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(54) **Title:** CONFIGURATION MANAGEMENT, PERFORMANCE MANAGEMENT, AND FAULT MANAGEMENT TO SUPPORT EDGE COMPUTING

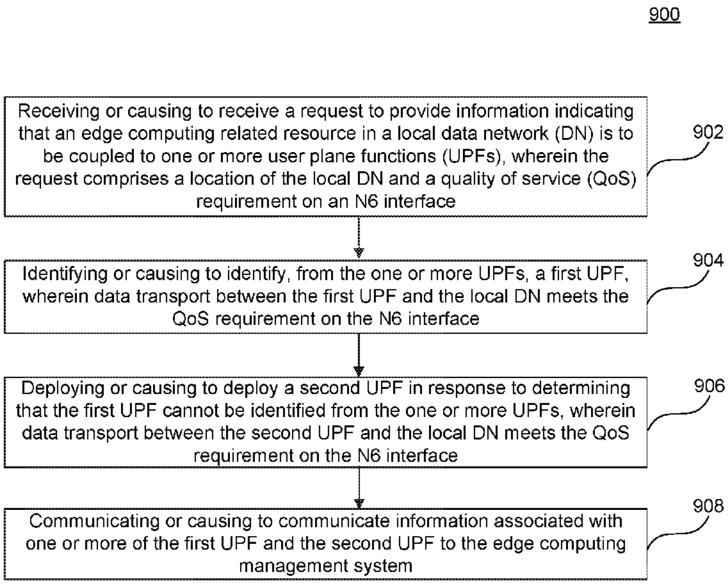

FIG. 9

(57) **Abstract:** A wireless communication management system is disclosed for use in a Third Generation Partnership Program (3GPP) wireless communication environment. The management system supports edge computing by assisting with the locating and/or deployment of a satisfactory user plane function near the requesting device. Specifically, the management system receives a request from an edge computing management system to provide information of a user plane function to which the edge computing related resources in a local data network can be connected. The management system then selects a satisfactory user plane function, or if none can be found, deploys a new user plane function. The management system then provides the information of the selected or deployed user plane function for use in edge computing to the edge computing management system.

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CONFIGURATION MANAGEMENT, PERFORMANCE MANAGEMENT, FAULT MANAGEMENT TO SUPPORT EDGE COMPUTING

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Application No. 62/782,074, filed December 19, 2018, which is hereby incorporated by reference in its entirety.

FIELD

[0002] The embodiments are generally directed to edge computing in an integrated Fifth Generation (5G) cellular communications environment.

BACKGROUND

[0003] Wireless cellular communications have undergone a number of evolutions, the 5G being the current aspiration. 5G anticipates to provide many advantages over 4G, including significantly higher data rates, lower latency, and increased capacity.

[0004] With regard to latency in particular, current cellular technology includes many “cloud” computing services. While this takes processing burdens off of user equipment devices, it centralizes that processing at a handful of cites across the landscape. This results in significant latency by requiring signals to be transmitted over extremely long distances. In other words, a user that is not located sufficiently close to a processing facility will notice large latency as the processing requests travel to the processing site and back. 5G seeks to address the latency problems in a number of ways, including primarily edge computing. Edge computing decentralizes processing, such that it still takes place in the network, but at many locations dispersed throughout the network. As a result, processing nodes can be located within a relative vicinity of the user, thereby greatly reducing latency.

SUMMARY

[0005] Embodiments of the present disclosure include a wireless communication management system for use in a Third Generation Partnership Program (3GPP) wireless communication environment. The management system supports edge computing by assisting with the locating and/or deployment of a satisfactory user plane function near the requesting device. The management system receives a request from an edge computing management system to provide information of a user plane function to which edge computing related resources in a local data network can be connected. The management system then selects a preexsisting user plane function that satisfies the request, or if none can be found, deploys a new user plane function. The management system then provides the information of the preexisting or newly-deployed user plane function for use in edge computing to the edge computing management system.

[0006] Embodiments of the present disclosure further include a wireless communication management system for supporting edge computing in a 3GPP network. The wireless communication management system collects data relating to performance from a plurality of network components associated with edge computing. The wireless communication management system receives a request from an edge computing management system to provide a 3GPP performance measurement associated with edge computing. In response, the wireless communication management system calculates the requested 3GPP performance measurement based on the request and the collected data, and then transmits the calculated 3GPP performance measurement to the edge computing management system.

[0007] Embodiments of the present disclosure further include a method of identifying a satisfactory user plane function for use with edge computing. In the method, a request is received from an edge computing management system for information of a user plane function to which edge computing related resources in a local data network can be connected. In response, a preexisting user plane function is selected that satisfies the request, or if none can be found that satisfies the request, then a new user plane function is deployed that satisfies the request. Then, information of the preexisting or newly-deployed user plane function is provided to the edge computing management system.

BRIEF DESCRIPTION OF THE DRAWINGS/FIGURES

[0008] Figure 1 illustrates an example system architecture within a network, according to an embodiment;

[0009] Figure 2A illustrates a block diagram of an exemplary architecture of a system that includes a first core network, according to an embodiment;

[0010] Figure 2B illustrates a block diagram of an exemplary architecture of a system that includes a second core network, according to an embodiment;

[0011] Figure 3A illustrates a block diagram of an exemplary infrastructure equipment, according to an embodiment;

[0012] Figure 3B illustrates a block diagram of an exemplary platform, according to an embodiment;

[0013] Figure 4 illustrates a block diagram of baseband circuitry and front end modules, according to an embodiment;

[0014] Figure 5 illustrates a block diagram of exemplary protocol functions that may be implemented in a wireless communication device, according to an embodiment;

[0015] Figure 6 illustrates a block diagram of exemplary core network components, according to an embodiment;

[0016] Figure 7 illustrates a block diagram of system components for supporting network function virtualization, according to an embodiment;

[0017] Figure 8 illustrates a block diagram of an exemplary computer system that can be utilized to implement various embodiments;

[0018] Figure 9 illustrates a flowchart diagram of exemplary processes that may be carried out, according to an embodiment; and

[0019] Figure 10 illustrates a block diagram of exemplary Third Generation Partnership Project (3GPP) network elements interacting with a non-3GPP access network according to an embodiment;

[0020] The features and advantages of the embodiments will become more apparent from the detailed description set forth below when taken in conjunction with the drawings, in which like reference characters identify corresponding elements throughout. In the drawings, like reference numbers generally indicate identical, functionally similar, and/or structurally similar elements. The drawing in which an element first appears is indicated by the leftmost digit(s) in the corresponding reference number.

DETAILED DESCRIPTION

[0021] The following detailed description refers to the accompanying drawings. The same reference numbers may be used in different drawings to identify the same or similar elements. In the following description, for purposes of explanation and not limitation, specific details are set forth such as particular structures, architectures, interfaces, techniques, etc. in order to provide a thorough understanding of the various aspects of various embodiments. However, it will be apparent to those skilled in the art having the benefit of the present disclosure that the various aspects of the various embodiments may be practiced in other examples that depart from these specific details. In certain instances, descriptions of well-known devices, circuits, and methods are omitted so as not to obscure the description of the various embodiments with unnecessary detail. For the purposes of the present document, the phrase "A or B" means (A), (B), or (A and B). An architecture includes, but is not limited to, a network topology. Examples of an architecture include, but is not limited to, a network, a network topology, and a system. Examples of a network include, but is not limited to, a time sensitive network (TSN), a core network (CN), any other suitable network known in the field of wireless communications, or any combination thereof.

[0022] One or more embodiments described herein are related to one or more 3GPP specifications. Examples of these specifications include, but are not limited to, one or more 3GPP new radio (NR) specifications and/or 5G mobile networks/systems.

[0023] The 5G networks are intended to support various new services such as internet-of-things (IoT), Cloud-based services, industrial control, autonomous driving, mission critical communications, etc., based on the network slicing technology. Some services, e.g., autonomous driving, may have ultra-low latency and high data capacity requirements due to safety and performance concerns. 5G Core Network (5GC) system architecture as defined in technical specification (TS) 23.501 supports edge computing to enable such services by applications that are hosted closer to the UE's access point of attachment in order to reduce the end-to-end latency and the load on the transport network.

[0024] Figure 10 illustrates a block diagram of exemplary 3GPP network elements interacting with a non-3GPP access network, such as Application Function (AF) and local Data Network (DN) to provide the services mentioned above. In an embodiment, the AF may send requests to a Session Management Function (SMF) via a Policy Function (PCF) or a Network Exposure Function (NEF) to influence a User Plane Function (UPF) (re)selection and traffic steering to route the user equipment (UE) traffic from the selected UPF to the application in the local DN via the N6 reference point. The end-to-end latency of the traffic traveling from UE to local DN includes the latency both inside and outside the 3GPP networks. The latency within the 3GPP networks is relevant to 5G QoS, as described in clause 5.7.3.1 in TS 23.501, which is the QoS data flow received edge-to-edge between the UE and the UPF. The latency outside the 3GPP networks is determined by the QoS over an N6 reference point that is related to the geographical locations of the UPF and the local DN. Therefore, it is necessary to deploy the local DN and the UPF in a manner that meets the end-to-end latency requirement of the services.

[0025] 3GPP networks support edge computing to enable UEs to communicate with applications hosted in a local DN that is closer to the UEs' access point of attachment in order to achieve an efficient service delivery through reduced end-to-end latency and load on a transport network (see clause 5.13 in TS 28.501).

[0026] Conventional 3GPP systems suffer from a number of setbacks in an edge computing environment. First, performance and alarms in 3GPP networks may impact the end-to-end performance of edge computing applications. Therefore, 3GPP management system needs to provide performance measurements and alarms of 3GPP networks to the edge computing management system. Second, to influence SMF routing decisions for traffic of PDU Session, an AF may send requests to PCF if AF is considered to be trusted by the operator, or NEF if the operator does not allow an AF to access the network directly (see clause 5.6.7 in TS 23.501). 3GPP networks are not aware of where AF is and how AF can be connected to PCF or NEF, since AF is not a 3GPP defined NF. Therefore, the information of PCF or NEF are needed for the edge computing management system to connect AF to PCF or NEF. Third, SMF needs to be configured with the information about the available UPFs, when a UPF is instantiated or terminated (see clause 6.3.3.2 in TS 23.501). The information enables SMF to select UPF to route the user traffic to the local Data Network as described in clause 6.3.3 of TS 23.501. Therefore, configuration management is needed to configure the SMF and NRF. The embodiments of the present disclosure address these failures of the conventional 3GPP systems.

[0027] Embodiments set forth herein describes available UPFs to support edge computing, performance measurements to support edge computing, fault management to support edge computing, and configuration management to support edge computing. Embodiments set forth herein also describe solutions in the form of UPF instantiation or termination to support edge computing, SMF configuration to support UE traffic routing, and NRF configuration to support UE traffic routing.

[0028] A first embodiment addresses the availability of UPF to support edge computing. In this embodiment, an operator has deployed the resources needed to support edge computing in the local data network (DN), and decides to deploy UPFs to support edge computing applications for UEs in a specific area. The UPFs should be deployed in locations where the data transported between UPFs and the edge computing applications in the local DN should meet the QoS requirements on the N6 interface.

[0029] In this scenario, edge computing management system has deployed the resources needed to support edge computing in the local DN, and is aware of the QoS requirements on the N6 interface. Thus, edge computing management system sends a request (with the location of the local DN and the QoS requirements on the N6 interface) asking a 3GPP management system to provide information of a preexisting UPF to which the edge computing related resources in the local DN can be connected.

[0030] 3GPP management system uses the local data network location to find the preexisting UPF where the data transport between UPF and local data network can meet the QoS requirements on the N6 interface.3GPP management system deploys a new UPF according to the steps described in use case 5.1.1, if such UPF cannot be located. 3GPP management system provides the information of UPF(s) to the edge computing management system. As a result, the information of UPF(s) have been sent to the edge computing management system. This embodiment is described in further detail below with respect to the figures.

