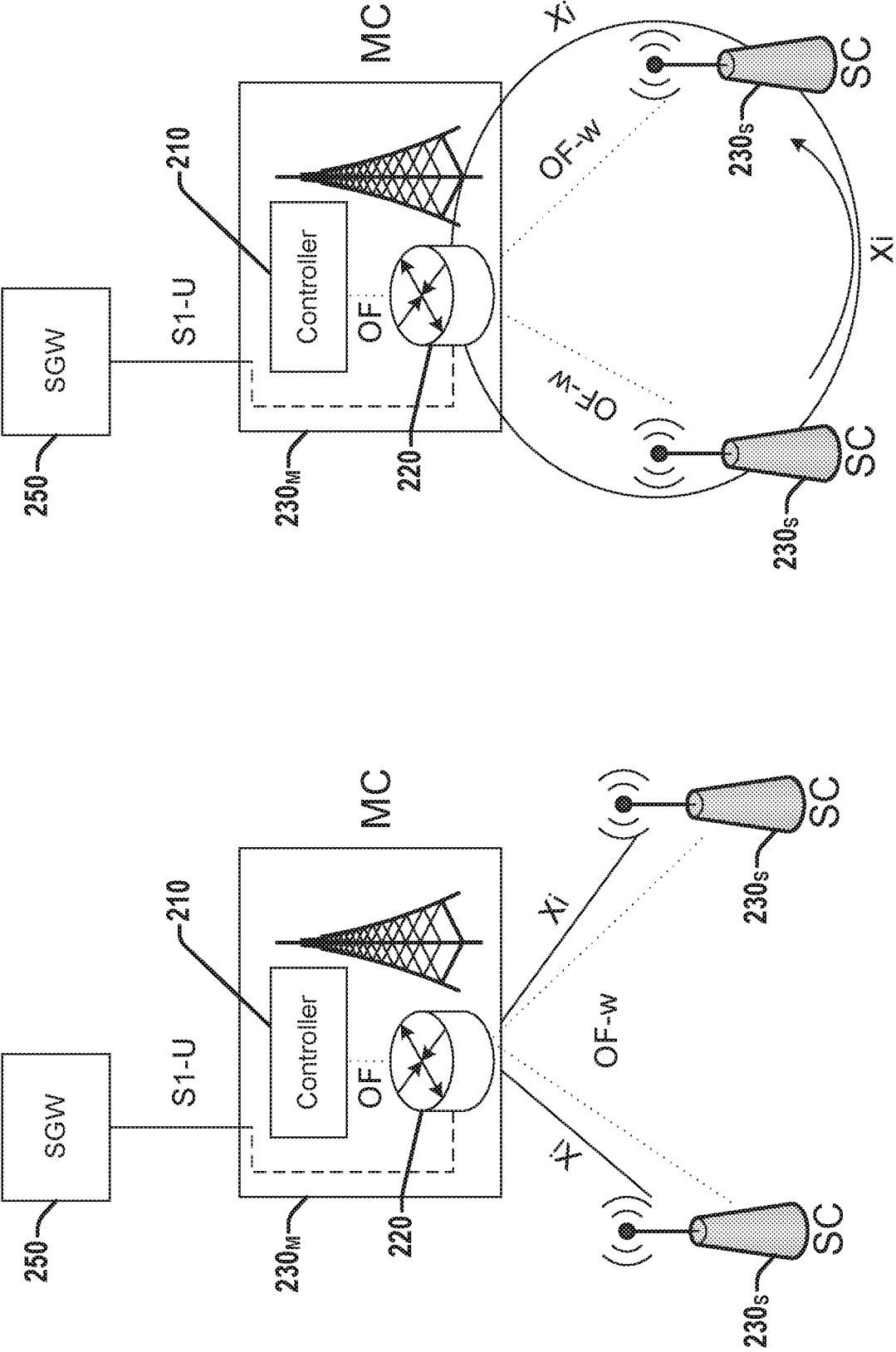


FIG. 10

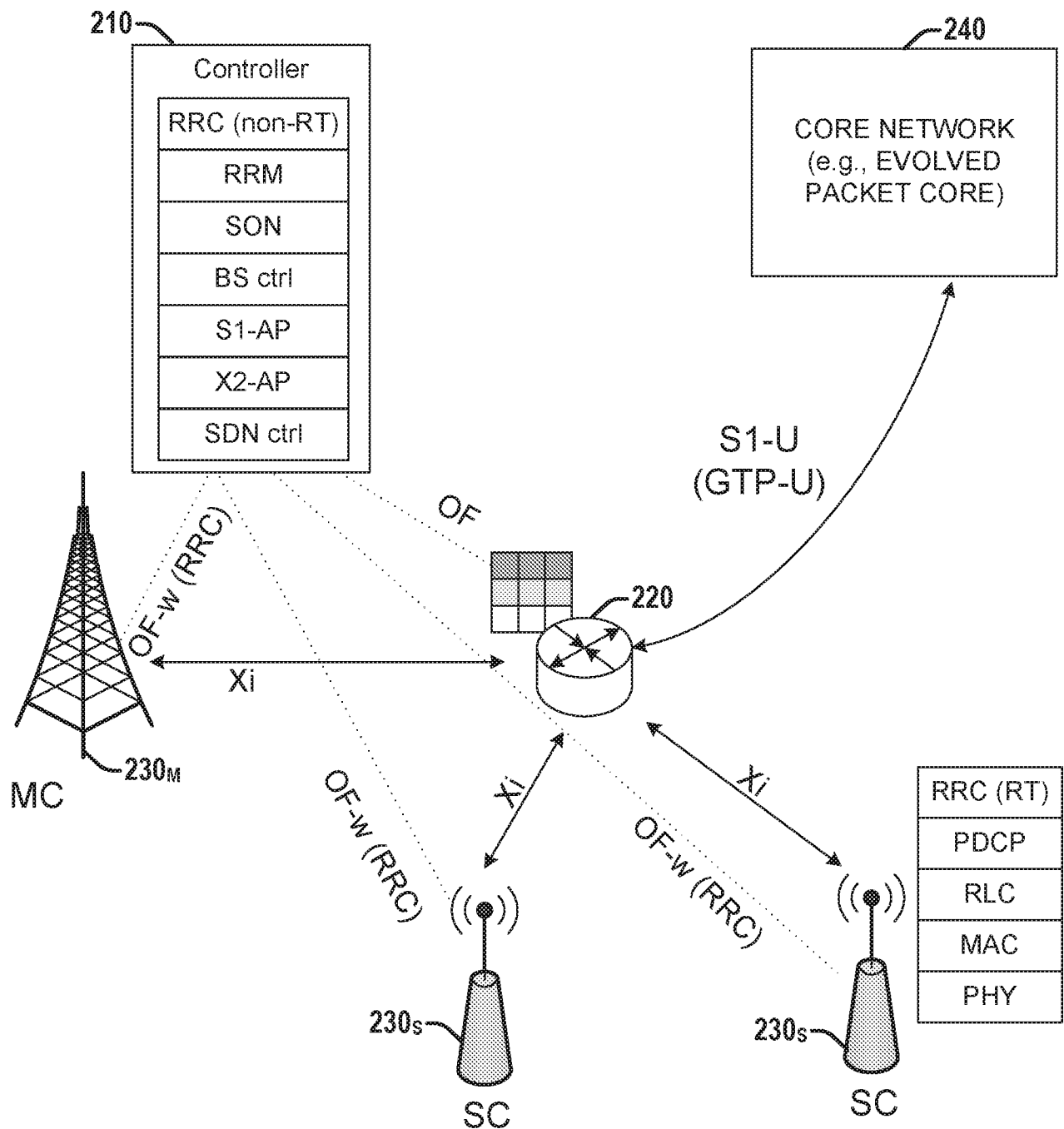


FIG. 11

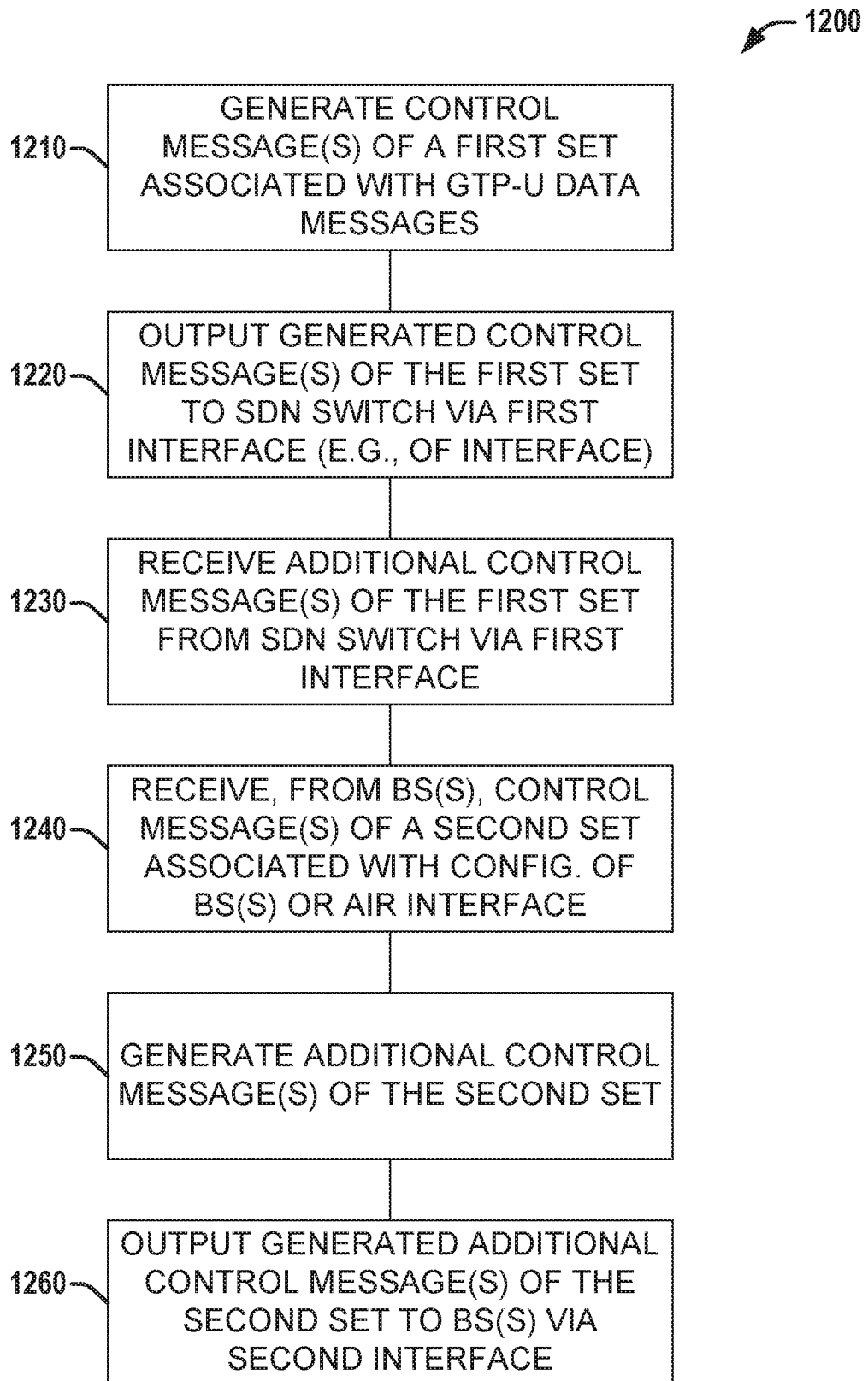


FIG. 12

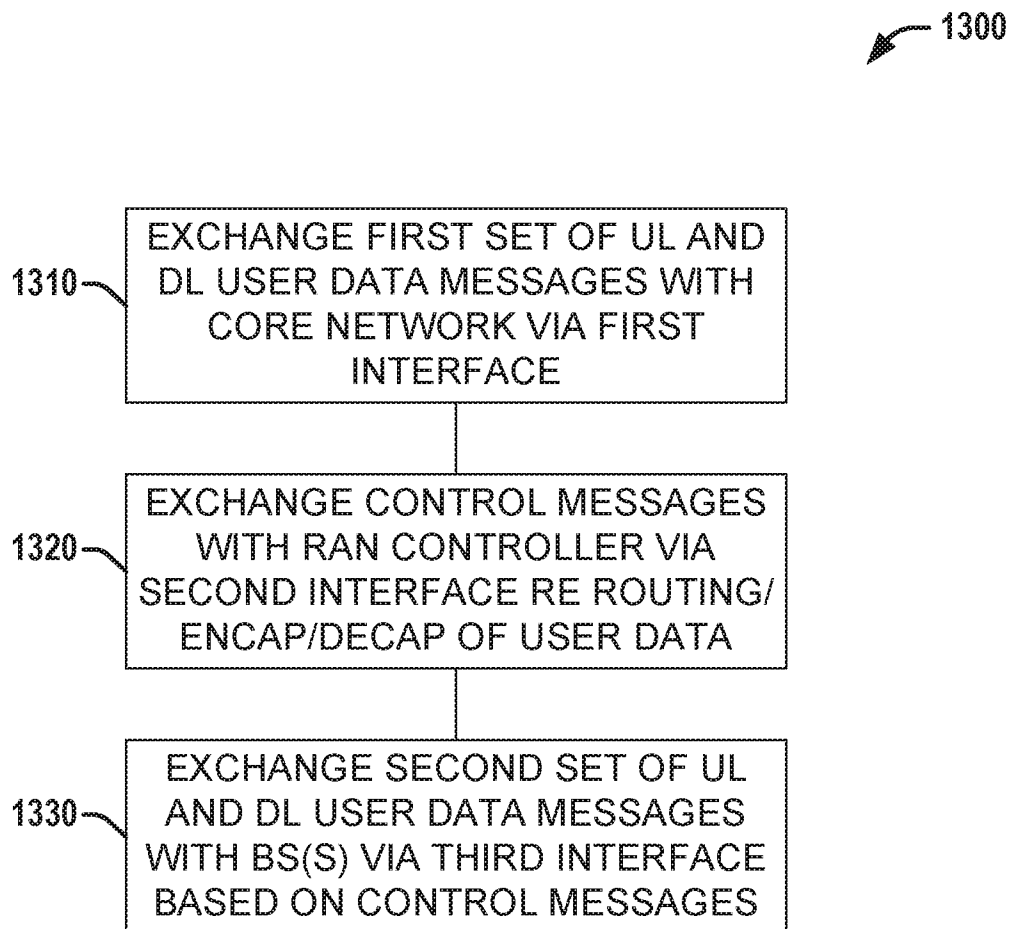


FIG. 13

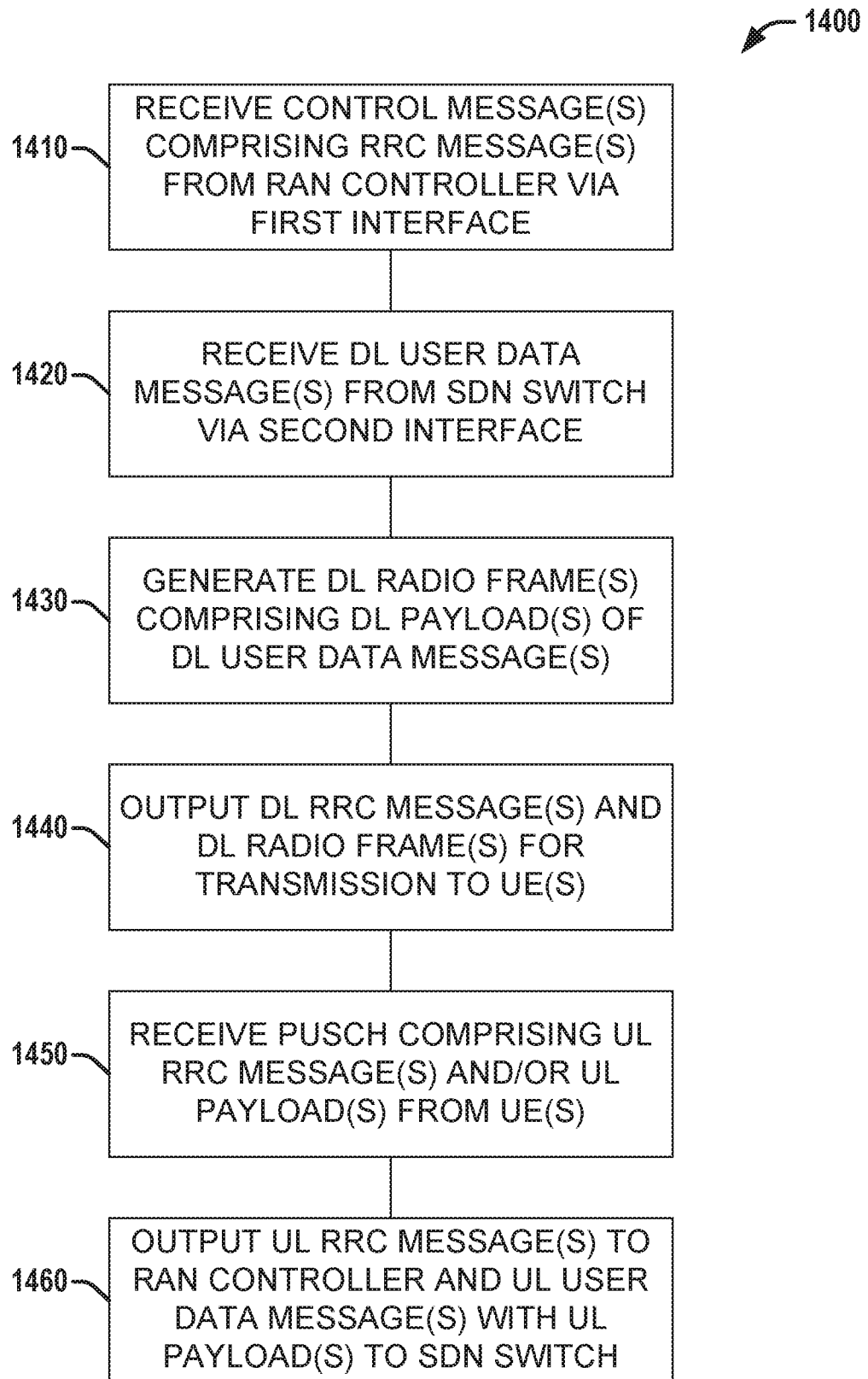


FIG. 14

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2016/024644

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04L12/46 H04W76/04
ADD.

