

(43) International Publication Date
18 May 2017 (18.05.2017)

(51) International Patent Classification:

H04W 36/10 (2009.01) H04W 92/12 (2009.01)
H04W 36/00 (2009.01) H04W 84/04 (2009.01)

(21) International Application Number:

PCT/US2016/025403

(22) International Filing Date:

31 March 2016 (31.03.2016)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

PCT/CN2015/094258

11 November 2015 (11.11.2015)

CN

(71) Applicant: INTEL CORPORATION [US/US]; 2200
Mission College Boulevard, Santa Clara, California 95054
(US).

(72) Inventors: SIROTKIN, Alexander; Intel, 94 Em
Hamoshavot Way., Park Azorim, P.O.Box 10097, 49527
Petach Tikva (IL). YANG, Feng; 8F Raycom infotech Park
A, No. 2 KeXueYuan South Rd, HaiDian District, Beijing
100190 (CN). ZHANG, Xu; 18-2-502 ChangQingYuan
2nd, XiSiHuan North Road, Beijing 100197 (CN).

(74) Agent: LEDELL, Brian; Ledell Ansari, LLP, c/o CPA
Global, P.O. Box 52050, Minneapolis, Minnesota 55402
(US).

(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR,
KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG,
MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM,
PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC,
SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ,
TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU,
TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,
DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU,
LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,
SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,
GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: MOBILITY MANAGEMENT FOR SOFTWARE DEFINED RADIO ACCESS NETWORKS

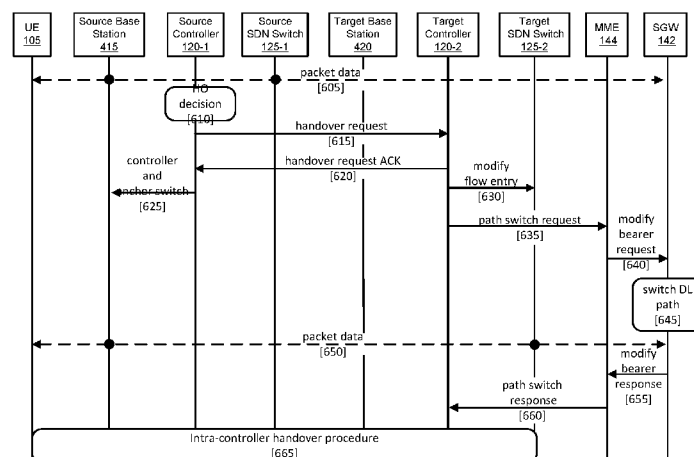


Fig. 6

(57) Abstract: An SDN architecture, for a cellular communications system, separates the control plane and the user plane in a RAN of the cellular communication system. A controller, in the RAN, may serve a number of base stations and perform mobility management control functions (i.e., functions related to handovers), via a control plane, for base stations in the RAN. User plane traffic may be separately communicated between base stations and an SDN switch. The SDN switch, in the RAN, may be used to route data plane traffic and terminate the backhaul connection towards the core network.

MOBILITY MANAGEMENT FOR SOFTWARE DEFINED RADIO ACCESS NETWORKS

RELATED APPLICATIONS

5 The present application claims the priority to International Application PCT/CN2015/094258, which was filed on November 11, 2015, the contents of which are hereby incorporated by reference as though fully set forth herein.

BACKGROUND

10 LTE (Long-Term Evolution) is a standard for wireless communication of high-speed data for mobile phones and data terminals (mobile devices). An LTE cellular communication system may include a Radio Access Network (RAN) section and a "core" network section. The RAN section may handle the wireless (radio) communications with the mobile devices. The "core" section may handle control functionality relating to providing data services to the mobile devices.

15 One trend in cellular network deployments has been the usage of high density access networks (sometimes called ultra-dense radio access networks (UDN)) in which a large number of standalone small cells (SC), each with a relatively limited coverage area, are deployed. UDN deployments may be used in either outdoor or indoor traffic hotspots where additional capacity is needed. UDN deployments, however, can result in additional challenges, such as inter-cell
20 interference. Additionally, a large number of small cells can lead to a high volume of signaling messages, from the small cells, in the network core.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments described herein will be readily understood by the following detailed description in conjunction with the accompanying drawings. To facilitate this description, like
25 reference numerals may designate like structural elements. Embodiments are illustrated by way of example and not by way of limitation in the figures of the accompanying drawings.

Fig. 1 is a diagram of an example environment, corresponding to a cellular network, in which systems and/or methods described herein may be implemented;

Fig. 2 is a flowchart illustrating a process for performing an intra-controller handover in
30 the environment of Fig. 1;

Fig. 3 is a signal flow diagram illustrating an example intra-controller handover;

Fig. 4 is a diagram of environment that particularly illustrates multiple controllers;

Fig. 5 is a flowchart illustrating a process for performing an inter-controller handover in the environment of Fig. 1;

35 Fig. 6 is a signal flow diagram illustrating an example inter-controller handover; and

Fig. 7 illustrates example components of an electronic device.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The following detailed description refers to the accompanying drawings. The same reference numbers in different drawings may identify the same or similar elements. It is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope of the present disclosure. Therefore, the following detailed description is not to be taken in a limiting sense, and the scope of embodiments is defined by the appended claims and their equivalents.

A Software Defined Network (SDN) architecture, for the RAN of a cellular communications system, is described herein. The described architecture separates the control plane and the user plane in the RAN. A controller, in the RAN, may serve a number of base stations and perform mobility management control functions (i.e., functions related to handovers), via the control plane, for base stations in the RAN. User plane traffic may be separately communicated between base stations and an SDN switch. The SDN switch, in the RAN, may be used to route data plane traffic and terminate the backhaul connection towards the core network.

The control and user plane separation may facilitate efficient mobility management decisions by the controller. Additionally, the control and user plane separation may enable multiple base stations to be associated with a "virtual" cell, in which mobility management decisions within the virtual cell may be hidden (i.e., may not need to be communicated) from the core network. In this manner, the amount of signaling with the core network can be reduced.

In one implementation, as described herein, intra-controller handover operations (i.e., between base stations within a virtual cell), may be made, by the controller, based on global knowledge relating to load within the virtual cell. For inter-controller handover operations (i.e., between base stations in different virtual cells), a control plane handover may first be performed between the controllers of the different virtual cells. The user plane handover between base stations may then be performed.

Fig. 1 is a diagram of an example environment 100, corresponding to a cellular network, in which systems and/or methods described herein may be implemented. Environment 100 may generally provide a Software Defined Network (SDN)-based architecture, in the RAN, that separates control plane signaling and user plane data traffic. In Fig. 1, the RAN control plane interface is illustrated with dashed lines and the RAN user plane interface is illustrated with solid lines.

As illustrated, environment 100 may include mobile devices, which may be referred to as

User Equipment (UE) 105, a RAN 110, and an Evolved Packet Core (EPC) 130. Environment 100 may represent a wireless cellular communications network, such as a network based on the Third Generation Partnership Project (3GPP) standards. RAN 110 may generally provide the wireless (e.g., radio) interface with UE 105. The core portion may provide back-end control
5 plane and user plane transport paths, user control and authentication, and other features.

UE 105 may include a portable computing and communication device, such as a personal digital assistant (PDA), a smart phone, a cellular phone, a laptop computer with connectivity to a cellular wireless network, a tablet computer, etc. UE 105 may also include non-portable
10 computing devices, such as desktop computers, consumer or business appliances, or other devices that have the ability to wirelessly connect (e.g., via radio links) to cellular wireless network. For simplicity, a single UE 105 is shown. In practice, multiple UEs 105 may operate in the context of a wireless network.

RAN 110 may represent a 3GPP access network that includes one or more Radio Access Technologies (RATs). RAN 110 may include one or more base stations, such as macrocells 112
15 and small cells 114. RAN 110 may additionally include a controller 120 and a SDN switch 125.

In the context of 3GPP networks, base stations, such as macrocells 112 and small cells 114, may be referred to as Evolved NodeBs (eNBs). Relative to existing eNBs, macrocells 112 and small cells 114 may include less control logic. Instead, the control logic may be
20 implemented by controller 120. Macrocells 112 may provide a radio interface, for UEs 105, to a relatively larger area than small cells 114. Small cells 114 may be deployed to increase system capacity and can include coverage areas within the coverage area of macrocell 112. Small cells 114 may include, for example, picocells, femtocells, and/or home NodeBs. Macrocells 112 and small cells 114 may implement, for example, logic relating to Packet Data Convergence
25 Protocol (PDCP) layer processing, Radio Link Control (RLC) processing, Medium Access Control (MAC) layer processing, and Physical (PHY) layer processing.

Controller 120 may include one or more computation and communication devices that act as a control node for RAN 110. Although a single controller is shown in Fig. 1, in practice, multiple controllers 120 may be used to control RAN 110, where each controller 120 may be
30 assigned to control a number of base stations (e.g., macrocells 112 and/or small cells 114). The base stations assigned to a particular controller 120 may be referred to as a "virtual cell" herein. Controller 120 may operate to perform the control functions for the air interface of RAN 110. For instance, as shown in Fig. 1 as non-limiting examples, controller 120 may perform control functions relating to: (1) Radio Resource Control (RRC) signaling; (2) Radio Resource
Management (RRM); (3) Self-Organizing Networks (SON); (4) base station (BS) control; (5)
35 S1-Application Protocol (S1-AP) signaling; (6) X2-Application Protocol (X2-AP) signaling;

and/or (7) SDN control.

As part of the RRC signaling, controller 120 may perform control functions relating to the RRC protocol sublayer that relates to the LTE air interface between UEs 105 and the base stations. Services and functions provided by the RRC sublayer may include broadcasting of
5 System Information related to the non-access stratum (NAS), broadcasting of System Information related to the access stratum (AS), paging, Quality of Service (QoS) management functions, and other functions. As part of RRM signaling, controller 120 may analyze and control radio resources, such as to manage co-channel interference and other wireless radio transmission characteristics. For example, controller 120 may control parameters, at macrocell
10 112 and small cells 114, relating to radio transmit power, user allocation, beamforming, data rates, the modulation scheme being used, the error coding scheme being used, etc. Controller 120 may also, in some implementations, control SON parameters at the base stations and/or at SDN switch 125. The SON parameters may generally relate to self-configuration, self-optimization, and self-healing of the base stations.