[0031] A second embodiment discloses deploying a UPF to support edge computing. In this embodiment, an operator decides to deploy UPFs to support edge computing applications for UEs in a specific area. The UPFs should be deployed in locations where the data transported between UE and UPF should meet the 5G QoS requirements (see clause 5.7.3.1 of TS 23.501).

[0032] The 3GPP management system is made aware of the 5G QoS requirements needed to support edge computing applications, and deploys the UPF software. Thus, 3GPP management system requests Network Functions Virtualization Orchestrator (NFVO) to instantiate the UPF with conditions (e.g. location constraints). NFVO responds that the UPF has been instantiated successfully. 3GPP management system configures SMF or NRF to add the newly instantiated UPF and may configure other NFs needed to support edge computing. It should be noted that the NRF may notify all SMFs with a subscription matching the UPF Provisioning Information of the new UPF (see clause 4.17.6.2 in TS 23.502). As a result, the UPF is available to support the edge computing application.

[0033] In a third embodiment, the system measures performance in order to support edge computing. In this embodiment, 3GPP networks support edge computing to enable UEs to communicate with applications hosted in the local data network that are closer to the UE's access point of attachment in order to achieve an efficient service delivery through the reduced end-to-end latency and load on the transport network (see clause 5.13 in TS 28.501). Performance in 3GPP networks may impact the end-to-end performance of edge computing applications. Therefore, 3GPP management system needs to provide performance measurements of 3GPP networks to the edge computing management system to monitor the end-to-end QoS requirements.

[0034] To carry out this objective, 3GPP network functions supporting the edge computing have been deployed, edge computing related in local data network have been deployed, and edge computing applications have been deployed. Then, edge computing management system requests 3GPP management system to provide the 3GPP performance measurements that are relevant to edge computing. 3GPP management system collects and reports the 3GPP performance measurements to the Edge computing management system. As a result, the performance measurements have been reported to the edge computing management system.

[0035] A fourth embodiment provides fault management to support edge computing. In this embodiment, 3GPP networks support edge computing to enable UEs to communicate with applications hosted in the local data network that are closer to the UE's access point of attachment in order to achieve an efficient service delivery through the reduced end-to-end latency and load on the transport network (see clause 5.13 in TS 28.501). Alarms in 3GPP networks may impact the end-to-end performance of edge computing applications. Therefore, 3GPP management system should send the 3GPP alarm notifications to the edge computing management system when it detects a fault in 3GPP networks that can impact the edge computing applications.

[0036] In order to achieve these objectives, 3GPP network functions supporting the edge computing have been deployed, edge computing related in local data network have been deployed, and edge computing applications have been deployed. Then, edge computing management system requests 3GPP management system to subscribe to the alarm notifications that are relevant to the edge computing. 3GPP management system detects an alarm, and sends the alarm notifications related to the edge computing to the edge computing management system. As a result, 3GPP alarm notifications have been sent to the edge computing management system.

[0037] A fifth embodiment provides configuration management to support edge computing. In this embodiment, to influence SMF routing decisions for traffic of PDU Session, an AF may send requests to PCF if AF is considered to be trusted by the operator, or NEF if the operator does not allow an AF to access the network directly (see clause 5.6.7 in TS 23.501). 3GPP networks is not aware of where AF is and how AF can be connected to PCF or NEF, since AF is not a 3GPP defined NF. Therefore, the information of PCF or NEF are needed for the edge computing management system to connect AF to PCF or NEF.

[0038] To achieve these objectives, 5GC network functions are in operation to support edge computing. Then, edge computing management system requests 3GPP management system to provide the connection information (e.g. IP address) of the PCF or NEF to which the AF can communicate to influence traffic routing (see procedures described in clause 4.3.6 in TS 23.502 in TS 23.502). 3GPP management system provides the connection information (e.g. IP address) of the PCF or NEF to the edge computing management system. As a result, the connection information (e.g. IP address) of the PCF or NEF have been sent to the edge computing management system.

[0039] In order to support the deployment of edge computing, UPF instantiation or termination is needed.

[0040] For UPF instantiation, 3GPP management system requests NFVO to instantiate the NS identified by `nsInstanceId`, with the parameter `additionalParamForVnf` providing the information for the UPF, and parameter `locationConstraints` indicating the constraints on where the UPF will be located (see clause 7.3.3.2 in GS NFV-IFA 013 TS 23.502).

[0041] NFVO sends the NS LCM Operation Occurrence Notification to the 3GPP management system indicating the start of NS instantiation procedure (see clause 7.3.3.4 in GS NFV-IFA 013 TS 23.502). NFVO then instantiates the NS and the UPF.

[0042] NFVO sends the NS LCM Operation Occurrence Notification to the 3GPP management system with the result of NS instantiation, including *vnfInstanceId* to indicate the UPF instance that has been instantiated (see clause 7.3.3.4 in GS NFV-IFA 013 TS 23.502).

[0043] NFVO sends the NS LCM Operation Occurrence Notification to the 3GPP management system with the result of NS instantiation, including *vnfInstanceId* to indicate the UPF instance that has been instantiated (see clause 7.3.3.4 in GS NFV-IFA 013 TS 23.502).

[0044] 3GPP management system consumes Provisioning for NF service with *createMOIAttributes* operation (see clause 6.3 in TS 28.541) to create the `UPFFunction` IOC for the UPF instance.

[0045] It should be noted that `UPFFunction` in NRM (see clause 5.3.3 in TS 28.541) should contain the NRF identity to contact for registration and UPF Provisioning Information (see clause 4.17.6.2 in TS 23.502 [y]).

[0046] For UPF termination, 3GPP management system requests NFVO to update the NS with updateType=RemoveVnf to terminate the UPF instance (see clause 7.3.5.2 in GS NFV-IFA 013 TS 23.502). NFVO sends the NS LCM Operation Occurrence Notification to the 3GPP management system indicating the start of NS update procedure (see clause 7.3.3.4 in GS NFV-IFA 013 TS 23.502). NFVO then removes the UPF instance from the NS.

[0047] NFVO sends the NS LCM Operation Occurrence Notification to the 3GPP management system with the result of NS update, including *vnfInstanceId* to indicate the UPF instance that has been terminated (see clause 7.3.3.4 in GS NFV-IFA 013 TS 23.502).

[0048] When a UPF is instantiated or terminated, it becomes necessary to configure an SMF with the information about the available UPFs (see clause 6.3.3.2 in TS 23.501). The information enables SMF to select UPF to route the user traffic to the local Data Network as described in clause 6.3.3 TS 23.501.

[0049] It is assumed that UPF has been instantiated and `UPFFunction` IOC has been created. Then, the 3GPP management system consumes Provisioning for NF service with *modifyMOIAttributes* operation (see clause 6.3 in TS 28.531 [y]) to configure the SMF – `SMFFunction` with the UPF provisioning information in order to add the UPF to the available UPF list (see clasue 6.3.3.2 in TS 23.501). It should be noted that `SMFFunction` in NRM (see clause 5.3.2 in TS 28.541) may contain a list of (S-NSSAI, DNN) and a SMF Area Identity the UPF can serve.

[0050] The SMF can likewise be configured upon the removal or termination of a UPF. Specifically, 3GPP management system consumes Provisioning for NF service with *modifyMOIAttributes* operation (see clause 6.3 in TS 28.531 [y]) to configure SMF with the UPF identifier of the UPF to be removed from the available UPF list.

[0051] In an embodiment, the SMF can receive the UPF information from an NRF. Specifically, NRF may obtain the UPF information via the following two options:

- OAM registers the UPF on the NRF (see step 6 in clause 4.17.6.2 in TS 23.502).
- The UPF instance issues an Nnrf_NFManagement_NFRegister Request operation (see step 4, 5 in clause 4.17.6.2 in TS 23.502).

[0052] NRF then send the UPF information to SMF via Nnrf_NFManagement_NFStatusNotify. Then, 3GPP management system consumes Provisioning for NF service with *modifyMOIAttributes* operation (see clause 6.3 in TS 28.531 [y]) to configure the NRF – `NRFFunction` with the available UPF (see clause 4.17.6.2 in TS 23.502 [y]). It should be noted that `NRFFunction` in NRM (see clause 5.3.10 in TS 28.541) may contain the UPF provisioning information. The NRF then issues Nnrf_NFManagement_NFStatusNotify to all SMFs with a subscription matching the UPF Provisioning Information of the new UPF (see clause 4.17.6.2 in TS 23.502 [y]).

[0053] The NRF can also receive UPF information from a UPF instance. In this scenario, it is assumed that a new UPF has been instantiated, and an `UPFFunction` IOC has been created. 3GPP management system then consumes Provisioning for NF service with *createMOIAttributes* operation (see clause 6.3 in TS 28.531 [y]) to create an `EP_SBI_X` IOC contained by `UPFFunction` IOC that is used by UPF to communicate with NRF. Thereafter, the NRF issues Nnrf_NFManagement_NFStatusNotify to all SMFs with a subscription matching the UPF Provisioning Information of the new UPF (see clause 4.17.6.2 in TS 23.502 [y]).

[0054] There are several potential requirements of the 3GPP management system that should be implemented in order to support edge computing and the embodiments of this disclosure. For example.

[0055] 1. The 3GPP management system should have a capability allowing edge computing management system to request the UPF information based on the local data network location and QoS requirements on the N6 interface.

[0056] 2. The 3GPP management system should have a capability to configure the SMF or NRF (e.g. to add or remove the UPF).

[0057] 3. The 3GPP management system should have a capability allowing edge computing management system to request the performance measurements relevant to edge computing.

[0058] 4. The 3GPP management system should have a capability to report the performance measurements related to edge computing to authorized consumer.

[0059] 5. The 3GPP management system should have a capability allowing edge computing management system to subscribe to the alarm notification related to the edge computing.

[0060] 6. The 3GPP management system should have a capability to send the alarm notifications related to edge computing to authorized consumer.

[0061] 7. The 3GPP management system should have a capability allowing edge computing management system to request the connection information (e.g. IP address) of PCF or NEF.

[0062] 8. The 3GPP management system should have a capability to provide the connection information (e.g. IP address) of PCF or NEF to the edge computing management system.

[0063] These embodiments and the network systems and configurations to support and implement them will now be described with respect to figures 1-9, below.

Systems and Implementations

[0064] Figure 1 illustrates an example architecture of a system 100 of a network, in accordance with various embodiments. The following description is provided for an example system 100 that operates in conjunction with the LTE system standards and 5G or NR system standards as provided by 3GPP technical specifications. However, the example embodiments are not limited in this regard and the described embodiments may apply to other networks that benefit from the principles described herein, such as future 3GPP systems (e.g., Sixth Generation (6G)) systems, IEEE 802.16 protocols (e.g., WMAN, WiMAX, etc.), or the like.

[0065] As shown by Figure 1, the system 100 includes UE 101a and UE 101b (collectively referred to as "UEs 101" or "UE 101"). In this example, UEs 101 are illustrated as smartphones (e.g., handheld touchscreen mobile computing devices connectable to one or more cellular networks), but may also comprise any mobile or non-mobile computing device, such as consumer electronics devices, cellular phones, smartphones, feature phones, tablet computers, wearable computer devices, personal digital assistants (PDAs), pagers, wireless handsets, desktop computers, laptop computers, in-vehicle infotainment (IVI), in-car entertainment (ICE) devices, an Instrument Cluster (IC), head-up display (HUD) devices, onboard diagnostic (OBD) devices, dashtop mobile equipment (DME), mobile data terminals (MDTs), Electronic Engine Management System (EEMS), electronic/engine control units (ECUs), electronic/engine control modules (ECMs), embedded systems, microcontrollers, control modules, engine management systems (EMS), networked or "smart" appliances, MTC devices, M2M, IoT devices, and/or the like.

[0066] In some embodiments, any of the UEs 101 may be IoT UEs, which may comprise a network access layer designed for low-power IoT applications utilizing short-lived UE connections. An IoT UE can utilize technologies such as M2M or MTC for exchanging data with an MTC server or device via a PLMN, ProSe or D2D communication, sensor networks, or IoT networks. The M2M or MTC exchange of data may be a machine-initiated exchange of data. An IoT network describes interconnecting IoT UEs, which may include uniquely identifiable embedded computing devices (within the Internet infrastructure), with short-lived connections. The IoT UEs may execute background applications (e.g., keep-alive messages, status updates, etc.) to facilitate the connections of the IoT network.