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

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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SHENZHEN COOLPAD TECHNOLOGIES: "Initial Views on 5G Technologies", 3GPP DRAFT; INITIAL VIEWS ON 5G TECHNOLOGIES COOLPAD, 3RD GENERATION PARTNERSHIP PROJECT (3GPP), MOBILE COMPETENCE CENTRE ; 650, ROUTE DES LUCIOLES ; F-06921 SOPHIA-ANTIPOLIS CEDEX ; FRANCE , vol. TSG RAN, no. Shenzhen; 20150917 - 20150918 3 September 2015 (2015-09-03), XP051043608, Retrieved from the Internet: URL:http://www.3gpp.org/ftp/Meetings_3GPP_SYNC/WORKSHOP/Docs/ [retrieved on 2015-09-03] page 5 ----- -/--	21-30
A		1-20



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"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

21 June 2016

Date of mailing of the international search report

30/06/2016

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INTERNATIONAL SEARCH REPORT

International application No

PCT/US2016/024644

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2014/341199 A1 (JEON YOUNG-KI [KR] ET AL) 20 November 2014 (2014-11-20) abstract; figure 1 -----	1-30
A	EP 2 790 442 A1 (ALCATEL LUCENT [FR]) 15 October 2014 (2014-10-15) paragraph [0002] paragraph [0064]; figure 3 -----	1-30

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/024644

Patent document cited in search report	Publication date	Patent family member(s)	Publication date	
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			US 2014341199 A1	20-11-2014
			WO 2014185721 A1	20-11-2014

EP 2790442	A1	15-10-2014	EP 2790442 A1	15-10-2014
			US 2016073278 A1	10-03-2016
			WO 2014166758 A1	16-10-2014