15 Controller 120 may also, in some implementations, control base stations ("BS ctrl"), such as controlling of the provisioning and operation of macro cells 112 and small cells 114. Controller 120 may also, in some implementations, perform functions for the S1-Application Protocol signaling between RAN 110 and EPC 130. The S1-AP signaling messages may be routed through SDN switch 125 to EPC 130. The S1-AP signaling messages may include, for
20 example, signaling relating to UE capability information, context transfer, S1 interface management, and/or other application protocol functions. Additionally, controller 120 may also perform functions for the X2-AP signaling. The X2-AP signaling messages may relate to, for example, UE mobility management and load management. Controller 120 may also perform functions relating to SDN configuration and control (SDN ctrl). For example, controller 120
25 may update routing tables in SDN switch 125 or update/configure other networking aspect of SDN switch 125.

SDN switch 125 may be a SDN device that operates to connect RAN 110 to EPC 130. SDN switch 125 may be configured by controller 120. Although referred to as a "switch," herein, SDN switch 125 may include functionality of a router or another networking device.
30 Software-defined networking, in general, refers to an approach to computer networking that allows network administrators to manage network services through abstraction of higher-level functionality. In SDN, decisions about where traffic is sent (the control plane) may be decoupled from systems that forward traffic to the selected destination (the data plane).

In one implementation, configuration of the SDN aspects (e.g., configuration of SDN
35 switch 125, macrocells 112, and/or small cells 114) may be performed using the OpenFlow

protocol. OpenFlow is a communications protocol that gives access to the forwarding plane of a network switch or router, such as SDN switch 125. For example, controller 120 may communicate, using OpenFlow messages, (labeled as interface "OF" in Fig. 1), to SDN switch 125, to configure the encapsulation, the de-capsulation, and routing of packets (e.g., GPRS Tunneling Protocol (GTP) user plane packets). Additionally, controller 120 may communicate, using messages (labeled as interface "OF-w" in Fig. 1), with the base stations to configure the base stations; set up, modify, and/or delete wireless pipes associated with the base stations; and perform aerial (radio) coordination.

A number of interfaces, including the OF and OF-w interfaces, are illustrated in Fig. 1. An interface may refer to a physical or logical connection between devices in environment 100. In addition to the control plane OF and OF-w interfaces, the user plane "Xi" and "S1" interfaces are illustrated in Fig. 1. The Xi interfaces may be used to transfer payload data (e.g., S1-U payload data) between the base stations and SDN switch 125. The S1 interfaces, which may include the 3GPP S1-user plane (S1-U) interface, may be used to transfer the payload data between SDN switch 125 and various devices (e.g., SGW 142 and MME 144) of EPC 130.

As is further shown in Fig. 1, EPC 130 may include a number of network devices, including serving gateway (SGW) 142, Mobility Management Entity (MME) 144, and packet data network gateway (PGW) 146. SGW 142 may include one or more network devices that aggregate traffic received from one or base stations. SGW 142 may generally handle user (data) plane traffic. MME 144 may include one or more computation and communication devices that perform operations to register UE 105 with EPC 130, and/or perform other operations. MME 144 may generally handle control plane traffic.

PGW 146 may include one or more devices that act as the point of interconnect between core network 140 and external IP networks and/or operator IP services. PGW 146 may route packets to and from the access networks, and external IP networks.

The quantity of devices and/or networks, illustrated in Fig. 1, is provided for explanatory purposes only. In practice, there may be additional devices and/or networks; fewer devices and/or networks; different devices and/or networks; or differently arranged devices and/or networks than illustrated in Fig. 1. Alternatively, or additionally, one or more of the devices of environment 100 may perform one or more functions described as being performed by another one or more of the devices of environment 100. Furthermore, while "direct" connections are shown in Fig. 1, these connections should be interpreted as logical communication pathways, and in practice, one or more intervening devices (e.g., routers, gateways, modems, switches, hubs, etc.) may be present.

As mentioned above, the OF-w interface may be a control interface used, by controller

120, to control the operation of macro cell 112 and/or small cells 140. One example implementation of OF-w messages are listed in Table I. In Table I, the "message name" column includes potential names or message labels, and the "description of main fields" column includes a more detailed description of the fields and/or function of the various messages.

Table I	
Message Name	Description of Main Fields
Cell configure	Radio frame structure (including scheduling of System Information Block (SIB)), antenna installation, intra-frequency /inter-frequency neighbor cells, etc.
Paging configure	Paging message from MME to UE, including UE Paging Identity chosen from subscriber identifier (e.g., SAE-Temporary Mobile Subscriber Identity or International Mobile Subscriber Identity)
Wireless pipe configure	UE Identity, signaling radio bearer (SRB) configuration including set up/modify/release a particular signaling pipe, data radio bearer (DRB) configure including set up/modify/release a particular data pipe, L1/L2 configure, MAC Control Element (used for Msg. 4)
UE context setup	UE identity, AS Security info, UE Aggregate Maximum Bit Rate (AMBR), dedicated bearer configuration, L1/L2 configure, random access channel (RACH) configuration (used for handover), sequence number (SN) status (used for handover), signaling radio bearers (SRB) configuration (used for handover)
UE context modify	UE identity, AS security info, UE AMBR
UE context release	UE Identity
UE handover command	UE Identity, RRC-packet data unit (PDU)

UE status report	UE Identity, SN status
Uplink (UL) RRC message transmission	UE Identity, RRC-PDU
Downlink (DL) RRC message transmission	UE Identity, RRC-PDU
Control & Anchor Switch	UE Identity, New Controller Identity, New SDN Switch Identity

Fig. 2 is a flowchart illustrating a process 200 for performing a handover operation in environment 100. For process 200, the handover operation may be an intra-controller handover operation. That is, the handover operation may be between base stations that are connected to a particular controller 120. Process 200 may be performed by controller 120. In the discussion that follows, the term "source" base station will be used to refer to, in the context of a network handover, the beginning base station to which the UE is attached. The term "target" base station will be used to refer to, in the context of a network handover, the base station at the end of the handover procedure to which the UE is attached.

Process 200 may include determining that a handover should occur (block 210). For process 200, assume that the handover operation is an intra-controller handover. For example, with reference to Fig. 1, the handover operation may be handover from one of small cells 114 to the other of small cells 114. The determination of the handover may be made based on a number of factors. For example, UE 105 may occasionally or periodically measure the strength of signals received by UE 105 from various cells in the vicinity of UE 105. UE 105 may report, to controller 120, the measurements. Controller 120 may determine, based on the received measurements and potentially based on other factors, such as congestion or load of other base stations that are in the virtual cell of controller 120, to initiate a handover operation to cause the UE to attach to a different base station (e.g., to a different small cell 114). In one implementation, controller 120 may additionally use trajectory or velocity information relating to UE 105, to select appropriate base stations for a handover.

Process 200 may further include updating the SDN switch, associated with the virtual cell (block 220). The updating of SDN switch 125 may include, for example, updating the routing/switching table of SDN switch 125 to modify entries, corresponding to the traffic flow or flows associated with UE 105, such that traffic from the target base station will continue to be forwarded to the correct entity (e.g., the correct SGW 142) in EPC 130. The updating of SDN switch 125 may be performed using the OF interface.

Process 200 may further include updating the source base station using the OF-w interface (block 230). For instance, with respect to the messages indicated in Table I, controller 120 may transmit the "UE handover command" message to the source base station. The source base station may respond with a "UE status report" message back to controller 120.

5 Process 200 may further include updating the target base station using the OF-w interface (block 240). The target base station may be updated to indicate that the UE will attach to the target base station. For instance, with respect to the messages indicated in Table I, controller 120 may transmit the "UE context setup" message to the target base station, which may provide context information, for the UE, to the target base station.

10 Because controller 120 controls each of the base stations in the virtual cell of controller 120, controller 120 has knowledge of the state of the base stations in the virtual cell (e.g., the traffic loading state of each base station, the available radio resources, etc.). Accordingly, when performing the intra-controller handover procedure pursuant to process 200, controller 120 can more effectively control the handover operation. As a result, handover failure caused by a
15 handover being initiated with an improper target base station (e.g., one that is highly loaded and does not have sufficient radio resource), may be reduced.

Fig. 3 is a signal flow diagram illustrating an example intra-controller handover involving various devices in environment 100. In Fig. 3, the source base station and target base station are labeled as source base station 310 and target base station 320, respectively.

20 UE 105 and controller 120 may exchange measurement information relating to the connectivity of UE 105 to the source base station or to other base stations (at 305, "measurement"). For example, UE 105 may communicate signal strength measurements corresponding to the various base stations in the vicinity of UE 105. Controller 120, based on the signal strength measurements, may make handover (HO) decisions relating to UE 105 (at
25 310, "HO decision"). For example, when the signal strength received from the base station, to which the UE is currently attached (source base station 310), falls below a threshold, controller 120 may choose another base station (target base station 320) to which the UE should attach. Target base station 320 may be chosen as another base station, in the vicinity of the UE, in which the signal strength between the UE and target base station 320 is above a threshold and in
30 which the target base station has available radio resources. Because controller 120 is aware of the state of all the base stations that are in the virtual cell of controller 120, controller 120 may be able to make an optimal, or near optimal, handover decision. In one implementation, the measurement information can be communicated, from the base station to the controller, by transparently transferring RRC messages (received from the UE) to the controller, via the OF-w
35 interface (i.e., via the control plane interface). For example, RRC messages, received by the

base station may be encapsulated, by the base station, as OF-w messages and sent to controller 120.

Controller 120 may subsequently modify SDN switch 125, such as by modifying the routing table associated with SDN switch 125, to update SDN switch 125 such that SDN switch 125 will buffer packets received for UE 105 (at 315, "modify flow entry"). In one implementation, the modification may particularly include deleting traffic flow entries associated with bearers in the SDN switch, to thus cause received packets associated with the bearers to be buffered by the SDN switch. The buffering may be performed until the handover operation is completed. For example, the OF interface may be used to modify an entry to the routing table, of SDN switch 125, to cause SDN switch 125 to buffer packets received for UE 105.