[0067] The UEs 101 may be configured to connect, for example, communicatively couple, with an or RAN 110. In embodiments, the RAN 110 may be an NG RAN or a 5G RAN, an E-UTRAN, or a legacy RAN, such as a UTRAN or GERAN. As used herein, the term "NG RAN" or the like may refer to a RAN 110 that operates in an NR or 5G system 100, and the term "E-UTRAN" or the like may refer to a RAN 110 that operates in an LTE or Fourth Generation (4G) system 100. The UEs 101 utilize connections (or channels) 103 and 104, respectively, each of which comprises a physical communications interface or layer (discussed in further detail below).

[0068] In this example, the connections 103 and 104 are illustrated as an air interface to enable communicative coupling, and can be consistent with cellular communications protocols, such as a GSM protocol, a CDMA network protocol, a PTT protocol, a POC protocol, a UMTS protocol, a 3GPP LTE protocol, a 5G protocol, a NR protocol, and/or any of the other communications protocols discussed herein. In embodiments, the UEs 101 may directly exchange communication data via a ProSe interface 105. The ProSe interface 105 may alternatively be referred to as a SL interface 105 and may comprise one or more logical channels, including but not limited to a PSCCH, a PSSCH, a PSDCH, and a PSBCH.

[0069] The UE 101b is shown to be configured to access an AP 106 (also referred to as "WLAN node 106," "WLAN 106," "WLAN Termination 106," "WT 106" or the like) via connection 107. The connection 107 can comprise a local wireless connection, such as a connection consistent with any IEEE 802.11 protocol, wherein the AP 106 would comprise a wireless fidelity (Wi-Fi®) router. In this example, the AP 106 is shown to be connected to the Internet without connecting to the core network of the wireless system (described in further detail below). In various embodiments, the UE 101b, RAN 110, and AP 106 may be configured to utilize LWA operation and/or LWIP operation. The LWA operation may involve the UE 101b in RRC_CONNECTED being configured by a RAN node 111a-b to utilize radio resources of LTE and WLAN. LWIP operation may involve the UE 101b using WLAN radio resources (e.g., connection 107) via IPsec protocol tunneling to authenticate and encrypt packets (e.g., IP packets) sent over the connection 107. IPsec tunneling may include encapsulating the entirety of original IP packets and adding a new packet header, thereby protecting the original header of the IP packets.

[0070] The RAN 110 can include one or more Access Network (AN) nodes or RAN nodes 111a and 111b (collectively referred to as "RAN nodes 111" or "RAN node 111") that enable the connections 103 and 104. As used herein, the terms "access node," "access point," or the like may describe equipment that provides the radio baseband functions for data and/or voice connectivity between a network and one or more users. These access nodes can be referred to as BS, gNBs, RAN nodes, eNBs, NodeBs, RSUs, TRxPs or

TRPs, and so forth, and can comprise ground stations (e.g., terrestrial access points) or satellite stations providing coverage within a geographic area (e.g., a cell). As used herein, the term “NG RAN node” or the like may refer to a RAN node 111 that operates in an NR or 5G system 100 (for example, a gNB), and the term “E-UTRAN node” or the like may refer to a RAN node 111 that operates in an LTE or 4G system 100 (e.g., an eNB). According to various embodiments, the RAN nodes 111 may be implemented as one or more of a dedicated physical device such as a macrocell base station, and/or a low power (LP) base station for providing femtocells, picocells or other like cells having smaller coverage areas, smaller user capacity, or higher bandwidth compared to macrocells.

[0071] In some embodiments, all or parts of the RAN nodes 111 may be implemented as one or more software entities running on server computers as part of a virtual network, which may be referred to as a CRAN and/or a virtual baseband unit pool (vBBUP). In these embodiments, the CRAN or vBBUP may implement a RAN function split, such as a PDCP split wherein RRC and PDCP layers are operated by the CRAN/vBBUP and other L2 protocol entities are operated by individual RAN nodes 111; a MAC/PHY split wherein RRC, PDCP, RLC, and MAC layers are operated by the CRAN/vBBUP and the PHY layer is operated by individual RAN nodes 111; or a “lower PHY” split wherein RRC, PDCP, RLC, MAC layers and upper portions of the PHY layer are operated by the CRAN/vBBUP and lower portions of the PHY layer are operated by individual RAN nodes 111. This virtualized framework allows the freed-up processor cores of the RAN nodes 111 to perform other virtualized applications. In some implementations, an individual RAN node 111 may represent individual gNB-DUs that are connected to a gNB-CU via individual F1 interfaces (not shown by Figure 1). In these implementations, the gNB-DUs may include one or more remote radio heads or RFEMs (see, e.g., Figure 3A), and the gNB-CU may be operated by a server that is located in the RAN 110 (not shown) or by a server pool in a similar manner as the CRAN/vBBUP. Additionally or alternatively, one or more of the RAN nodes 111 may be next generation eNBs (ng-eNBs), which are RAN nodes that provide E-UTRA user plane and control plane protocol terminations toward the UEs 101, and are connected to a 5GC (e.g., CN 220B of Figure 2B) via an NG interface (discussed infra).

[0072] In V2X scenarios one or more of the RAN nodes 111 may be or act as RSUs. The term "Road Side Unit" or "RSU" may refer to any transportation infrastructure entity used for V2X communications. An RSU may be implemented in or by a suitable RAN node or a stationary (or relatively stationary) UE, where an RSU implemented in or by a UE may be referred to as a "UE-type RSU," an RSU implemented in or by an eNB may be referred to as an "eNB-type RSU," an RSU implemented in or by a gNB may be referred to as a "gNB-type RSU," and the like. In one example, an RSU is a computing device coupled with radio frequency circuitry located on a roadside that provides connectivity support to passing vehicle UEs 101 (vUEs 101). The RSU may also include internal data storage circuitry to store intersection map geometry, traffic statistics, media, as well as applications/software to sense and control ongoing vehicular and pedestrian traffic. The RSU may operate on the 5.9 GHz Direct Short Range Communications (DSRC) band to provide very low latency communications required for high speed events, such as crash avoidance, traffic warnings, and the like. Additionally or alternatively, the RSU may operate on the cellular V2X band to provide the aforementioned low latency communications, as well as other cellular communications services. Additionally or alternatively, the RSU may operate as a Wi-Fi hotspot (2.4 GHz band) and/or provide connectivity to one or more cellular networks to provide uplink and downlink communications. The computing device(s) and some or all of the radiofrequency circuitry of the RSU may be packaged in a weatherproof enclosure suitable for outdoor installation, and may include a network interface controller to provide a wired connection (e.g., Ethernet) to a traffic signal controller and/or a backhaul network.

[0073] Any of the RAN nodes 111 can terminate the air interface protocol and can be the first point of contact for the UEs 101. In some embodiments, any of the RAN nodes 111 can fulfill various logical functions for the RAN 110 including, but not limited to, radio network controller (RNC) functions such as radio bearer management, uplink and downlink dynamic radio resource management and data packet scheduling, and mobility management.

[0074] In embodiments, the UEs 101 can be configured to communicate using OFDM communication signals with each other or with any of the RAN nodes 111 over a multicarrier communication channel in accordance with various communication techniques, such as, but not limited to, an OFDMA communication technique (e.g., for downlink communications) or a SC-FDMA communication technique (e.g., for uplink and ProSe or sidelink communications), although the scope of the embodiments is not limited in this respect. The OFDM signals can comprise a plurality of orthogonal subcarriers.

[0075] In some embodiments, a downlink resource grid can be used for downlink transmissions from any of the RAN nodes 111 to the UEs 101, while uplink transmissions can utilize similar techniques. The grid can be a time-frequency grid, called a resource grid or time-frequency resource grid, which is the physical resource in the downlink in each slot. Such a time-frequency plane representation is a common practice for OFDM systems, which makes it intuitive for radio resource allocation. Each column and each row of the resource grid corresponds to one OFDM symbol and one OFDM subcarrier, respectively. The duration of the resource grid in the time domain corresponds to one slot in a radio frame. The smallest time-frequency unit in a resource grid is denoted as a resource element. Each resource grid comprises a number of resource blocks, which describe the mapping of certain physical channels to resource elements. Each resource block comprises a collection of resource elements; in the frequency domain, this may represent the smallest quantity of resources that currently can be allocated. There are several different physical downlink channels that are conveyed using such resource blocks.

[0076] According to various embodiments, the UEs 101, 102 and the RAN nodes 111, 112 communicate data (for example, transmit and receive) data over a licensed medium (also referred to as the “licensed spectrum” and/or the “licensed band”) and an unlicensed shared medium (also referred to as the “unlicensed spectrum” and/or the “unlicensed band”). The licensed spectrum may include channels that operate in the frequency range of approximately 400 MHz to approximately 3.8 GHz, whereas the unlicensed spectrum may include the 5 GHz band.

[0077] To operate in the unlicensed spectrum, the UEs 101, 102 and the RAN nodes 111, 112 may operate using LAA, eLAA, and/or feLAA mechanisms. In these implementations, the UEs 101, 102 and the RAN nodes 111, 112 may perform one or more known medium-sensing operations and/or carrier-sensing operations in order to determine whether one or more channels in the unlicensed spectrum is unavailable or otherwise occupied prior to transmitting in the unlicensed spectrum. The medium/carrier sensing operations may be performed according to a listen-before-talk (LBT) protocol.

[0078] LBT is a mechanism whereby equipment (for example, UEs 101, 102, RAN nodes 111, 112, etc.) senses a medium (for example, a channel or carrier frequency) and transmits when the medium is sensed to be idle (or when a specific channel in the medium is sensed to be unoccupied). The medium sensing operation may include CCA, which utilizes at least ED to determine the presence or absence of other signals on a channel in order to determine if a channel is occupied or clear. This LBT mechanism allows cellular/LAA networks to coexist with incumbent systems in the unlicensed spectrum and with other LAA networks. ED may include sensing RF energy across an intended transmission band for a period of time and comparing the sensed RF energy to a predefined or configured threshold.

[0079] Typically, the incumbent systems in the 5 GHz band are WLANs based on IEEE 802.11 technologies. WLAN employs a contention-based channel access mechanism, called CSMA/CA. Here, when a WLAN node (e.g., a mobile station (MS) such as UE 101 or 102, AP 106, or the like) intends to transmit, the WLAN node may first perform CCA before transmission. Additionally, a backoff mechanism is used to avoid collisions in situations where more than one WLAN node senses the channel as idle and transmits at the same time. The backoff mechanism may be a counter that is drawn randomly within the CWS, which is increased exponentially upon the occurrence of collision and reset to a minimum value when the transmission succeeds. The LBT mechanism designed for LAA is somewhat similar to the CSMA/CA of WLAN. In some implementations, the LBT procedure for DL or UL transmission bursts including PDSCH or PUSCH transmissions, respectively, may have an LAA contention window that is variable in length between X and Y ECCA slots, where X and Y are minimum and maximum values for the CWSs for LAA. In one example, the minimum CWS for an LAA transmission may be 9 microseconds (μs); however, the size of the CWS and a MCOT (for example, a transmission burst) may be based on governmental regulatory requirements.

[0080] The LAA mechanisms are built upon CA technologies of LTE-Advanced systems. In CA, each aggregated carrier is referred to as a CC. A CC may have a bandwidth of 1.4, 3, 5, 10, 15 or 20 MHz and a maximum of five CCs can be aggregated, and therefore, a maximum aggregated bandwidth is 100 MHz. In FDD systems, the number of aggregated carriers can be different for DL and UL, where the number of UL CCs is equal to or lower than the number of DL component carriers. In some cases, individual CCs can have a different bandwidth than other CCs. In TDD systems, the number of CCs as well as the bandwidths of each CC is usually the same for DL and UL.

[0081] CA also comprises individual serving cells to provide individual CCs. The coverage of the serving cells may differ, for example, because CCs on different frequency bands will experience different pathloss. A primary service cell or PCell may provide a PCC for both UL and DL, and may handle RRC and NAS related activities. The other serving cells are referred to as SCells, and each SCell may provide an individual SCC for both UL and DL. The SCCs may be added and removed as required, while changing the PCC may require the UE 101, 102 to undergo a handover. In LAA, eLAA, and feLAA, some or all of the SCells may operate in the unlicensed spectrum (referred to as "LAA SCells"), and the LAA SCells are assisted by a PCell operating in the licensed spectrum. When a UE is configured with more than one LAA SCell, the UE may receive UL grants on the configured LAA SCells indicating different PUSCH starting positions within a same subframe.

[0082] The PDSCH carries user data and higher-layer signaling to the UEs 101. The PDCCH carries information about the transport format and resource allocations related to the PDSCH channel, among other things. It may also inform the UEs 101 about the transport format, resource allocation, and HARQ information related to the uplink shared channel. Typically, downlink scheduling (assigning control and shared channel resource blocks to the UE 101b within a cell) may be performed at any of the RAN nodes 111 based on channel quality information fed back from any of the UEs 101. The downlink resource assignment information may be sent on the PDCCH used for (e.g., assigned to) each of the UEs 101.

[0083] The PDCCH uses CCEs to convey the control information. Before being mapped to resource elements, the PDCCH complex-valued symbols may first be organized into quadruplets, which may then be permuted using a sub-block interleaver for rate matching. Each PDCCH may be transmitted using one or more of these CCEs, where each CCE may correspond to nine sets of four physical resource elements known as REGs. Four Quadrature Phase Shift Keying (QPSK) symbols may be mapped to each REG. The PDCCH can be transmitted using one or more CCEs, depending on the size of the DCI and the channel condition. There can be four or more different PDCCH formats defined in LTE with different numbers of CCEs (e.g., aggregation level, L=1, 2, 4, or 8).

[0084] Some embodiments may use concepts for resource allocation for control channel information that are an extension of the above-described concepts. For example, some embodiments may utilize an EPDCCH that uses PDSCH resources for control information transmission. The EPDCCH may be transmitted using one or more ECCEs. Similar to above, each ECCE may correspond to nine sets of four physical resource elements known as an EREGs. An ECCE may have other numbers of EREGs in some situations.

[0085] The RAN nodes 111 may be configured to communicate with one another via interface 112. In embodiments where the system 100 is an LTE system (e.g., when CN 120 is an EPC 220A as in Figure 2A), the interface 112 may be an X2 interface 112. The X2 interface may be defined between two or more RAN nodes 111 (e.g., two or more eNBs and the like) that connect to EPC 120, and/or between two eNBs connecting to EPC 120. In some implementations, the X2 interface may include an X2 user plane interface (X2-U) and an X2 control plane interface (X2-C). The X2-U may provide flow control mechanisms for user data packets transferred over the X2 interface, and may be used to communicate information about the delivery of user data between eNBs. For example, the X2-U may provide specific sequence number information for user data transferred from a MeNB to an SeNB; information about successful in sequence delivery of PDCP PDUs to a UE 101 from an SeNB for user data; information of PDCP PDUs that were not delivered to a UE 101; information about a current minimum desired buffer size at the SeNB for transmitting to the UE user data; and the like. The X2-C may provide intra-LTE access mobility functionality, including context transfers from source to target eNBs, user plane transport control, etc.; load management functionality; as well as inter-cell interference coordination functionality.

[0086] In embodiments where the system 100 is a 5G or NR system (e.g., when CN 120 is an 5GC 220B as in Figure 2B), the interface 112 may be an Xn interface 112. The Xn interface is defined between two or more RAN nodes 111 (e.g., two or more gNBs and the like) that connect to 5GC 120, between a RAN node 111 (e.g., a gNB) connecting to 5GC 120 and an eNB, and/or between two eNBs connecting to 5GC 120. In some implementations, the Xn interface may include an Xn user plane (Xn-U) interface and an

Xn control plane (Xn-C) interface. The Xn-U may provide non-guaranteed delivery of user plane PDUs and support/provide data forwarding and flow control functionality. The Xn-C may provide management and error handling functionality, functionality to manage the Xn-C interface; mobility support for UE 101 in a connected mode (e.g., CM-CONNECTED) including functionality to manage the UE mobility for connected mode between one or more RAN nodes 111. The mobility support may include context transfer from an old (source) serving RAN node 111 to new (target) serving RAN node 111; and control of user plane tunnels between old (source) serving RAN node 111 to new (target) serving RAN node 111. A protocol stack of the Xn-U may include a transport network layer built on Internet Protocol (IP) transport layer, and a GTP-U layer on top of a UDP and/or IP layer(s) to carry user plane PDUs. The Xn-C protocol stack may include an application layer signaling protocol (referred to as Xn Application Protocol (Xn-AP)) and a transport network layer that is built on SCTP. The SCTP may be on top of an IP layer, and may provide the guaranteed delivery of application layer messages. In the transport IP layer, point-to-point transmission is used to deliver the signaling PDUs. In other implementations, the Xn-U protocol stack and/or the Xn-C protocol stack may be same or similar to the user plane and/or control plane protocol stack(s) shown and described herein.

[0087] The RAN 110 is shown to be communicatively coupled to a core network—in this embodiment, core network (CN) 120. The CN 120 may comprise a plurality of network elements 122, which are configured to offer various data and telecommunications services to customers/subscribers (e.g., users of UEs 101) who are connected to the CN 120 via the RAN 110. The components of the CN 120 may be implemented in one physical node or separate physical nodes including components to read and execute instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium). In some embodiments, NFV may be utilized to virtualize any or all of the above-described network node functions via executable instructions stored in one or more computer-readable storage mediums (described in further detail below). A logical instantiation of the CN 120 may be referred to as a network slice, and a logical instantiation of a portion of the CN 120 may be referred to as a network sub-slice. NFV architectures and infrastructures may be used to virtualize one or more network functions, alternatively performed by proprietary hardware, onto physical resources comprising a combination of industry-standard server hardware, storage hardware, or switches. In other words, NFV systems can be used to execute virtual or reconfigurable implementations of one or more EPC components/functions.

[0088] Generally, the application server 130 may be an element offering applications that use IP bearer resources with the core network (e.g., UMTS PS domain, LTE PS data services, etc.). The application server 130 can also be configured to support one or more communication services (e.g., VoIP sessions, PTT sessions, group communication sessions, social networking services, etc.) for the UEs 101 via the EPC 120.

[0089] In embodiments, the CN 120 may be a 5GC (referred to as "5GC 120" or the like), and the RAN 110 may be connected with the CN 120 via an NG interface 113. In embodiments, the NG interface 113 may be split into two parts, an NG user plane (NG-U) interface 114, which carries traffic data between the RAN nodes 111 and a UPF, and the S1 control plane (NG-C) interface 115, which is a signaling interface between the RAN nodes 111 and AMFs. Embodiments where the CN 120 is a 5GC 120 are discussed in more detail with regard to Figure 2B.

[0090] In embodiments, the CN 120 may be a 5G CN (referred to as "5GC 120" or the like), while in other embodiments, the CN 120 may be an EPC). Where CN 120 is an EPC (referred to as "EPC 120" or the like), the RAN 110 may be connected with the CN 120 via an S1 interface 113. In embodiments, the S1 interface 113 may be split into two parts, an S1 user plane (S1-U) interface 114, which carries traffic data between the RAN nodes 111 and the S-GW, and the S1-MME interface 115, which is a signaling interface between the RAN nodes 111 and MMEs. An example architecture wherein the CN 120 is an EPC 120 is shown by Figure 2A.

[0091] Figure 2A illustrates an example architecture of a system 200A including a first CN 220A, in accordance with various embodiments. In this example, system 200A may implement the LTE standard wherein the CN 220A is an EPC 220A that corresponds with CN 120 of Figure 1. Additionally, the UE 201 may be the same or similar as the UEs 101 of Figure 1, and the E-UTRAN 210A may be a RAN that is the same or similar to the RAN 110 of Figure 1, and which may include RAN nodes 111 discussed previously. The CN 220A may comprise MMEs 221A, an S-GW 222A, a P-GW 223A, a HSS 224A, and a SGSN 225A.

[0092] The MMEs 221A may be similar in function to the control plane of legacy SGSN, and may implement MM functions to keep track of the current location of a UE 201. The MMEs 221A may perform various MM procedures to manage mobility aspects in access such as gateway selection and tracking area list management. MM (also referred to as "EPS MM" or "EMM" in E-UTRAN systems) may refer to all applicable procedures, methods, data storage, etc. that are used to maintain knowledge about a present location of the UE 201, provide user identity confidentiality, and/or perform other like services to users/subscribers. Each UE 201 and the MME 221A may include an MM or EMM sublayer, and an MM context may be established in the UE 201 and the MME 221A when an attach procedure is successfully completed. The MM context may be a data structure or database object that stores MM-related information of the UE 201. The MMEs 221A may be coupled with the HSS 224A via an S6a reference point, coupled with the SGSN 225A via an S3 reference point, and coupled with the S-GW 222A via an S11 reference point.

[0093] The SGSN 225A may be a node that serves the UE 201 by tracking the location of an individual UE 201 and performing security functions. In addition, the SGSN 225A may perform Inter-EPC node signaling for mobility between 2G/3G and E-UTRAN 3GPP access networks; PDN and S-GW selection as specified by the MMEs 221A; handling of UE 201 time zone functions as specified by the MMEs 221A; and MME selection for handovers to E-UTRAN 3GPP access network. The S3 reference point between the MMEs 221A and the SGSN 225A may enable user and bearer information exchange for inter-3GPP access network mobility in idle and/or active states.

[0094] The HSS 224A may comprise a database for network users, including subscription-related information to support the network entities' handling of communication sessions. The EPC 220A may comprise one or several HSSs 224A, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS 224A can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc. An S6a reference point between the HSS 224A and the MMEs 221A may enable transfer of subscription and authentication data for authenticating/authorizing user access to the EPC 220A between HSS 224A and the MMEs 221A.

[0095] The S-GW 222A may terminate the S1 interface 113 ("S1-U" in Figure 2A) toward the RAN 210A, and routes data packets between the RAN 210A and the EPC 220A. In addition, the S-GW 222A may be a local mobility anchor point for inter-RAN node handovers and also may provide an anchor for inter-3GPP mobility. Other responsibilities may include lawful intercept, charging, and some policy enforcement. The S11 reference point between the S-GW 222A and the MMEs 221A may provide a control plane between the MMEs 221A and the S-GW 222A. The S-GW 222A may be coupled with the P-GW 223A via an S5 reference point.

[0096] The P-GW 223A may terminate an SGi interface toward a PDN 230. The P-GW 223A may route data packets between the EPC 220A and external networks such as a network including the application server 130 (alternatively referred to as an "AF") via an IP interface 125 (see e.g., Figure 1). In embodiments, the P-GW 223A may be communicatively coupled to an application server (application server 130 of Figure 1 or PDN 230 in Figure 2A) via an IP communications interface 125 (see, e.g., Figure 1). The S5 reference point between the P-GW 223A and the S-GW 222A may provide user plane tunneling and tunnel management between the P-GW 223A and the S-GW 222A. The S5 reference point may also be used for S-GW 222A relocation due to UE 201 mobility and if the S-GW 222A needs to connect to a non-collocated P-GW 223A for the required PDN connectivity. The P-GW 223A may further include a node for policy enforcement and charging data collection (e.g., PCEF (not shown)). Additionally, the SGi reference point between the P-GW 223A and the packet data network (PDN) 230 may be an operator external public, a private PDN, or an intra operator packet data network, for example, for provision of IMS services. The P-GW 223A may be coupled with a PCRF 226A via a Gx reference point.