Controller 120 may subsequently transmit a UE handover command message to source base station 310 (at 320, "UE handover command"). The UE handover command may be transmitted, via the OF-w interface, and may correspond to the message "UE handover command" (Table I). The message may include, for instance, an identification of UE 105 and an indication of the RRC connection(s) that are to be reconfigured. In response, source base station 310 may initiate the RRC connection reconfiguration with UE 105 (at 325, "RRC connection reconfiguration"). Source base station 310 may update controller 120 with a status report relating to the RRC reconfiguration (at 330, "UE status report"). The UE status report may be transmitted, via the OF-w interface, and may correspond to the message "UE status report" (Table I).

Controller 120 may subsequently inform target base station 220 of the handover. In particular, UE context information, needed to process the handover in a manner that will not cause interruption at the UE, may be transmitted to target base station 320. As illustrated, controller 120 may transmit a UE context setup message, via the OF-w interface, to target base station 320 (at 335, "UE context setup"). As detailed in Table I, the UE context setup message may include a number of information fields, including a UE identification field, security information, dedicated bear configuration information, and random access channel (RACH) configuration information.

As part of a handover operation, a RACH procedure may be performed. For instance, as shown, a random access preamble may be transmitted from UE 105 to target base station 320 and the random access response may be transmitted from target base station 320 to UE 105 (at 340 and 345, "random access preamble" and "random access response"). During this period, packets received at SDN switch 125 (e.g., packets from EPC 130), for UE 105, may be buffered at SDN switch 125 (at 350, "packet buffering"). The handover operation, in the air interface,

may be completed based on the communication, between UE 105 and target base station 320, of an "RRC connection reconfiguration complete" message (at 355). Using the OF-w interface, target base station 320 may transmit an "UL RRC message transfer" message to controller 120 (at 360), and controller 120 may additionally release the UE context from source base station 310 (at 365, "UE context release").

Controller 120 may modify SDN switch 125, such as by modifying the routing table associated with SDN switch 125, to update SDN switch 125 such that SDN switch 125 will appropriately forward traffic flows received from target base station 320 to EPC 130, and forward traffic flows received from EPC 130 to target base station 320 (at 370, "modify flow entry"). For example, the OF interface may be used to add an entry to the routing table, of SDN switch 125, to forward traffic flows, corresponding to UE 105 and from target base station 320, to EPC 130.

Fig. 4 is a diagram of environment 100 that particularly illustrates multiple controllers 120. As previously mentioned, each controller 120 may control a number of base stations, where the set of base stations controlled by a particular controller 120 may be referred to herein as the virtual cell for controller 120. In Fig. 4, two controllers 120 are shown, labeled as controller 120-1 and controller 120-2. Additionally, four base stations are illustrated, labeled as base stations 405-420. Base stations 405 and 410 are illustrated as being affiliated with controller 120-1, and base station 420 is illustrated as being affiliated with controller 120-2. Base station 415 may connect, via control plane message, to both base controllers 120-1 and 120-2. This base station may be considered to be in an "inter-controller handover (HO) zone" that is affiliated with both controller 120-1 and 120-2 (i.e., both controllers 120 may control base station 415). Base stations 405, 410, and 420, in contrast, may be considered to be in an "intra-controller handover (HO) zone," as these base stations are only potentially controlled by one controller. Whether a particular base station is potentially connected to multiple controllers 120 (inter-controller HO zone) or to a single controller 120 may be statically determined (e.g., configured by a network administrator) or dynamically determined and configured by the network.

Fig. 5 is a flowchart illustrating a process 500 for performing a handover operation in an inter-controller handover scenario. In the discussion that follows, the term "source" will be used to refer to, in the context of a network handover, the beginning network device (i.e., base station, controller, or SDN switch) to which the UE is affiliated at the beginning of the handover operation. Similarly, the term "target" will be used to refer to, in the context of a network handover, the ending network device (i.e., base station, controller, or SDN switch) to which the UE is affiliated at the completion of the handover operation.

Process 500 may include determining that a handover operation should occur (block 510). For process 500, assume that the handover operation is an inter-controller handover. That is, the source base station may be associated with a different controller 120 than the target base station or the source base station may be a base station that is in an inter-controller handover zone. For example, assume that UE 105 is attached to base station 415 and is affiliated with controller 120-1 (the source controller). Controller 120-1 may determine (e.g., on the basis of the UE's historical data, including trajectory, location, velocity, observed neighboring cells, etc.) that a handover is appropriate and that the target base station is base station 420, which is affiliated with controller 120-2 (the target controller).

The source controller may transmit a handover request to the target controller (block 520). As mentioned, the target controller may be controller 120-2. The request may indicate that an inter-controller handover is to occur. Process 500 may further include affiliating the target controller (controller 120-2), with the UE, as the active controller (block 530). Process 500 may further include affiliating the target SDN switch (e.g., SDN switch 125-2), with the UE, as the active switch (block 540). The configuration that is performed in blocks 520-540 may all be performed in the control plane of the RAN.

Process 500 may further include signaling the EPC to request the handover operation (block 550). For instance, the target controller may communicate with EPC 130, such as with SGW 142 and MME 144, to request bearer modifications, in EPC 130, relating to the handover.

After the target controller and the target SDN switch have been set (blocks 530 and 540), the handover operation is equivalent to the intra-controller handover operation, as discussed above with respect to Figs. 2 and 3. Process 500 may further include performing the intra-controller handover procedure (block 560). In this manner, the handover between the source and target base station may be performed.

Fig. 6 is a signal flow diagram illustrating an example inter-controller handover involving various devices in environment 100. The inter-controller handover procedure can be divided into two phases. The first phase includes control plane operations relating to switching the active controller 120 (and, if a different SDN switch 125 is being used by the target controller, switching the SDN switch) and notifying EPC 130. The second phase follows the intra-controller handover operation, as discussed with respect to Figs. 2 and 3.

As shown in Fig. 6, UE 105 may initially be communicating, with SGW 142 of the EPC, using source base station 415 and source SDN switch 125-1 (at 605, "packet data"). At some point, source controller 120-1 may determine that a handover operation should be performed (at 610, "HO decision"). As previously mentioned, the handover decision may be based on information such as the trajectory of the UE, the location of the UE, the velocity of the UE,

signal strength measurements made by the UE, etc. The handover decision may involve a handover between base stations in different virtual cells, such as, with reference to Fig. 4, a handover that involves base stations associated with two different controllers 120 (e.g., between source base station 415 and target base station 420).

5 Source controller 120-1 may transmit a handover request to target controller 120-2 (at 615, "handover request"). The handover request may be made via a control plane signaling in RAN 110. The handover request may be acknowledged by target controller 120-2 (at 620, "handover request ACK"). Source controller 120-1 may indicate, to source base station 415, that the controller and SDN switch that are to be used, for the particular UE, are being switched
10 to target controller 120-2, and target SDN switch 125-2 (at 625, "controller and anchor switch"). Target controller 120-2 may correspondingly update target SDN switch 125-2 to modify or add entries for the traffic flows, corresponding to the UE (at 630, "modify flow entry").

Target controller 120-2 may inform EPC 130 of the handover. As shown, target controller 120-2 may transmit a path switch request to MME 144 (at 635, "path switch request").
15 In response, MME 144 may control SGW 142 to modify the bearer path (at 640, "modify bearer request"). SGW 142 may switch the downlink (DL) path for the bearer (at 142, "switch DL path"). At this point, packet data communicated between SGW 142 and UE 105 may be transmitted via target SDN switch 152-2 and source base station 415. Acknowledgement of the downlink path switch may be transmitted back to target controller 120-2 (at 655 and 660,
20 "modify bearer response" and "path switch response"). At this point, the target controller and target SDN switch are affiliated with UE 105, and the handover procedure may be completed as in the intra-controller handover procedure (described with respect to Figs. 2 and 3) (at 665, "intra-controller handover procedure").

With the techniques described above, high-density radio access networks may be
25 employed in a flexible manner and in which signaling to the core network, due to handovers, may be reduced. In particular, core network signaling may only be needed for inter-controller handovers. Handovers within the virtual cell of a controller, however, may be handled in the RAN.

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

by, one or more software or firmware modules. In some embodiments, circuitry may include logic, at least partially operable in hardware.

Embodiments described herein may be implemented into a system using any suitably configured hardware and/or software. Fig. 7 illustrates, for one embodiment, example components of an electronic device 700. In embodiments, the electronic device 700 may be a UE, a base station, an SDN switch, a controller (e.g., controller 120), an MME, PGW, or SGW. In some embodiments, the electronic device 700 may include application circuitry 702, baseband circuitry 704, Radio Frequency (RF) circuitry 706, front-end module (FEM) circuitry 708 and one or more antennas 760, coupled together at least as shown. In embodiments in which a radio interface is not needed for electronic device 700 (e.g., a data gateway, network controller, etc.), the RF circuitry 706, FEM circuitry 708, and antennas 760 may be omitted. In other embodiments, any of said circuitries can be included in different devices.

Application circuitry 702 may include one or more application processors. For example, the application circuitry 702 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. The memory/storage may include, for example, computer-readable medium 703, which may be a non-transitory computer-readable medium. Application circuitry 702 may, in some embodiments, connect to or include one or more sensors, such as environmental sensors, cameras, etc.

Baseband circuitry 704 may include circuitry such as, but not limited to, one or more single-core or multi-core processors. The baseband circuitry 704 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 706 and to generate baseband signals for a transmit signal path of the RF circuitry 706. Baseband processing circuitry 704 may interface with the application circuitry 702 for generation and processing of the baseband signals and for controlling operations of the RF circuitry 706. For example, in some embodiments, the baseband circuitry 704 may include a second generation (2G) baseband processor 704a, third generation (3G) baseband processor 704b, fourth generation (4G) baseband processor 704c, and/or other baseband processor(s) 704d for other existing generations, generations in development or to be developed in the future (e.g., fifth generation (5G), 7G, etc.). The baseband circuitry 704 (e.g., one or more of baseband processors 704a-d) may handle various radio control functions that enable communication with one or more radio networks via the RF circuitry 706. The radio

control functions may include, but are not limited to, signal modulation/demodulation, encoding/decoding, radio frequency shifting, etc. In some implementations, the functionality of baseband circuitry 704 may be wholly or partially implemented by memory/storage devices configured to execute instructions stored in the memory/storage. The memory/storage may
5 include, for example, a non-transitory computer-readable medium 704h.