[0097] PCRF 226A is the policy and charging control element of the EPC 220A. In a non-roaming scenario, there may be a single PCRF 226A in the Home Public Land Mobile Network (HPLMN) associated with a UE 201's Internet Protocol Connectivity Access Network (IP-CAN) session. In a roaming scenario with local breakout of traffic, there may be two PCRFs associated with a UE 201's IP-CAN session, a Home PCRF (H-PCRF) within an HPLMN and a Visited PCRF (V-PCRF) within a Visited Public Land Mobile Network (VPLMN). The PCRF 226A may be communicatively coupled to the application server 230 via the P-GW 223A. The application server 230 may signal the

PCRF 226A to indicate a new service flow and select the appropriate QoS and charging parameters. The PCRF 226A may provision this rule into a PCEF (not shown) with the appropriate TFT and QCI, which commences the QoS and charging as specified by the application server 230. The Gx reference point between the PCRF 226A and the P-GW 223A may allow for the transfer of QoS policy and charging rules from the PCRF 226A to PCEF in the P-GW 223A. An Rx reference point may reside between the PDN 230 (or "AF 230") and the PCRF 226A.

[0098] Figure 2B illustrates an architecture of a system 200B including a second CN 220B in accordance with various embodiments. The system 200B is shown to include a UE 201, which may be the same or similar to the UEs 101 and UE 201 discussed previously; a (R)AN 210B, which may be the same or similar to the RAN 110 and RAN 210A discussed previously, and which may include RAN nodes 111 discussed previously; and a DN 203, which may be, for example, operator services, Internet access or 3rd party services; and a 5GC 220B. The 5GC 220B may include an Authentication Server Function (AUSF) 222B; an AMF 221B; a SMF 224B; a NEF 223B; a PCF 226B; a NRF 225B; a UDM 227; an AF 228; a UPF 202; and a NSSF 229.

[0099] The UPF 202 may act as an anchor point for intra-RAT and inter-RAT mobility, an external PDU session point of interconnect to DN 203, and a branching point to support multi-homed PDU session. The UPF 202 may also perform packet routing and forwarding, perform packet inspection, enforce the user plane part of policy rules, lawfully intercept packets (UP collection), perform traffic usage reporting, perform QoS handling for a user plane (e.g., packet filtering, gating, UL/DL rate enforcement), perform Uplink Traffic verification (e.g., SDF to QoS flow mapping), transport level packet marking in the uplink and downlink, and perform downlink packet buffering and downlink data notification triggering. UPF 202 may include an uplink classifier to support routing traffic flows to a data network. The DN 203 may represent various network operator services, Internet access, or third party services. DN 203 may include, or be similar to, application server 130 discussed previously. The UPF 202 may interact with the SMF 224B via an N4 reference point between the SMF 224B and the UPF 202.

[0100] The AUSF 222B may store data for authentication of UE 201 and handle authentication-related functionality. The AUSF 222B may facilitate a common authentication framework for various access types. The AUSF 222B may communicate with the AMF 221B via an N12 reference point between the AMF 221B and the AUSF 222B; and may communicate with the UDM 227 via an N13 reference point between the UDM 227 and the AUSF 222B. Additionally, the AUSF 222B may exhibit an Nausf service-based interface.

[0101] The AMF 221B may be responsible for registration management (e.g., for registering UE 201, etc.), connection management, reachability management, mobility management, and lawful interception of AMF-related events, and access authentication and authorization. The AMF 221B may be a termination point for the an N11 reference point between the AMF 221B and the SMF 224B. The AMF 221B may provide transport for SM messages between the UE 201 and the SMF 224B, and act as a transparent proxy for routing SM messages. AMF 221B may also provide transport for SMS messages between UE 201 and an SMSF (not shown by Figure 2B). AMF 221B may act as SEAF, which may include interaction with the AUSF 222B and the UE 201, receipt of an intermediate key that was established as a result of the UE 201 authentication process. Where USIM based authentication is used, the AMF 221B may retrieve the security material from the AUSF 222B. AMF 221B may also include a SCM function, which receives a key from the SEA that it uses to derive access-network specific keys. Furthermore, AMF 221B may be a termination point of a RAN CP interface, which may include or be an N2 reference point between the (R)AN 210B and the AMF 221B; and the AMF 221B may be a termination point of NAS (N1) signalling, and perform NAS ciphering and integrity protection.

[0102] AMF 221B may also support NAS signalling with a UE 201 over an N3 IWF interface. The N3IWF may be used to provide access to untrusted entities. N3IWF may be a termination point for the N2 interface between the (R)AN 210B and the AMF 221B for the control plane, and may be a termination point for the N3 reference point between the (R)AN 210B and the UPF 202 for the user plane. As such, the AMF 221B may handle N2 signalling from the SMF 224B and the AMF 221B for PDU sessions and QoS, encapsulate/de-encapsulate packets for IPSec and N3 tunnelling, mark N3 user-plane packets in the uplink, and enforce QoS corresponding to N3 packet marking taking into account QoS requirements associated with such marking received over N2. N3IWF may also relay uplink and downlink control-plane NAS signalling between the UE 201 and AMF 221B via an N1 reference point between the UE 201 and the AMF 221B, and relay uplink and downlink user-plane packets between the UE 201 and UPF 202. The N3IWF also provides mechanisms for IPsec tunnel establishment with the UE 201. The AMF 221B may exhibit an Namf service-based interface, and may be a termination point for an N14 reference point between two AMFs 221B and an N17 reference point between the AMF 221B and a 5G-EIR (not shown by Figure 2B).

[0103] The UE 201 may need to register with the AMF 221B in order to receive network services. RM is used to register or deregister the UE 201 with the network (e.g., AMF 221B), and establish a UE context in the network (e.g., AMF 221B). The UE 201 may operate in an RM-REGISTERED state or an RM-DEREGISTERED state. In the RM-DEREGISTERED state, the UE 201 is not registered with the network, and the UE context in AMF 221B holds no valid location or routing information for the UE 201 so the UE 201 is not reachable by the AMF 221B. In the RM-REGISTERED state, the UE 201 is registered with the network, and the UE context in AMF 221B may hold a valid location or routing information for the UE 201 so the UE 201 is reachable by the AMF 221B. In the RM-REGISTERED state, the UE 201 may perform mobility Registration Update procedures, perform periodic Registration Update procedures triggered by expiration of the periodic update timer (e.g., to notify the network that the UE 201 is still active), and perform a Registration Update procedure to update UE capability information or to re-negotiate protocol parameters with the network, among others.

[0104] The AMF 221B may store one or more RM contexts for the UE 201, where each RM context is associated with a specific access to the network. The RM context may be a data structure, database object, etc. that indicates or stores, inter alia, a registration state per access type and the periodic update timer. The AMF 221B may also store a 5GC MM context that may be the same or similar to the (E)MM context discussed previously. In various embodiments, the AMF 221B may store a CE mode B Restriction parameter of the UE 201 in an associated MM context or RM context. The AMF 221B may also derive the value, when needed, from the UE's usage setting parameter already stored in the UE context (and/or MM/RM context).

[0105] CM may be used to establish and release a signaling connection between the UE 201 and the AMF 221B over the N1 interface. The signaling connection is used to enable NAS signaling exchange between the UE 201 and the CN 220, and comprises both the signaling connection between the UE and the AN (e.g., RRC connection or UE-N3IWF connection for non-3GPP access) and the N2 connection for the UE 201 between the AN (e.g., RAN 210B) and the AMF 221B. The UE 201 may operate in one of two CM states, CM-IDLE mode or CM-CONNECTED mode. When the UE 201 is operating in the CM-IDLE state/mode, the UE 201 may have no NAS signaling connection established with the AMF 221B over the N1 interface, and there may be (R)AN 210B signaling connection (e.g., N2 and/or N3 connections) for the UE 201. When the UE 201 is operating in the CM-CONNECTED state/mode, the UE 201 may have an established NAS signaling connection with the AMF 221B over the N1 interface, and there may be a (R)AN 210B signaling connection (e.g., N2 and/or N3 connections) for the UE 201. Establishment of an N2 connection between the (R)AN 210B and the AMF 221B may cause the UE 201 to transition from CM-IDLE mode to CM-CONNECTED mode, and the UE 201 may transition from the CM-CONNECTED mode to the CM-IDLE mode when N2 signaling between the (R)AN 210B and the AMF 221B is released.

[0106] The SMF 224B may be responsible for SM (e.g., session establishment, modify and release, including tunnel maintain between UPF and AN node); UE IP address allocation and management (including optional authorization); selection and control of UP function; configuring traffic steering at UPF to route traffic to proper destination; termination of interfaces toward policy control functions; controlling part of policy enforcement and QoS; lawful intercept (for SM events and interface to LI system); termination of SM parts of NAS messages; downlink data notification; initiating AN specific SM information, sent via AMF over N2 to AN; and determining SSC mode of a session. SM may refer to management of a PDU session, and a PDU session or “session” may refer to a PDU connectivity service that provides or enables the exchange of PDUs between a UE 201 and a data network (DN) 203 identified by a Data Network Name (DNN). PDU sessions may be established upon UE 201 request, modified upon UE 201 and 5GC 220 request, and released upon UE 201 and 5GC 220 request using NAS SM signaling exchanged over the N1 reference point between the UE 201 and the SMF 224B. Upon request from an application server, the 5GC 220 may trigger a specific application in the UE 201. In response to receipt of the trigger message, the UE 201 may pass the trigger message (or relevant parts/information of the trigger message) to one or more identified applications in the UE 201. The identified application(s) in the UE 201 may establish a PDU session to a specific DNN. The SMF 224B may check whether the UE

201 requests are compliant with user subscription information associated with the UE 201. In this regard, the SMF 224B may retrieve and/or request to receive update notifications on SMF 224B level subscription data from the UDM 227.

[0107] The SMF 224B may include the following roaming functionality: handling local enforcement to apply QoS SLAs (VPLMN); charging data collection and charging interface (VPLMN); lawful intercept (in VPLMN for SM events and interface to LI system); and support for interaction with external DN for transport of signalling for PDU session authorization/authentication by external DN. An N16 reference point between two SMFs 224B may be included in the system 200B, which may be between another SMF 224B in a visited network and the SMF 224B in the home network in roaming scenarios. Additionally, the SMF 224B may exhibit the Nsmf service-based interface.

[0108] The NEF 223B may provide means for securely exposing the services and capabilities provided by 3GPP network functions for third party, internal exposure/re-exposure, Application Functions (e.g., AF 228), edge computing or fog computing systems, etc. In such embodiments, the NEF 223B may authenticate, authorize, and/or throttle the AFs. NEF 223B may also translate information exchanged with the AF 228 and information exchanged with internal network functions. For example, the NEF 223B may translate between an AF-Service-Identifier and an internal 5GC information. NEF 223B may also receive information from other network functions (NFs) based on exposed capabilities of other network functions. This information may be stored at the NEF 223B as structured data, or at a data storage NF using standardized interfaces. The stored information can then be re-exposed by the NEF 223B to other NFs and AFs, and/or used for other purposes such as analytics. Additionally, the NEF 223B may exhibit an Nnef service-based interface.

[0109] The NRF 225B may support service discovery functions, receive NF discovery requests from NF instances, and provide the information of the discovered NF instances to the NF instances. NRF 225B also maintains information of available NF instances and their supported services. As used herein, the terms “instantiate,” “instantiation,” and the like may refer to the creation of an instance, and an “instance” may refer to a concrete occurrence of an object, which may occur, for example, during execution of program code. Additionally, the NRF 225B may exhibit the Nnrf service-based interface.

[0110] The PCF 226B may provide policy rules to control plane function(s) to enforce them, and may also support unified policy framework to govern network behaviour. The PCF 226B may also implement an FE to access subscription information relevant for policy decisions in a UDR of the UDM 227. The PCF 226B may communicate with the AMF 221B via an N15 reference point between the PCF 226B and the AMF 221B, which may include a PCF 226B in a visited network and the AMF 221B in case of roaming scenarios. The PCF 226B may communicate with the AF 228 via an N5 reference point between the PCF 226B and the AF 228; and with the SMF 224B via an N7 reference point between the PCF 226B and the SMF 224B. The system 200B and/or CN 220B may also include an N24 reference point between the PCF 226B (in the home network) and a PCF 226B in a visited network. Additionally, the PCF 226B may exhibit an Npcf service-based interface.

[0111] The UDM 227 may handle subscription-related information to support the network entities' handling of communication sessions, and may store subscription data of UE 201. For example, subscription data may be communicated between the UDM 227 and the AMF 221B via an N8 reference point between the UDM 227 and the AMF. The UDM 227 may include two parts, an application FE and a UDR (the FE and UDR are not shown by Figure 2B). The UDR may store subscription data and policy data for the UDM 227 and the PCF 226B, and/or structured data for exposure and application data (including PFDs for application detection, application request information for multiple UEs 201) for the NEF 223B. The Nudr service-based interface may be exhibited by the UDR 221 to allow the UDM 227, PCF 226B, and NEF 223B to access a particular set of the stored data, as well as to read, update (e.g., add, modify), delete, and subscribe to notification of relevant data changes in the UDR. The UDM may include a UDM-FE, which is in charge of processing credentials, location management, subscription management and so on. Several different front ends may serve the same user in different transactions. The UDM-FE accesses subscription information stored in the UDR and performs authentication credential processing, user identification handling, access authorization, registration/mobility management, and subscription management. The UDR may interact with the SMF 224B via an N10 reference point between the UDM 227 and the SMF 224B. UDM 227 may also support SMS management, wherein an SMS-FE implements the similar application logic as discussed previously. Additionally, the UDM 227 may exhibit the Nudm service-based interface.

[0112] The AF 228 may provide application influence on traffic routing, provide access to the NCE, and interact with the policy framework for policy control. The NCE may be a mechanism that allows the 5GC 220B and AF 228 to provide information to each other via NEF 223B, which may be used for edge computing implementations. In such implementations, the network operator and third party services may be hosted close to the UE 201 access point of attachment to achieve an efficient service delivery through the reduced end-to-end latency and load on the transport network. For edge computing implementations, the 5GC may select a UPF 202 close to the UE 201 and execute traffic steering from the UPF 202 to DN 203 via the N6 interface. This may be based on the UE subscription data, UE location, and information provided by the AF 228. In this way, the AF 228 may influence UPF (re)selection and traffic routing. Based on operator deployment, when AF 228 is considered to be a trusted entity, the network operator may permit AF 228 to interact directly with relevant NFs. Additionally, the AF 228 may exhibit an Naf service-based interface.

[0113] The NSSF 229 may select a set of network slice instances serving the UE 201. The NSSF 229 may also determine allowed NSSAI and the mapping to the subscribed S-NSSAIs, if needed. The NSSF 229 may also determine the AMF set to be used to serve the UE 201, or a list of candidate AMF(s) 221B based on a suitable configuration and possibly by querying the NRF 225B. The selection of a set of network slice instances for the UE 201 may be triggered by the AMF 221B with which the UE 201 is registered by interacting with the NSSF 229, which may lead to a change of AMF 221B. The NSSF 229 may interact with the AMF 221B via an N22 reference point between AMF 221B and NSSF 229; and may communicate with another NSSF 229 in a visited network via an N31 reference point (not shown by Figure 2B). Additionally, the NSSF 229 may exhibit an Nnssf service-based interface.

[0114] As discussed previously, the CN 220B may include an SMSF, which may be responsible for SMS subscription checking and verification, and relaying SM messages to/from the UE 201 to/from other entities, such as an SMS-GMSC/IWMSC/SMS-router. The SMS may also interact with AMF 221B and UDM 227 for a notification procedure that the UE 201 is available for SMS transfer (e.g., set a UE not reachable flag, and notifying UDM 227 when UE 201 is available for SMS).

[0115] The CN 120 may also include other elements that are not shown by Figure 2B, such as a Data Storage system/architecture, a 5G-EIR, a SEPP, and the like. The Data Storage system may include a SDSF, an UDSF, and/or the like. Any NF may store and retrieve unstructured data into/from the UDSF (e.g., UE contexts), via N18 reference point between any NF and the UDSF (not shown by Figure 2B). Individual NFs may share a UDSF for storing their respective unstructured data or individual NFs may each have their own UDSF located at or near the individual NFs. Additionally, the UDSF may exhibit an Nudsf service-based interface (not shown by Figure 2B). The 5G-EIR may be an NF that checks the status of PEI for determining whether particular equipment/entities are blacklisted from the network; and the SEPP may be a non-transparent proxy that performs topology hiding, message filtering, and policing on inter-PLMN control plane interfaces.

[0116] Additionally, there may be many more reference points and/or service-based interfaces between the NF services in the NFs; however, these interfaces and reference points have been omitted from Figure 2B for clarity. In one example, the CN 220B may include an Nx interface, which is an inter-CN interface between the MME (e.g., MME 221A) and the AMF 221B in order to enable interworking between CN 220A and CN 220B. Other example interfaces/reference points may include an N5g-EIR service-based interface exhibited by a 5G-EIR, an N27 reference point between the NRF in the visited network and the NRF in the home network; and an N31 reference point between the NSSF in the visited network and the NSSF in the home network.

[0117] Figure 3A illustrates an example of infrastructure equipment 300A in accordance with various embodiments. The infrastructure equipment 300A (or "system 300A") may be implemented as a base station, radio head, RAN node such as the RAN nodes 111 and/or AP 106 shown and described previously, application server(s) 130, and/or any other element/device discussed herein. In other examples, the system 300A could be implemented in or by a UE.

[0118] The system 300A includes application circuitry 305, baseband circuitry 310, one or more radio front end modules (RFEMs) 315, memory circuitry 320, power management integrated circuitry (PMIC) 325, power tee circuitry 330A, network controller circuitry 335, network interface connector 340A, satellite positioning circuitry 345, and user interface 350. In some embodiments, the device 300A may include additional elements such as, for example, memory/storage, display, camera, sensor, or input/output (I/O) interface. In other embodiments, the components described below may be included in more than one device. For example, said circuitries may be separately included in more than one device for CRAN, vBBU, or other like implementations.

[0119] Application circuitry 305 includes circuitry such as, but not limited to one or more processors (or processor cores), cache memory, and one or more of low drop-out voltage regulators (LDOs), interrupt controllers, serial interfaces such as SPI, I^2C or universal programmable serial interface module, real time clock (RTC), timer-counters including interval and watchdog timers, general purpose input/output (I/O or IO), memory card controllers such as Secure Digital (SD) MultiMediaCard (MMC) or similar, Universal Serial Bus (USB) interfaces, Mobile Industry Processor Interface (MIPI) interfaces and Joint Test Access Group (JTAG) test access ports. The processors (or cores) of the application circuitry 305 may be coupled with or may include memory/storage elements and may be configured to execute instructions stored in the memory/storage to enable various applications or operating systems to run on the system 300A. In some implementations, the memory/storage elements may be on-chip memory circuitry, which may include any suitable volatile and/or non-volatile memory, such as DRAM, SRAM, EPROM, EEPROM, Flash memory, solid-state memory, and/or any other type of memory device technology, such as those discussed herein.

[0120] The processor(s) of application circuitry 305 may include, for example, one or more processor cores (CPUs), one or more application processors, one or more graphics processing units (GPUs), one or more reduced instruction set computing (RISC) processors, one or more Acorn RISC Machine (ARM) processors, one or more complex instruction set computing (CISC) processors, one or more digital signal processors (DSP), one or more FPGAs, one or more PLDs, one or more ASICs, one or more microprocessors or controllers, or any suitable combination thereof. In some embodiments, the application circuitry 305 may comprise, or may be, a special-purpose processor/controller to operate according to the various embodiments herein. As examples, the processor(s) of application circuitry 305 may include one or more Intel Pentium®, Core®, or Xeon® processor(s); Advanced Micro Devices (AMD) Ryzen®

processor(s), Accelerated Processing Units (APUs), or Epyc® processors; ARM-based processor(s) licensed from ARM Holdings, Ltd. such as the ARM Cortex-A family of processors and the ThunderX2® provided by Cavium(TM), Inc.; a MIPS-based design from MIPS Technologies, Inc. such as MIPS Warrior P-class processors; and/or the like. In some embodiments, the system 300A may not utilize application circuitry 305, and instead may include a special-purpose processor/controller to process IP data received from an EPC or 5GC, for example.

[0121] In some implementations, the application circuitry 305 may include one or more hardware accelerators, which may be microprocessors, programmable processing devices, or the like. The one or more hardware accelerators may include, for example, computer vision (CV) and/or deep learning (DL) accelerators. As examples, the programmable processing devices may be one or more a field-programmable devices (FPDs) such as field-programmable gate arrays (FPGAs) and the like; programmable logic devices (PLDs) such as complex PLDs (CPLDs), high-capacity PLDs (HCPLDs), and the like; ASICs such as structured ASICs and the like; programmable SoCs (PSoCs); and the like. In such implementations, the circuitry of application circuitry 305 may comprise logic blocks or logic fabric, and other interconnected resources that may be programmed to perform various functions, such as the procedures, methods, functions, etc. of the various embodiments discussed herein. In such embodiments, the circuitry of application circuitry 305 may include memory cells (e.g., erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), flash memory, static memory (e.g., static random access memory (SRAM), anti-fuses, etc.)) used to store logic blocks, logic fabric, data, etc. in look-up-tables (LUTs) and the like.

[0122] The baseband circuitry 310 may be implemented, for example, as a solder-down substrate including one or more integrated circuits, a single packaged integrated circuit soldered to a main circuit board or a multi-chip module containing two or more integrated circuits. The various hardware electronic elements of baseband circuitry 310 are discussed infra with regard to Figure 4.

[0123] User interface circuitry 350 may include one or more user interfaces designed to enable user interaction with the system 300A or peripheral component interfaces designed to enable peripheral component interaction with the system 300A. User interfaces may include, but are not limited to, one or more physical or virtual buttons (e.g., a reset button), one or more indicators (e.g., light emitting diodes (LEDs)), a physical keyboard or keypad, a mouse, a touchpad, a touchscreen, speakers or other audio emitting devices, microphones, a printer, a scanner, a headset, a display screen or display device, etc. Peripheral component interfaces may include, but are not limited to, a nonvolatile memory port, a universal serial bus (USB) port, an audio jack, a power supply interface, etc.

[0124] The radio front end modules (RFEMs) 315 may comprise a millimeter wave (mmWave) RFEM and one or more sub-mmWave radio frequency integrated circuits (RFICs). In some implementations, the one or more sub-mmWave RFICs may be physically separated from the mmWave RFEM. The RFICs may include connections to one or more antennas or antenna arrays (see e.g., antenna array 4111 of Figure 4 infra), and the RFEM may be connected to multiple antennas. In alternative implementations, both mmWave and sub-mmWave radio functions may be implemented in the same physical RFEM 315, which incorporates both mmWave antennas and sub-mmWave.

[0125] The memory circuitry 320 may include one or more of volatile memory including dynamic random access memory (DRAM) and/or synchronous dynamic random access memory (SDRAM), and nonvolatile memory (NVM) including high-speed electrically erasable memory (commonly referred to as Flash memory), phase change random access memory (PRAM), magnetoresistive random access memory (MRAM), etc., and may incorporate the three-dimensional (3D) cross-point (XPOINT) memories from Intel® and Micron®. Memory circuitry 320 may be implemented as one or more of solder down packaged integrated circuits, socketed memory modules and plug-in memory cards.

[0126] The PMIC 325 may include voltage regulators, surge protectors, power alarm detection circuitry, and one or more backup power sources such as a battery or capacitor. The power alarm detection circuitry may detect one or more of brown out (under-voltage) and surge (over-voltage) conditions. The power tee circuitry 330A may provide for electrical power drawn from a network cable to provide both power supply and data connectivity to the infrastructure equipment 300A using a single cable.

[0127] The network controller circuitry 335 may provide connectivity to a network using a standard network interface protocol such as Ethernet, Ethernet over GRE Tunnels, Ethernet over Multiprotocol Label Switching (MPLS), or some other suitable protocol. Network connectivity may be provided to/from the infrastructure equipment 300A via network interface connector 340A using a physical connection, which may be electrical (commonly referred to as a “copper interconnect”), optical, or wireless. The network controller circuitry 335 may include one or more dedicated processors and/or FPGAs to communicate using one or more of the aforementioned protocols. In some implementations, the network controller circuitry 335 may include multiple controllers to provide connectivity to other networks using the same or different protocols.