In some embodiments, modulation/demodulation circuitry of the baseband circuitry 704 may include Fast-Fourier Transform (FFT), precoding, and/or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 704 may include convolution, tail-biting convolution, turbo, Viterbi, and/or Low Density Parity
10 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. In some embodiments, the baseband circuitry 704 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),
15 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) 704e of the baseband circuitry 704 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) 704f. The
20 audio DSP(s) 704f may include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments.

In some embodiments, the baseband circuitry 704 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),
25 radio link control (RLC), packet data convergence protocol (PDCP), and/or radio resource control (RRC) elements. A central processing unit (CPU) 704e of the baseband circuitry 704 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) 704f. The audio DSP(s) 104f may include
30 elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments.

Baseband circuitry 704 may further include memory/storage 704g. The memory/storage 704g may be used to load and store data and/or instructions for operations performed by the processors of the baseband circuitry 704. Memory/storage 704g may particularly include a non-
35 transitory memory. Memory/storage for one embodiment may include any combination of

suitable volatile memory and/or non-volatile memory. The memory/storage 704g may include any combination of various levels of memory/storage including, but not limited to, read-only memory (ROM) having embedded software instructions (e.g., firmware), random access memory (e.g., dynamic random access memory (DRAM)), cache, buffers, etc. The
5 memory/storage 704g may be shared among the various processors or dedicated to particular processors.

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
10 embodiments, some or all of the constituent components of the baseband circuitry 704 and the application circuitry 702 may be implemented together such as, for example, on a system on a chip (SOC).

In some embodiments, the baseband circuitry 704 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 704 may support communication with an evolved universal terrestrial radio
15 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 704 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

RF circuitry 706 may enable communication with wireless networks using modulated
20 electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 706 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 706 may include a receive signal path which may include circuitry to down-convert RF signals received from the FEM circuitry 708 and provide baseband signals to the baseband circuitry 704. RF circuitry 706 may also include a transmit signal path
25 which may include circuitry to up-convert baseband signals provided by the baseband circuitry 704 and provide RF output signals to the FEM circuitry 708 for transmission.

In some embodiments, the RF circuitry 706 may include a receive signal path and a transmit signal path. The receive signal path of the RF circuitry 706 may include mixer circuitry 706a, amplifier circuitry 706b and filter circuitry 706c. The transmit signal path of the RF
30 circuitry 706 may include filter circuitry 706c and mixer circuitry 706a. RF circuitry 706 may also include synthesizer circuitry 706d for synthesizing a frequency for use by the mixer circuitry 706a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 706a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 708 based on the synthesized frequency provided by
35 synthesizer circuitry 706d. The amplifier circuitry 706b may be configured to amplify the

down-converted signals and the filter circuitry 706c 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 704 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 706a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

In various embodiments, when the electronic device 700 is implemented as part of a base station or a controller, electronic device 700 may include an apparatus for controlling the mobility of UEs. The electronic device may include handover circuitry, or other logic, to determine that the UE should be switched, from a source (serving) base station; determine whether the source base station lies within an intra-controller handover zone or an inter-controller-handover zone; select one or more of a target base station or target controller for the UE to be switched to; and cause switchover of the connection between the UE and the serving base station to the target base station.

In some embodiments, the mixer circuitry 706a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 706d to generate RF output signals for the FEM circuitry 708. The baseband signals may be provided by the baseband circuitry 704 and may be filtered by filter circuitry 706c. The filter circuitry 706c may include a low-pass filter (LPF), although the scope of the embodiments is not limited in this respect.

In some embodiments, the mixer circuitry 706a of the receive signal path and the mixer circuitry 706a 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 706a of the receive signal path and the mixer circuitry 706a 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 706a of the receive signal path and the mixer circuitry 706a may be arranged for direct downconversion and/or direct upconversion, respectively. In some embodiments, the mixer circuitry 706a of the receive signal path and the mixer circuitry 706a of the transmit signal path may be configured for super-heterodyne operation.

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 706 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 704 may include a digital baseband interface to communicate with the RF circuitry 706.

5 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.

In some embodiments, the synthesizer circuitry 706d may be a fractional-N synthesizer or a fractional N/N+6 synthesizer, although the scope of the embodiments is not limited in this
10 respect as other types of frequency synthesizers may be suitable. For example, synthesizer circuitry 706d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

The synthesizer circuitry 706d may be configured to synthesize an output frequency for use by the mixer circuitry 706a of the RF circuitry 706 based on a frequency input and a divider
15 control input. In some embodiments, the synthesizer circuitry 706d may be a fractional N/N+6 synthesizer.

In some embodiments, frequency input may be provided by a voltage-controlled oscillator (VCO), although that is not a requirement. Divider control input may be provided by either the baseband circuitry 704 or the applications processor 702 depending on the desired
20 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 702.

Synthesizer circuitry 706d of the RF circuitry 706 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
25 (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or N+6 (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into Nd equal packets of phase, where Nd is the number of
30 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.

In some embodiments, synthesizer circuitry 706d 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
35 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 706 may include an IQ/polar converter.

FEM circuitry 708 may include a receive signal path which may include circuitry
5 configured to operate on RF signals received from one or more antennas 760, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 706 for further processing. FEM circuitry 708 may also include a transmit signal path which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 706 for transmission by one or more of the one or more antennas 760.

10 In some embodiments, the FEM circuitry 708 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 706). The transmit signal path of the FEM
15 circuitry 708 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 706), and one or more filters to generate RF signals for subsequent transmission (e.g., by one or more of the one or more antennas 760).

In some embodiments, the electronic device 700 may include additional elements such as, for example, memory/storage, display, camera, sensors, and/or input/output (I/O) interface.

20 In some embodiments, the electronic device of Fig. 7 may be configured to perform one or more methods, processes, and/or techniques such as those described herein.

A number of examples, relating to implementations of the techniques described above, will next be given.

In a first example, a controller device for a radio access network (RAN) of a
25 cellular communication network may include circuitry to: receive measurement information relating to a strength of a connectivity of User Equipment (UE) to a source base station of a plurality of base stations in the RAN; determine, based on the received measurement information, to perform a handover operation; and when the source base station is affiliated with a second controller device in the RAN, perform an inter-controller handover operation in which
30 the circuitry is further to: determine the second controller device as a controller device with which the UE is to be affiliated, and communicate with the second controller device to switch an affiliation of the UE from the controller device to the second controller device.

In example, 2, the subject matter of example 1, or any of the examples herein, may further include wherein the circuitry is further to: store affiliations of the plurality of base
35 stations, to controller devices to which the plurality of base stations are affiliated, at least some

of the plurality of the base stations being affiliated with the controller device and others of the plurality of the base stations being affiliated with the controller device and with the second controller device in the RAN; and when the source base station is affiliated with the controller device and not the second controller device, perform an intra-controller handover operation in which the circuitry is further to: determine a target base station to which the UE is to attach after completion of the handover operation, modify configuration of a Software Defined Network (SDN) switch, in the RAN, to indicate that traffic flows with the UE should be communicated with a core portion of the cellular communication network via the SDN switch and the target base station.

10 In example 3, the subject matter of example 1 or 2, or any of the examples herein, may further include wherein the measurement information and the configuration of the SDN switch is performed via control plane interfaces.

In example 4, the subject matter of example 1 or 2, or any of the examples herein, may further include wherein the circuitry is further to: inform, during an inter-controller handover operation, a core portion of the cellular communication network, of the handover operation, and refrain from informing the core portion of the cellular communication network during an intra-controller handover operation.

15 In example 5, the subject matter of example 4, or any of the examples herein, may further include wherein informing the core portion of the cellular network includes transmitting a path switch request to a Mobility Management Entity (MME).

20 In example 6, the subject matter of example 1 or 2, or any of the examples herein, may further include wherein the measurement information includes measurement information, obtained by the UE, and forwarded, from the source base station to the control device, via a control plane interface.

25 In example 7, the subject matter of example 2, or any of the examples herein, may further include wherein the determination of the target base station includes determining an optimal target base station based on load information relating to the plurality of base stations.

In example 8, the subject matter of example 2, or any of the examples herein, may further include wherein the configuration of the SDN switch includes deleting one or more traffic flow entries to the SDN switch to cause buffering of packets, associated with the traffic entries, at the SDN switch.

30 In example 9, the subject matter of example 8, or any of the examples herein, may further include wherein the modification to the SDN switch additionally includes adding traffic flow entries to the SDN switch to cause the traffic flows to be communicated with the target base station.

In example 10, the subject matter of examples 8 or 9, or any of the examples herein, may further include wherein the modifications to the SDN? switch are performed via a control plane in the RAN.

5 In an eleventh example, a computer readable medium may contain program instructions for causing one or more processors, associated with a controller device for a radio access network (RAN) of a cellular communication network, to: store an indication of a plurality of base stations, in the RAN, to which the controller device is affiliated, at least some of the plurality of the base stations being affiliated with the controller device and others of the plurality of the base stations being affiliated with the controller device and with a second controller
10 device in the RAN; receive measurement information relating to a strength of the connectivity of the UE to a source base station of the plurality of base stations, in the RAN, and to which the UE is attached; determine, based on the received measurement information, to perform a handover operation, as an inter-controller handover operation, when the source base station is affiliated with another controller device in the RAN, wherein the one or more processors, as part
15 of performance of the inter-controller handover, are further to: determine the second controller device as a controller device with which the UE is to be affiliated, and communicate with the second controller device to switch an affiliation of the UE from the controller device to the second controller device, the switching of the affiliation of the UE from the controller device to the second controller device being performed before handover operations are performed with
20 respect to an air interface of the RAN and before handover operations are performed with respect to a core portion of the cellular communication network.