[0128] The positioning circuitry 345 includes circuitry to receive and decode signals transmitted/broadcasted by a positioning network of a global navigation satellite system (GNSS). Examples of navigation satellite constellations (or GNSS) include United States’ Global Positioning System (GPS), Russia’s Global Navigation System (GLONASS), the European Union’s Galileo system, China’s BeiDou Navigation Satellite System, a regional navigation system or GNSS augmentation system (e.g., Navigation with Indian Constellation (NAVIC), Japan’s Quasi-Zenith Satellite System (QZSS), France’s Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS), etc.), or the like. The positioning circuitry 345 comprises various hardware elements (e.g., including hardware devices such as switches, filters, amplifiers, antenna elements, and the like to facilitate OTA communications) to communicate with components of a positioning network, such as navigation satellite constellation nodes. In some embodiments, the positioning circuitry 345 may include a Micro-Technology for Positioning, Navigation, and Timing (Micro-PNT) IC that uses a master timing clock to perform position tracking/estimation without GNSS assistance. The positioning circuitry 345 may also be part of, or interact with, the baseband circuitry 310 and/or RFEMs 315 to communicate with the nodes and components of the positioning network. The positioning circuitry 345 may also provide position data and/or time data to the application circuitry 305, which may use the data to synchronize operations with various infrastructure (e.g., RAN nodes 111, etc.), or the like.

[0129] The components shown by Figure 3A may communicate with one another using interface circuitry, which may include any number of bus and/or interconnect (IX) technologies such as industry standard architecture (ISA), extended ISA (EISA), peripheral component interconnect (PCI), peripheral component interconnect extended (PCIx), PCI express (PCIe), or any number of other technologies. The bus/IX may be a proprietary bus, for example, used in a SoC based system. Other bus/IX systems may be included, such as an I^2C interface, an SPI interface, point to point interfaces, and a power bus, among others.

[0130] Figure 3B illustrates an example of a platform 300B (or “device 300B”) in accordance with various embodiments. In embodiments, the computer platform 300B may be suitable for use as UEs 101, 102, 201, application servers 130, and/or any other element/device discussed herein. The platform 300B may include any combinations of the components shown in the example. The components of platform 300B may be implemented as integrated circuits (ICs), portions thereof, discrete electronic devices, or other modules, logic, hardware, software, firmware, or a combination thereof adapted in the computer platform 300B, or as components otherwise incorporated within a chassis of a larger system. The block diagram of Figure 3B is intended to show a high level view of components of the computer platform 300B. However, some of the components shown may be omitted, additional components may be present, and different arrangement of the components shown may occur in other implementations.

[0131] Application circuitry 305 includes circuitry such as, but not limited to one or more processors (or processor cores), cache memory, and one or more of LDOs, interrupt controllers, serial interfaces such as SPI, I^2C or universal programmable serial interface module, RTC, timer-counters including interval and watchdog timers, general purpose I/O, memory card controllers such as SD MMC or similar, USB interfaces, MIPI interfaces, and JTAG test access ports. The processors (or cores) of the application circuitry 305 may be coupled with or may include memory/storage elements and may be configured to execute instructions stored in the memory/storage to enable various applications or operating systems to run on the system 300B. In some implementations, the memory/storage elements may be on-chip memory circuitry, which may include any suitable volatile and/or non-volatile memory, such as DRAM, SRAM, EPROM, EEPROM, Flash memory, solid-state memory, and/or any other type of memory device technology, such as those discussed herein.

[0132] The processor(s) of application circuitry 305 may include, for example, one or more processor cores, one or more application processors, one or more GPUs, one or more RISC processors, one or more ARM processors, one or more CISC processors, one or more DSP, one or more FPGAs, one or more PLDs, one or more ASICs, one or more microprocessors or controllers, a multithreaded processor, an ultra-low voltage processor, an embedded processor, some other known processing element, or any suitable combination thereof. In some embodiments, the application circuitry 305 may comprise, or may be, a special-purpose processor/controller to operate according to the various embodiments herein.

[0133] As examples, the processor(s) of application circuitry 305 may include an Intel® Architecture Core™ based processor, such as a Quark™, an Atom™, an i3, an i5, an i7, or an MCU-class processor, or another such processor available from Intel® Corporation, Santa Clara, CA. The processors of the application circuitry 305 may also be one or more of Advanced Micro Devices (AMD) Ryzen® processor(s) or Accelerated Processing Units (APUs); A5-A9 processor(s) from Apple® Inc., Snapdragon™ processor(s) from Qualcomm® Technologies, Inc., Texas Instruments, Inc.® Open Multimedia Applications Platform (OMAP)™ processor(s); a MIPS-based design from MIPS Technologies, Inc. such as MIPS Warrior M-class, Warrior I-class, and Warrior P-class processors; an ARM-based design licensed from ARM Holdings, Ltd., such as the ARM Cortex-A, Cortex-R, and Cortex-M family of processors; or the like. In some implementations, the application circuitry 305 may be a part of a system on a chip (SoC) in which the application circuitry 305 and other components are formed into a single integrated circuit, or a single package, such as the Edison™ or Galileo™ SoC boards from Intel® Corporation.

[0134] Additionally or alternatively, application circuitry 305 may include circuitry such as, but not limited to, one or more a field-programmable devices (FPDs) such as FPGAs and the like; programmable logic devices (PLDs) such as complex PLDs (CPLDs), high-capacity PLDs (HCPLDs), and the like; ASICs such as structured ASICs and the like; programmable SoCs (PSoCs); and the like. In such embodiments, the circuitry of application circuitry 305 may comprise logic blocks or logic fabric, and other interconnected resources that may be programmed to perform various functions, such as the procedures, methods, functions, etc. of the various embodiments discussed herein. In such embodiments, the circuitry of application circuitry 305 may include memory cells (e.g., erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), flash memory, static memory (e.g., static random access memory (SRAM), anti-fuses, etc.)) used to store logic blocks, logic fabric, data, etc. in look-up tables (LUTs) and the like.

[0135] The baseband circuitry 310 may be implemented, for example, as a solder-down substrate including one or more integrated circuits, a single packaged integrated circuit soldered to a main circuit board or a multi-chip module containing two or more integrated circuits. The various hardware electronic elements of baseband circuitry 310 are discussed infra with regard to Figure 4.

[0136] The RFEMs 315 may comprise a millimeter wave (mmWave) RFEM and one or more sub-mmWave radio frequency integrated circuits (RFICs). In some implementations, the one or more sub-mmWave RFICs may be physically separated from the mmWave RFEM. The RFICs may include connections to one or more antennas or antenna arrays (see e.g., antenna array 4111 of Figure 4 infra), and the RFEM may be connected to multiple antennas. In alternative implementations, both mmWave and sub-mmWave radio functions may be implemented in the same physical RFEM 315, which incorporates both mmWave antennas and sub-mmWave.

[0137] The memory circuitry 320 may include any number and type of memory devices used to provide for a given amount of system memory. As examples, the memory circuitry 320 may include one or more of volatile memory including random access memory (RAM), dynamic RAM (DRAM) and/or synchronous dynamic RAM (SDRAM), and nonvolatile memory (NVM) including high-speed electrically erasable memory (commonly referred to as Flash memory), phase change random access memory (PRAM), magnetoresistive random access memory (MRAM), etc. The memory circuitry 320 may be developed in accordance with a Joint Electron Devices Engineering Council (JEDEC) low power double data rate (LPDDR)-based design, such as LPDDR2, LPDDR3, LPDDR4, or the like. Memory circuitry 320 may be implemented as one or more of solder down packaged integrated circuits, single die package (SDP), dual die package (DDP) or quad die package (Q17P), socketed memory modules, dual inline memory modules (DIMMs) including microDIMMs or MiniDIMMs, and/or soldered onto a motherboard via a ball grid array (BGA). In low power implementations, the memory circuitry 320 may be on-die memory or registers associated with the application circuitry 305. To provide for persistent storage of information such as data, applications, operating systems and so forth, memory circuitry 320 may include one or more mass storage devices, which may include, inter alia, a solid state disk drive (SSDD), hard disk drive (HDD), a micro HDD, resistance change memories, phase change memories, holographic memories, or chemical memories, among others. For example, the computer platform 300B may incorporate the three-dimensional (3D) cross-point (XPOINT) memories from Intel® and Micron®.

[0138] Removable memory circuitry 323 may include devices, circuitry, enclosures/housings, ports or receptacles, etc. used to couple portable data storage devices with the platform 300B. These portable data storage devices may be used for mass storage purposes, and may include, for example, flash memory cards (e.g., Secure Digital (SD) cards, microSD cards, xD picture cards, and the like), and USB flash drives, optical discs, external HDDs, and the like.

[0139] The platform 300B may also include interface circuitry (not shown) that is used to connect external devices with the platform 300B. The external devices connected to the platform 300B via the interface circuitry include sensor circuitry 321 and electro-mechanical components (EMCs) 322, as well as removable memory devices coupled to removable memory circuitry 323.

[0140] The sensor circuitry 321 include devices, modules, or subsystems whose purpose is to detect events or changes in its environment and send the information (sensor data) about the detected events to some other a device, module, subsystem, etc. Examples of such sensors include, inter alia, inertia measurement units (IMUs) comprising accelerometers, gyroscopes, and/or magnetometers; microelectromechanical systems (MEMS) or nanoelectromechanical systems (NEMS) comprising 3-axis accelerometers, 3-axis gyroscopes, and/or magnetometers; level sensors; flow sensors; temperature sensors (e.g., thermistors); pressure sensors; barometric pressure sensors; gravimeters; altimeters; image capture devices (e.g., cameras or lensless apertures); light detection and ranging (LiDAR) sensors; proximity sensors (e.g., infrared radiation detector and the like), depth sensors, ambient light sensors, ultrasonic transceivers; microphones or other like audio capture devices; etc.

[0141] EMCs 322 include devices, modules, or subsystems whose purpose is to enable platform 300B to change its state, position, and/or orientation, or move or control a mechanism or (sub)system. Additionally, EMCs 322 may be configured to generate and send messages/signalling to other components of the platform 300B to indicate a current state of the EMCs 322. Examples of the EMCs 322 include one or more power switches, relays including electromechanical relays (EMRs) and/or solid state relays (SSRs), actuators (e.g., valve actuators, etc.), an audible sound generator, a visual warning device, motors (e.g., DC motors, stepper motors, etc.), wheels, thrusters, propellers, claws, clamps, hooks, and/or other like electro-mechanical components. In embodiments, platform 300B is configured to operate one or more EMCs 322 based on one or more captured events and/or instructions or control signals received from a service provider and/or various clients.

[0142] In some implementations, the interface circuitry may connect the platform 300B with positioning circuitry 345. The positioning circuitry 345 includes circuitry to receive and decode signals transmitted/broadcasted by a positioning network of a GNSS. Examples of navigation satellite constellations (or GNSS) include United States' GPS, Russia's GLONASS, the European Union's Galileo system, China's BeiDou Navigation Satellite System, a regional navigation system or GNSS augmentation system (e.g., NAVIC), Japan's QZSS, France's DORIS, etc.), or the like. The positioning circuitry 345 comprises various hardware elements (e.g., including hardware devices such as switches, filters, amplifiers, antenna elements, and the like to facilitate OTA communications) to communicate with components of a positioning network, such as navigation satellite constellation nodes. In some embodiments, the positioning circuitry 345 may include a Micro-PNT IC that uses a master timing clock to perform position tracking/estimation without GNSS assistance. The positioning circuitry 345 may also be part of, or interact with, the baseband circuitry 310 and/or RFEMs 315 to communicate with the nodes and components of the positioning network. The positioning circuitry 345 may also provide position data and/or time data to the application circuitry 305, which may use the data to synchronize operations with various infrastructure (e.g., radio base stations), for turn-by-turn navigation applications, or the like

[0143] In some implementations, the interface circuitry may connect the platform 300B with Near-Field Communication (NFC) circuitry 340B. NFC circuitry 340B is configured to provide contactless, short-range communications based on radio frequency identification (RFID) standards, wherein magnetic field induction is used to enable communication between NFC circuitry 340B and NFC-enabled devices external to the platform 300B (e.g., an "NFC touchpoint"). NFC circuitry 340B comprises an NFC controller coupled with an antenna element and a processor coupled with the NFC controller. The NFC controller may be a chip/IC providing NFC functionalities to the

NFC circuitry 340B by executing NFC controller firmware and an NFC stack. The NFC stack may be executed by the processor to control the NFC controller, and the NFC controller firmware may be executed by the NFC controller to control the antenna element to emit short-range RF signals. The RF signals may power a passive NFC tag (e.g., a microchip embedded in a sticker or wristband) to transmit stored data to the NFC circuitry 340B, or initiate data transfer between the NFC circuitry 340B and another active NFC device (e.g., a smartphone or an NFC-enabled POS terminal) that is proximate to the platform 300B.