In example 12, the subject matter of example 11, or any of the examples herein, may further include wherein the program instructions are further to cause the one or more processors to: determine, based on the received measurement information, to perform a handover operation,
25 as an intra-controller handover operation, when the source base station is not affiliated with another controller device in the RAN, wherein the one or more processors are further to: determine a target base station to which the UE is to attach after completion of the handover operation, and modify configuration of a Software Defined Network (SDN) switch, in the RAN, to indicate that traffic flows with the UE should be communicated with the core portion of the
30 cellular communication network via the SDN switch and the target base station.

In example 13, the subject matter of example 12, or any of the examples herein, may further include wherein the measurement information and the configuration of the SDN switch is performed via control plane interfaces.

In example 14, the subject matter of example 12, or any of examples herein, may further
35 include wherein the program instructions are further to cause the one or more processors to:

inform, during an inter-controller handover operation, a core portion of the cellular communication network, of the handover operation, and refrain from informing the core portion of the cellular communication network during an intra-controller handover operation.

In example 15, the subject matter of example 14, or any of the examples herein, may further include wherein informing the core portion of the cellular network includes transmitting a path switch request to a Mobility Management Entity (MME).

In example 16, the subject matter of example 21, or any of examples herein, may further include wherein the measurement information includes measurement information, obtain by the UE, and forwarded, from the source base station to the control device, via a control plane interface.

In example 17, the subject matter of example 12, or any of examples herein, may further include wherein the determination of the target base station includes determining an optimal target base station based on load information relating to the plurality of base stations.

In example 18, the subject matter of example 12, or any of examples herein, may further include wherein the modification to the SDN switch includes deleting one or more traffic flow entries to the SDN switch to cause buffering of packets, associated with the traffic entries, in the SDN switch.

In example 19, the subject matter of example 18, or any of examples herein, may further include wherein the modification to the SDN switch additionally includes adding traffic flow entries to the SDN switch to cause the traffic flows to be communicated with the target base station.

In a 20th example, a base station for a cellular communication network may comprise: a radio interface to connect to User Equipment (UE) devices; a control plane interface to connect to a controller device for a radio access network (RAN) of the cellular communication network; a data plane interface to a Software Defined Network (SDN) switch in the RAN; and processing circuitry to: decode a Radio Resource Control (RRC) layer measurement report received over the radio interface from a particular UE, of the UE devices, the measurement report indicating a strength of the connectivity of the particular UE to the base station; cause providing of the measurement report, to the controller device, via the control plane interface; cause transmission of the received user plane data, to a core portion of the cellular communications network, via the data plane interface; process an indication, from the controller device, to perform a handover of the particular UE with a second base station; and cause transmission, via the radio interface, of a RRC connection reconfiguration message to the particular UE, to cause the particular UE to initiate communication with the second base station.

In example 21, the subject matter of example 20, or any of the examples herein, may further include wherein the indication to perform the handover operation is received via the control plane interface.

5 In example 22, the subject matter of example 20, or any of the examples herein, may further include wherein the control plane interface includes an OpenFlow-based interface.

In example 23, the subject matter of example 20, or any of the examples herein, may further include wherein the control plane interface connects the base station to a plurality of controller devices in the RAN.

10 In a 24th example, a base station for a cellular communication network may comprise: means for implementing a data plane interface to a Software Defined Network (SDN) switch in Radio Access Network (RAN) of the cellular communications network; and means for receiving, from a particular User Equipment (UE) device, and over a radio interface, a Radio Resource Control (RRC) layer measurement report indicating a strength of the connectivity of the particular UE to a base station; means for providing the measurement report, to a controller
15 device for the RAN of the cellular communication network; means for receiving, from the particular UE and over the radio interface, user plane data; means for transmitting the received user plane data, to a core portion of the cellular communications network, via the data plane interface; means for receiving, from the controller device and based on the provided measurement report, an indication to perform a handover of the particular UE with a second
20 base station; and means for transmitting, in response to the indication to perform the handover, a RRC connection reconfiguration message to the particular UE, via the radio interface, to cause the particular UE to initiate communication with the second base station.

In example 25, the subject matter of example 24, or any of the examples herein, wherein the indication to perform the handover operation is received via the control plane interface.

25 In example 26, the subject matter of example 24, or any of examples herein, wherein the control plane interface includes an OpenFlow-based interface.

In the preceding specification, various embodiments have been described with reference to the accompanying drawings. It will, however, be evident that various modifications and changes may be made thereto, and additional embodiments may be implemented, without
30 departing from the broader scope as set forth in the claims that follow. The specification and drawings are accordingly to be regarded in an illustrative rather than restrictive sense.

For example, while series of signals and/or operations have been described with regard to Figs. 2, 3, 5, and 6, the order of the signals may be modified in other implementations. Further, non-dependent signals may be performed in parallel.

It will be apparent that example aspects, as described above, may be implemented in many different forms of software, firmware, and hardware in the implementations illustrated in the figures. The actual software code or specialized control hardware used to implement these aspects should not be construed as limiting. Thus, the operation and behavior of the aspects
5 were described without reference to the specific software code—it being understood that software and control hardware could be designed to implement the aspects based on the description herein.

Even though particular combinations of features are recited in the claims and/or disclosed in the specification, these combinations are not intended to be limiting. In fact, many of these
10 features may be combined in ways not specifically recited in the claims and/or disclosed in the specification.

No element, act, or instruction used in the present application should be construed as critical or essential unless explicitly described as such. An instance of the use of the term "and," as used herein, does not necessarily preclude the interpretation that the phrase "and/or" was
15 intended in that instance. Similarly, an instance of the use of the term "or," as used herein, does not necessarily preclude the interpretation that the phrase "and/or" was intended in that instance. Also, as used herein, the article "a" is intended to include one or more items, and may be used interchangeably with the phrase "one or more." Where only one item is intended, the terms "one," "single," "only," or similar language is used.

20

WHAT IS CLAIMED IS:

1. A controller device for a radio access network (RAN) of a cellular communication network, the controller device comprising circuitry to:
receive measurement information relating to a strength of a connectivity of User
5 Equipment (UE) to a source base station of a plurality of base stations in the RAN;
determine, based on the received measurement information, to perform a handover operation; and
when the source base station is affiliated with a second controller device in the RAN, perform an inter-controller handover operation in which the circuitry is further to:
10 determine the second controller device as a controller device with which the UE is to be affiliated, and
communicate with the second controller device to switch an affiliation of the UE from the controller device to the second controller device.

2. The controller device of claim 1, wherein the circuitry is further to:
store affiliations of the plurality of base stations, to controller devices to which the plurality of base stations are affiliated, at least some of the plurality of the base stations being affiliated with the controller device and others of the plurality of the base stations being affiliated with the controller device and with the second controller device in the RAN; and
20 when the source base station is affiliated with the controller device and not the second controller device, perform an intra-controller handover operation in which the circuitry is further to:
determine a target base station to which the UE is to attach after completion of the handover operation,
25 modify configuration of a Software Defined Network (SDN) switch, in the RAN, to indicate that traffic flows with the UE should be communicated with a core portion of the cellular communication network via the SDN switch and the target base station.

3. The controller device of claim 1 or claim 2, wherein the measurement
30 information and the configuration of the SDN switch is performed via control plane interfaces.

4. The controller device of claim 1 or claim 2, wherein the circuitry is further to:
inform, during an inter-controller handover operation, a core portion of the cellular communication network, of the handover operation, and refrain from informing the core portion
35 of the cellular communication network during an intra-controller handover operation.

5. The controller device of claim 4, wherein informing the core portion of the cellular network includes transmitting a path switch request to a Mobility Management Entity (MME).

5

6. The controller device of claim 1 or claim 2, wherein the measurement information includes measurement information, obtained by the UE, and forwarded, from the source base station to the control device, via a control plane interface.

10

7. The controller device of claim 2, wherein the determination of the target base station includes determining an optimal target base station based on load information relating to the plurality of base stations.

15

8. The controller device of claim 2, wherein the configuration of the SDN switch includes deleting one or more traffic flow entries to the SDN switch to cause buffering of packets, associated with the traffic entries, at the SDN switch.

20

9. The controller device of claim 8, wherein the modification to the SDN switch additionally includes adding traffic flow entries to the SDN switch to cause the traffic flows to be communicated with the target base station.

10. The controller device of claim 8 or 9, wherein the modifications to the SDN switch are performed via a control plane in the RAN.

25

11. A computer-readable medium containing program instructions for causing one or more processors, associated with a controller device for a radio access network (RAN) of a cellular communication network, to:

30

receive measurement information relating to a strength of the connectivity of a User Equipment (UE) to a source base station of a plurality of base stations, in the RAN, and to which the UE is attached;

determine, based on the received measurement information, to perform a handover operation, as an inter-controller handover operation, when the source base station is affiliated with another controller device in the RAN, wherein the one or more processors, as part of performance of the inter-controller handover, are further to:

35

determine a second controller device as a controller device with which the UE is

to be affiliated, and

communicate with the second controller device to switch an affiliation of the UE from the controller device to the second controller device, the switching of the affiliation of the UE from the controller device to the second controller device being performed before handover operations are performed with respect to an air interface of the RAN and before handover operations are performed with respect to a core portion of the cellular communication network.

12. The computer-readable medium of claim 11, wherein the program instructions are further to cause the one or more processors to:

10 determine, based on the received measurement information, to perform a handover operation, as an intra-controller handover operation, when the source base station is not affiliated with another controller device in the RAN, wherein the one or more processors are further to:

15 determine a target base station to which the UE is to attach after completion of the handover operation, and

modify configuration of a Software Defined Network (SDN) switch, in the RAN, to indicate that traffic flows with the UE should be communicated with the core portion of the cellular communication network via the SDN switch and the target base station.

20 13. The computer-readable medium of claim 12, wherein the measurement information and the configuration of the SDN switch is performed via control plane interfaces.

14. The computer-readable medium of claim 12, wherein the program instructions are further to cause the one or more processors to:

25 inform, during an inter-controller handover operation, a core portion of the cellular communication network, of the handover operation, and refrain from informing the core portion of the cellular communication network during an intra-controller handover operation.

30 15. The computer-readable medium of claim 14, wherein informing the core portion of the cellular network includes transmitting a path switch request to a Mobility Management Entity (MME).

16. The computer-readable medium of claim 12, wherein the measurement information includes measurement information, obtain by the UE, and forwarded, from the source base station to the control device, via a control plane interface.

17. The computer-readable medium of claim 12, wherein the determination of the target base station includes determining an optimal target base station based on load information relating to the plurality of base stations.

5

18. The computer-readable medium of claim 12, wherein the modification to the SDN switch includes deleting one or more traffic flow entries to the SDN switch to cause buffering of packets, associated with the traffic entries, in the SDN switch.

10

19. The computer-readable medium of claim 18, wherein the modification to the SDN switch additionally includes adding traffic flow entries to the SDN switch to cause the traffic flows to be communicated with the target base station.

15

20. A base station for a cellular communication network, the base station comprising:
a radio interface to connect to User Equipment (UE) devices;
a control plane interface to connect to a controller device for a radio access network (RAN) of the cellular communication network;
a data plane interface to a Software Defined Network (SDN) switch in the RAN; and
processing circuitry to:

20

decode a Radio Resource Control (RRC) layer measurement report received over the radio interface from a particular UE, of the UE devices, the measurement report indicating a strength of the connectivity of the particular UE to the base station;

cause providing of the measurement report, to the controller device, via the control plane interface;

25

cause transmission of the received user plane data, to a core portion of the cellular communications network, via the data plane interface;

process an indication, from the controller device, to perform a handover of the particular UE with a second base station; and

generate a RRC connection reconfiguration message for the particular UE, to

30

cause the particular UE to initiate communication with the second base station.

21. The base station of claim 20, wherein the indication to perform the handover operation is received via the control plane interface.

35

22. The base station of claim 20, wherein the control plane interface includes an

OpenFlow-based interface.

23. The base station of claim 20, wherein the control plane interface connects the base station to a plurality of controller devices in the RAN.

5

24. A base station for a cellular communication network, the base station comprising:
means for implementing a data plane interface to a Software Defined Network (SDN)
switch in Radio Access Network (RAN) of the cellular communications network;

10 means for receiving, from a particular User Equipment (UE) device, and over a radio
interface, a Radio Resource Control (RRC) layer measurement report indicating a strength of the
connectivity of the particular UE to a base station;

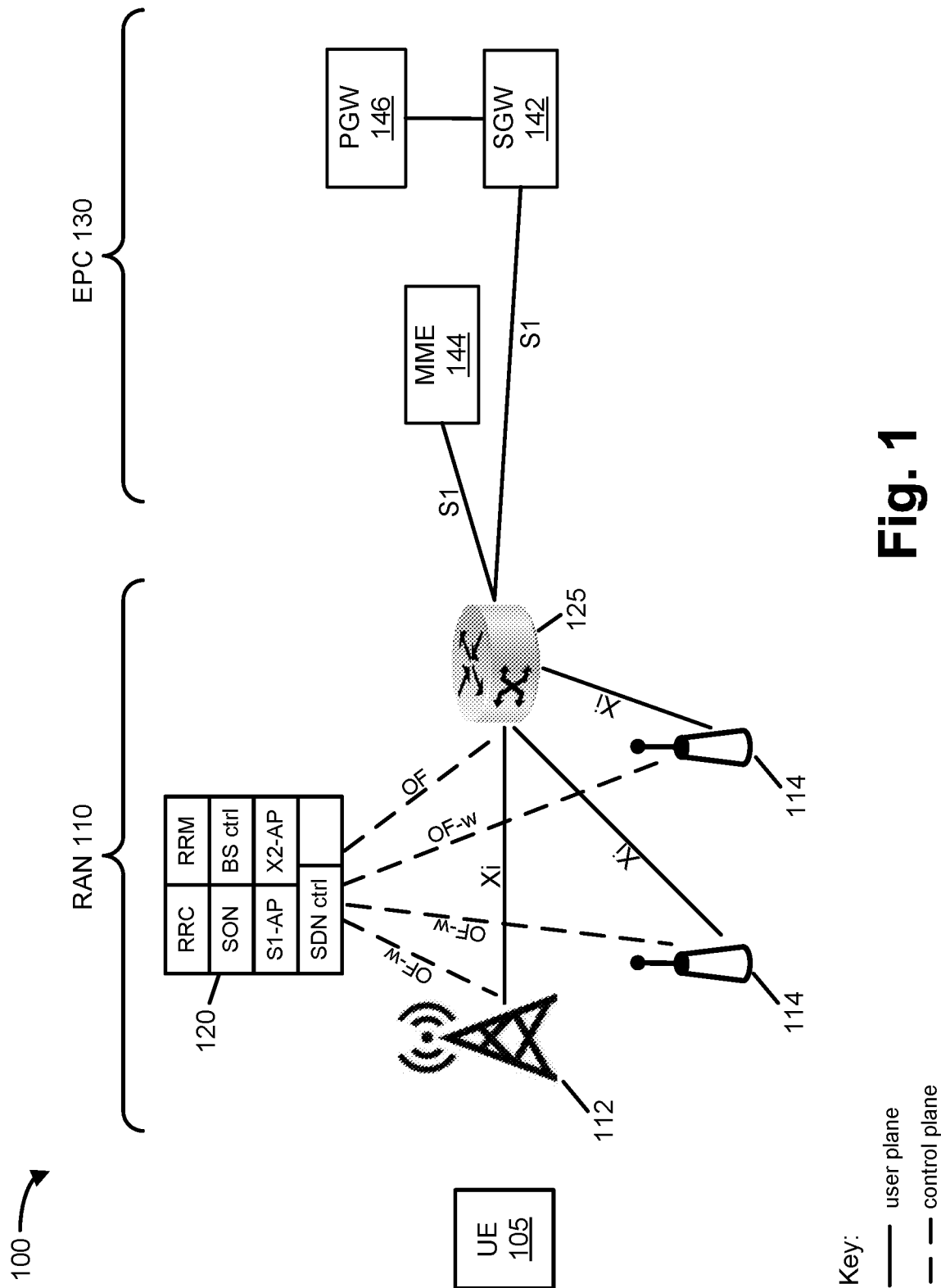
means for providing the measurement report, to a controller device for the RAN of the
cellular communication network;

15 means for receiving, from the particular UE and over the radio interface, user plane data;
means for transmitting the received user plane data, to a core portion of the cellular
communications network, via the data plane interface;

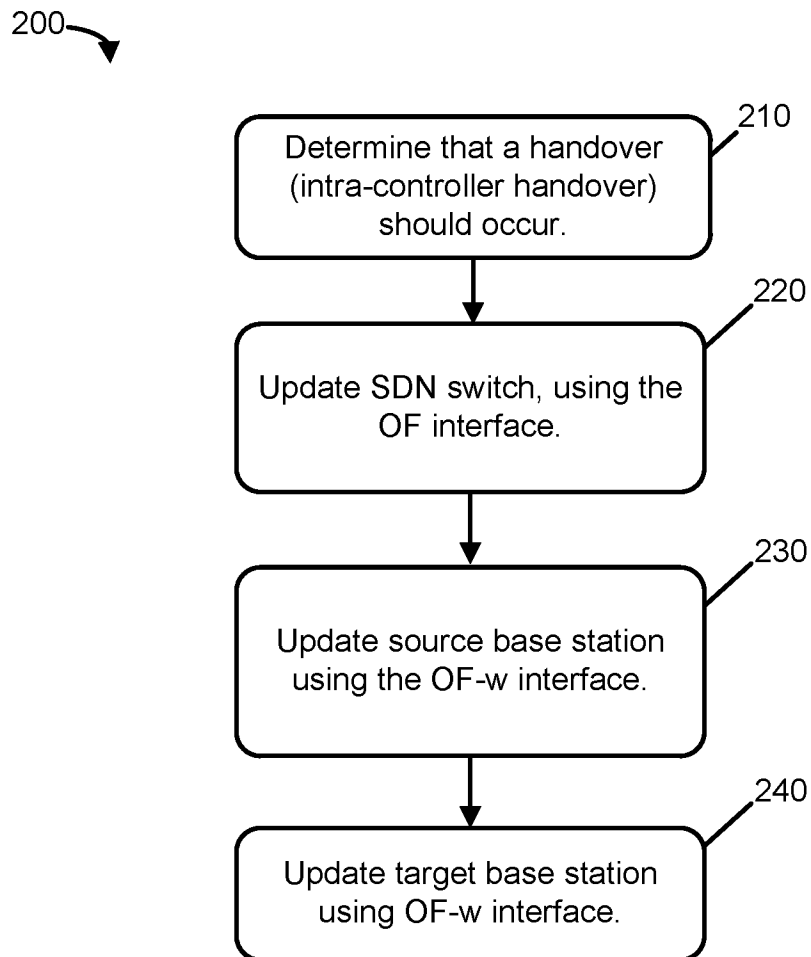
means for receiving, from the controller device and based on the provided measurement
report, an indication to perform a handover of the particular UE with a second base station; and

20 means for transmitting, in response to the indication to perform the handover, a RRC
connection reconfiguration message to the particular UE, via the radio interface, to cause the
particular UE to initiate communication with the second base station.

25. The base station of claim 24, wherein the indication to perform the handover
operation is received via the control plane interface.



2/7

**Fig. 2**

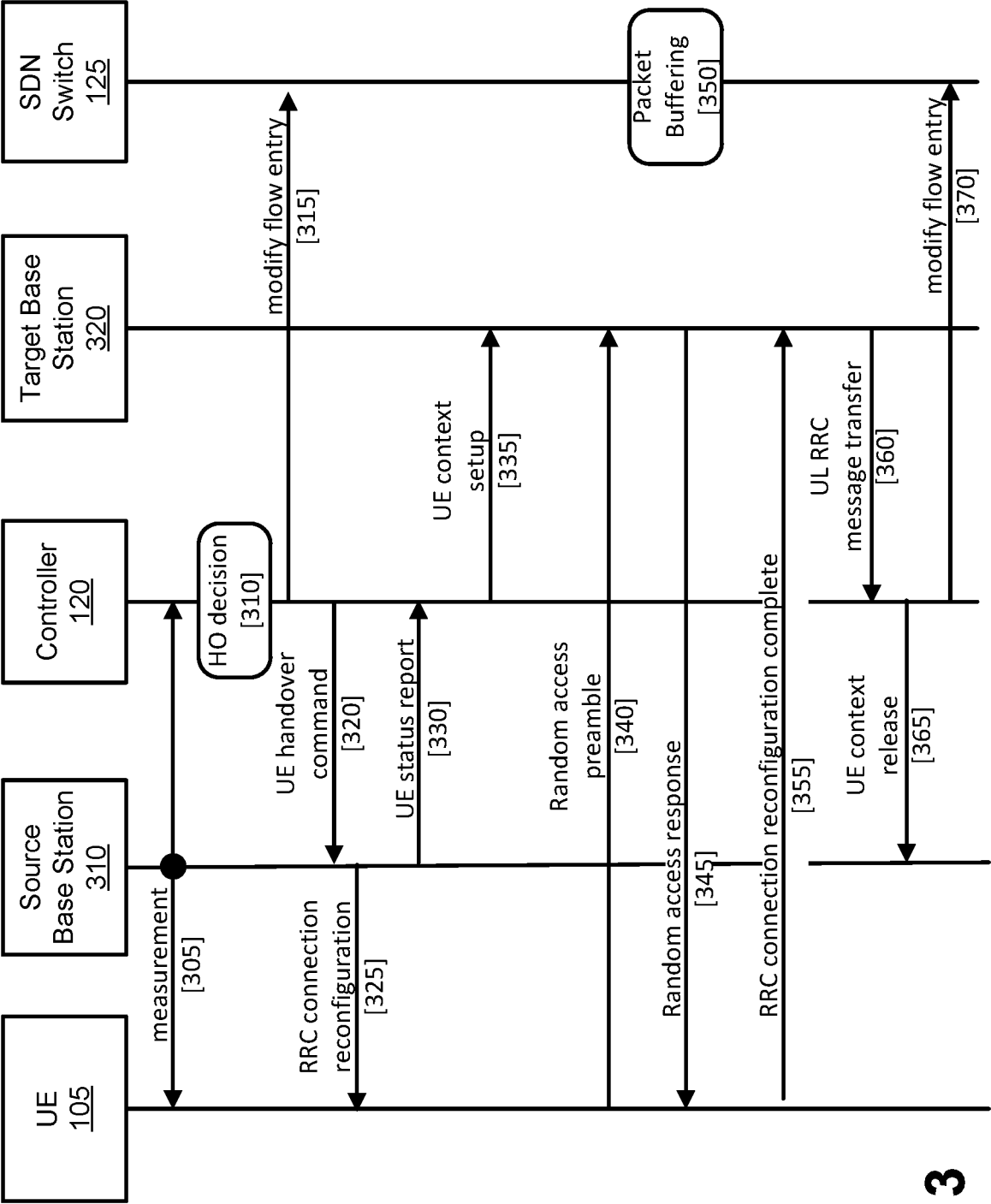


Fig. 3

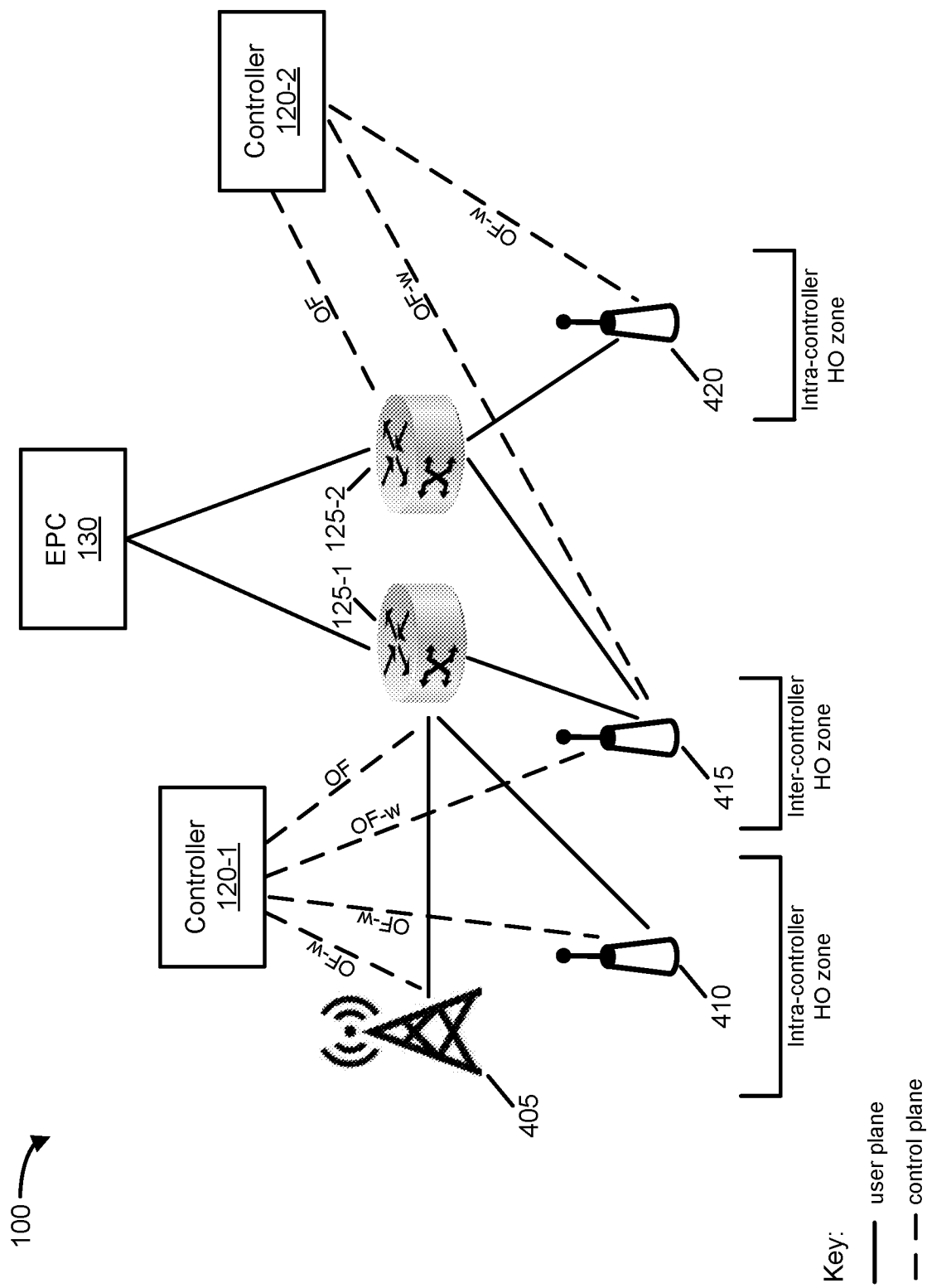
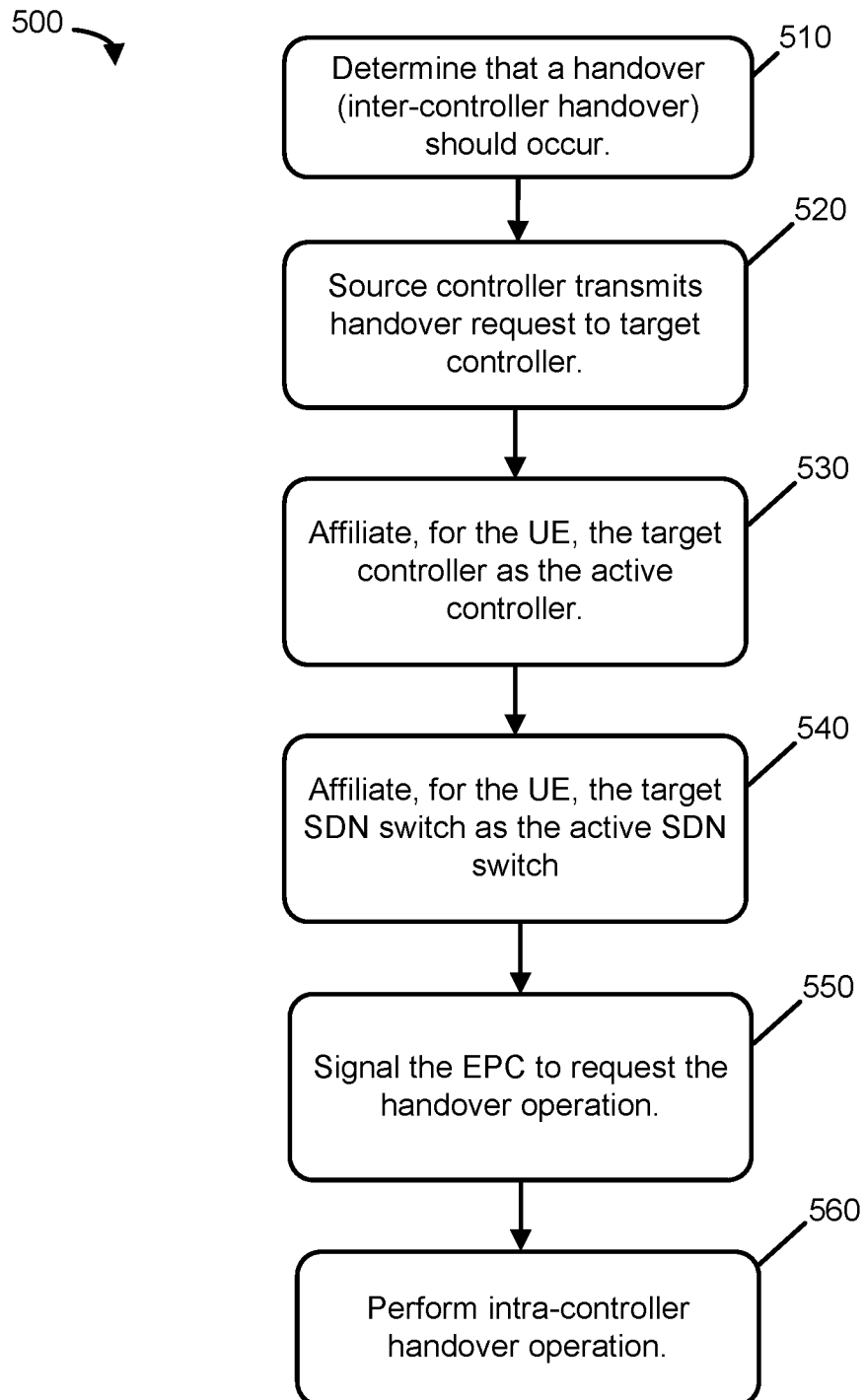


Fig. 4

5/7

**Fig. 5**

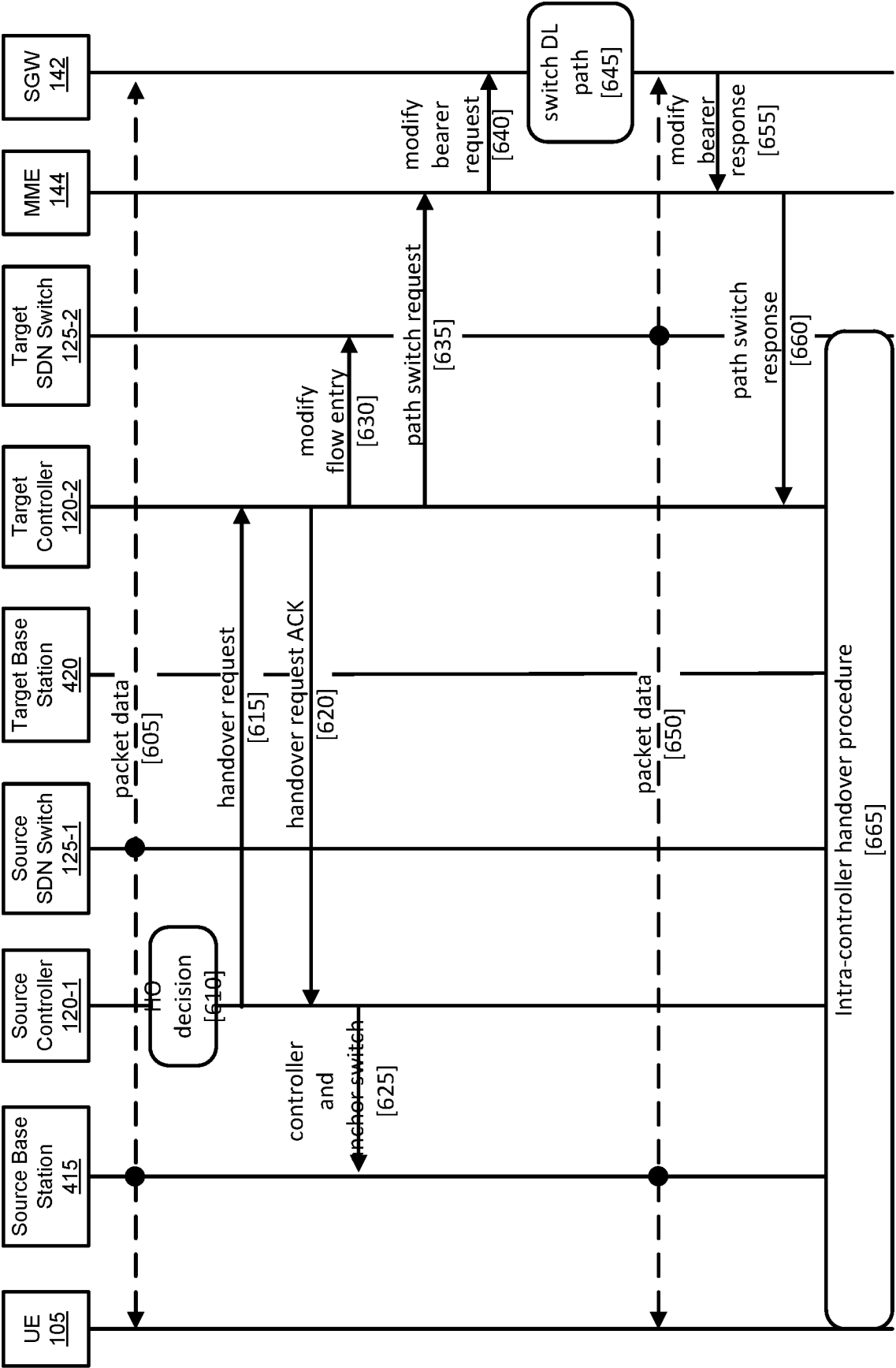


Fig. 6

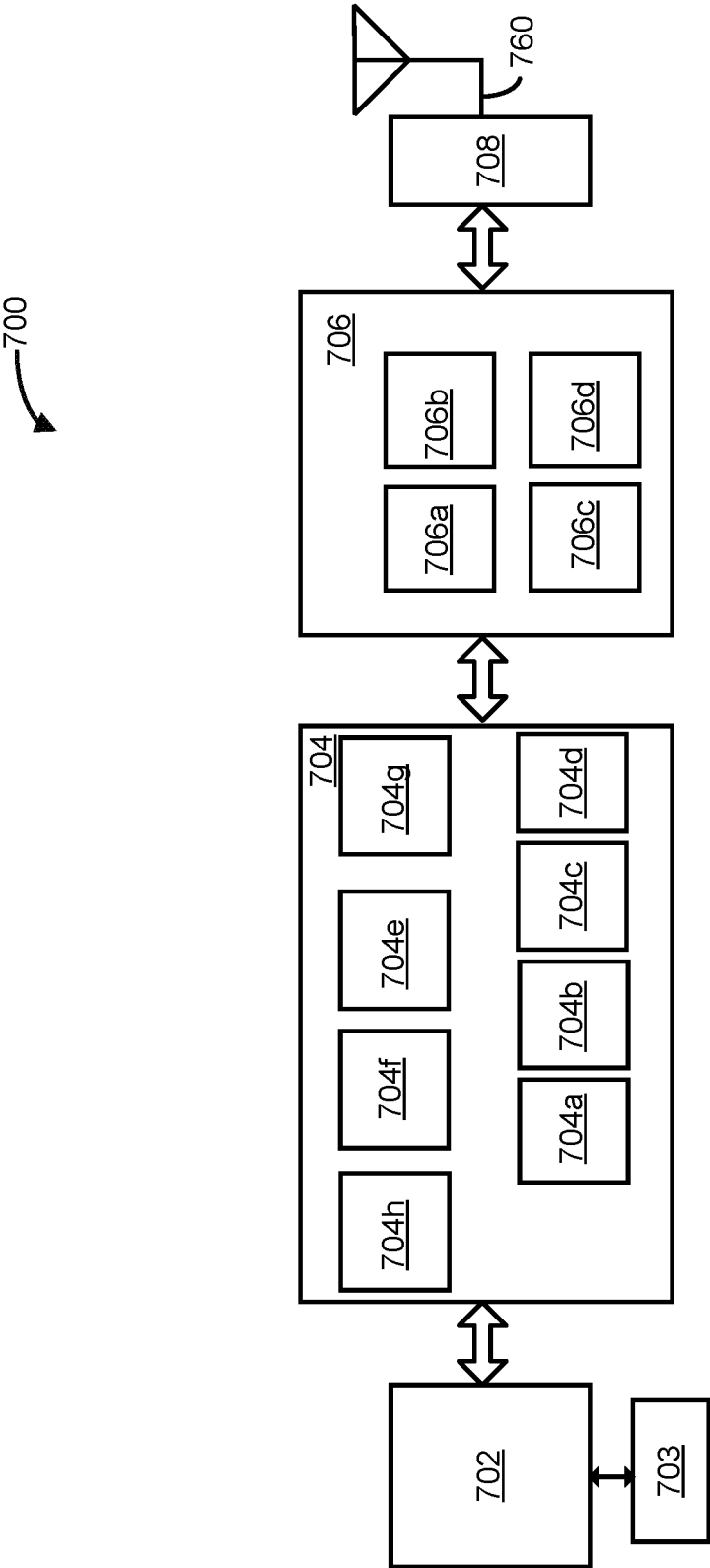


Fig. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/025403

A. CLASSIFICATION OF SUBJECT MATTER

INV. H04W36/10
ADD. H04W36/00 H04W92/12 H04W84/04

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

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)

EP0-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.
A	GURUSANTHOSH P ET AL: "SDMA: A semi-distributed mobility anchoring in LTE networks", 2013 INTERNATIONAL CONFERENCE ON SELECTED TOPICS IN MOBILE AND WIRELESS NETWORKING (MOWNET), IEEE, 19 August 2013 (2013-08-19), pages 133-139, XP032490864, DOI: 10.1109/MOWNET.2013.6613809 [retrieved on 2013-09-27] abstract paragraphs [III.A.], [III.D.] ----- -/--	1-25

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

15 July 2016

Date of mailing of the international search report

29/07/2016

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Bösch, Michael

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/025403

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 2014/254373 A1 (VARMA SUBIR [US]) 11 September 2014 (2014-09-11) figures 2,4,5,12 paragraph [0006] paragraph [0038] - paragraph [0040] paragraph [0051] - paragraph [0058] paragraph [0064] - paragraph [0070] paragraphs [0083], [0084] -----	1-25
A	US 2014/269535 A1 (PAZHYANNUR RAJESH S [US] ET AL) 18 September 2014 (2014-09-18) figures 1,7,8 paragraph [0016] paragraph [0019] - paragraph [0030] paragraph [0044] paragraph [0050] - paragraph [0054] -----	1-25
A	US 2015/103665 A1 (KAIPPALLIMALIL JOHN [US] ET AL) 16 April 2015 (2015-04-16) figures 2,4,5 paragraph [0006] paragraph [0063] - paragraph [0065] paragraph [0070] - paragraph [0075] paragraph [0110] - paragraph [0118] -----	1-25

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/025403

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014254373 A1	11-09-2014	NONE	
US 2014269535 A1	18-09-2014	NONE	
US 2015103665 A1	16-04-2015	CN 105637905 A EP 3050325 A1 US 2015103665 A1 WO 2015057723 A1	01-06-2016 03-08-2016 16-04-2015 23-04-2015