[0144] The driver circuitry 346 may include software and hardware elements that operate to control particular devices that are embedded in the platform 300B, attached to the platform 300B, or otherwise communicatively coupled with the platform 300B. The driver circuitry 346 may include individual drivers allowing other components of the platform 300B to interact with or control various input/output (I/O) devices that may be present within, or connected to, the platform 300B. For example, driver circuitry 346 may include a display driver to control and allow access to a display device, a touchscreen driver to control and allow access to a touchscreen interface of the platform 300B, sensor drivers to obtain sensor readings of sensor circuitry 321 and control and allow access to sensor circuitry 321, EMC drivers to obtain actuator positions of the EMCs 322 and/or control and allow access to the EMCs 322, a camera driver to control and allow access to an embedded image capture device, audio drivers to control and allow access to one or more audio devices.

[0145] The power management integrated circuitry (PMIC) 325 (also referred to as "power management circuitry 325") may manage power provided to various components of the platform 300B. In particular, with respect to the baseband circuitry 310, the PMIC 325 may control power-source selection, voltage scaling, battery charging, or DC-to-DC conversion. The PMIC 325 may often be included when the platform 300B is capable of being powered by a battery 330B, for example, when the device is included in a UE 101, 102, 201.

[0146] In some embodiments, the PMIC 325 may control, or otherwise be part of, various power saving mechanisms of the platform 300B. For example, if the platform 300B is in an RRC_Connected state, where it is still connected to the RAN node as it expects to receive traffic shortly, then it may enter a state known as Discontinuous Reception Mode

(DRX) after a period of inactivity. During this state, the platform 300B may power down for brief intervals of time and thus save power. If there is no data traffic activity for an extended period of time, then the platform 300B may transition off to an RRC_Idle state, where it disconnects from the network and does not perform operations such as channel quality feedback, handover, etc. The platform 300B goes into a very low power state and it performs paging where again it periodically wakes up to listen to the network and then powers down again. The platform 300B may not receive data in this state; in order to receive data, it must transition back to RRC_Connected state. An additional power saving mode may allow a device to be unavailable to the network for periods longer than a paging interval (ranging from seconds to a few hours). During this time, the device is totally unreachable to the network and may power down completely. Any data sent during this time incurs a large delay and it is assumed the delay is acceptable.

[0147] A battery 330B may power the platform 300B, although in some examples the platform 300B may be mounted deployed in a fixed location, and may have a power supply coupled to an electrical grid. The battery 330B may be a lithium ion battery, a metal-air battery, such as a zinc-air battery, an aluminum-air battery, a lithium-air battery, and the like. In some implementations, such as in V2X applications, the battery 330B may be a typical lead-acid automotive battery.

[0148] In some implementations, the battery 330B may be a “smart battery,” which includes or is coupled with a Battery Management System (BMS) or battery monitoring integrated circuitry. The BMS may be included in the platform 300B to track the state of charge (SoCh) of the battery 330B. The BMS may be used to monitor other parameters of the battery 330B to provide failure predictions, such as the state of health (SoH) and the state of function (SoF) of the battery 330B. The BMS may communicate the information of the battery 330B to the application circuitry 305 or other components of the platform 300B. The BMS may also include an analog-to-digital (ADC) convertor that allows the application circuitry 305 to directly monitor the voltage of the battery 330B or the current flow from the battery 330B. The battery parameters may be used to determine actions that the platform 300B may perform, such as transmission frequency, network operation, sensing frequency, and the like.

[0149] A power block, or other power supply coupled to an electrical grid may be coupled with the BMS to charge the battery 330B. In some examples, the power block

330A may be replaced with a wireless power receiver to obtain the power wirelessly, for example, through a loop antenna in the computer platform 300B. In these examples, a wireless battery charging circuit may be included in the BMS. The specific charging circuits chosen may depend on the size of the battery 330B, and thus, the current required. The charging may be performed using the Airfuel standard promulgated by the Airfuel Alliance, the Qi wireless charging standard promulgated by the Wireless Power Consortium, or the Rezence charging standard promulgated by the Alliance for Wireless Power, among others.

[0150] User interface circuitry 350 includes various input/output (I/O) devices present within, or connected to, the platform 300B, and includes one or more user interfaces designed to enable user interaction with the platform 300B and/or peripheral component interfaces designed to enable peripheral component interaction with the platform 300B. The user interface circuitry 350 includes input device circuitry and output device circuitry. Input device circuitry includes any physical or virtual means for accepting an input including, inter alia, one or more physical or virtual buttons (e.g., a reset button), a physical keyboard, keypad, mouse, touchpad, touchscreen, microphones, scanner, headset, and/or the like. The output device circuitry includes any physical or virtual means for showing information or otherwise conveying information, such as sensor readings, actuator position(s), or other like information. Output device circuitry may include any number and/or combinations of audio or visual display, including, inter alia, one or more simple visual outputs/indicators (e.g., binary status indicators (e.g., light emitting diodes (LEDs)) and multi-character visual outputs, or more complex outputs such as display devices or touchscreens (e.g., Liquid Chrystal Displays (LCD), LED displays, quantum dot displays, projectors, etc.), with the output of characters, graphics, multimedia objects, and the like being generated or produced from the operation of the platform 300. The output device circuitry may also include speakers or other audio emitting devices, printer(s), and/or the like. In some embodiments, the sensor circuitry 321 may be used as the input device circuitry (e.g., an image capture device, motion capture device, or the like) and one or more EMCs may be used as the output device circuitry (e.g., an actuator to provide haptic feedback or the like). In another example, NFC circuitry comprising an NFC controller coupled with an antenna element and a processing device may be included to read electronic tags and/or connect with another

NFC-enabled device. Peripheral component interfaces may include, but are not limited to, a non-volatile memory port, a USB port, an audio jack, a power supply interface, etc.

[0151] Although not shown, the components of platform 300 may communicate with one another using a suitable bus or interconnect (IX) technology, which may include any number of technologies, including ISA, EISA, PCI, PCIx, PCIe, a Time-Trigger Protocol (TTP) system, a FlexRay system, or any number of other technologies. The bus/IX may be a proprietary bus/IX, for example, used in a SoC based system. Other bus/IX systems may be included, such as an I^2C interface, an SPI interface, point-to-point interfaces, and a power bus, among others.

[0152] Figure 4 illustrates example components of baseband circuitry 4110 and radio front end modules (RFEM) 4115 in accordance with various embodiments. The baseband circuitry 4110 corresponds to the baseband circuitry 310 and 310 of Figures 3 and 3, respectively. The RFEM 4115 corresponds to the RFEM 315 and 315 of Figures 3 and 3, respectively. As shown, the RFEMs 4115 may include Radio Frequency (RF) circuitry 4106, front-end module (FEM) circuitry 4108, antenna array 4111 coupled together at least as shown.

[0153] The baseband circuitry 4110 includes circuitry and/or control logic configured to carry out various radio/network protocol and radio control functions that enable communication with one or more radio networks via the RF circuitry 4106. 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 4110 may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 4110 may include convolution, tail-biting convolution, turbo, Viterbi, 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. The baseband circuitry 4110 is configured to process baseband signals received from a receive signal path of the RF circuitry 4106 and to generate baseband signals for a transmit signal path of the RF circuitry 4106. The baseband circuitry 4110 is configured to interface with application circuitry 305/305 (see Figures 3 and 3) for generation and processing of the baseband signals and for controlling operations of the RF circuitry 4106. The baseband circuitry 4110 may handle various radio control functions.

[0154] The aforementioned circuitry and/or control logic of the baseband circuitry 4110 may include one or more single or multi-core processors. For example, the one or more processors may include a 3G baseband processor 4104A, a 4G/LTE baseband processor 4104B, a 5G/NR baseband processor 4104C, or some other baseband processor(s) 4104D for other existing generations, generations in development or to be developed in the future (e.g., sixth generation (6G), etc.). In other embodiments, some or all of the functionality of baseband processors 4104A-D may be included in modules stored in the memory 4104G and executed via a Central Processing Unit (CPU) 4104E. In other embodiments, some or all of the functionality of baseband processors 4104A-D may be provided as hardware accelerators (e.g., FPGAs, ASICs, etc.) loaded with the appropriate bit streams or logic blocks stored in respective memory cells. In various embodiments, the memory 4104G may store program code of a real-time OS (RTOS), which when executed by the CPU 4104E (or other baseband processor), is to cause the CPU 4104E (or other baseband processor) to manage resources of the baseband circuitry 4110, schedule tasks, etc. Examples of the RTOS may include Operating System Embedded (OSE)™ provided by Enea®, Nucleus RTOS™ provided by Mentor Graphics®, Versatile Real-Time Executive (VRTX) provided by Mentor Graphics®, ThreadX™ provided by Express Logic®, FreeRTOS, REX OS provided by Qualcomm®, OKL4 provided by Open Kernel (OK) Labs®, or any other suitable RTOS, such as those discussed herein. In addition, the baseband circuitry 4110 includes one or more audio digital signal processor(s) (DSP) 4104F. The audio DSP(s) 4104F include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments.

[0155] In some embodiments, each of the processors 4104A-4104E include respective memory interfaces to send/receive data to/from the memory 4104G. The baseband circuitry 4110 may further include one or more interfaces to communicatively couple to other circuitries/devices, such as an interface to send/receive data to/from memory external to the baseband circuitry 4110; an application circuitry interface to send/receive data to/from the application circuitry 305 of FIGS. 3-4); an RF circuitry interface to send/receive data to/from RF circuitry 4106 of Figure 4; a wireless hardware connectivity interface to send/receive data to/from one or more wireless hardware elements (e.g., Near Field Communication (NFC) components, Bluetooth®/ Bluetooth® Low Energy components, Wi-Fi® components, and/or the like); and a power management interface to send/receive power or control signals to/from the PMIC 325.

[0156] In alternate embodiments (which may be combined with the above described embodiments), baseband circuitry 4110 comprises one or more digital baseband systems, which are coupled with one another via an interconnect subsystem and to a CPU subsystem, an audio subsystem, and an interface subsystem. The digital baseband subsystems may also be coupled to a digital baseband interface and a mixed-signal baseband subsystem via another interconnect subsystem. Each of the interconnect subsystems may include a bus system, point-to-point connections, network-on-chip (NOC) structures, and/or some other suitable bus or interconnect technology, such as those discussed herein. The audio subsystem may include DSP circuitry, buffer memory, program memory, speech processing accelerator circuitry, data converter circuitry such as analog-to-digital and digital-to-analog converter circuitry, analog circuitry including one or more of amplifiers and filters, and/or other like components. In an aspect of the present disclosure, baseband circuitry 4110 may include protocol processing circuitry with one or more instances of control circuitry (not shown) to provide control functions for the digital baseband circuitry and/or radio frequency circuitry (e.g., the radio front end modules 4115).

[0157] Although not shown by Figure 4, in some embodiments, the baseband circuitry 4110 includes individual processing device(s) to operate one or more wireless communication protocols (e.g., a “multi-protocol baseband processor” or “protocol processing circuitry”) and individual processing device(s) to implement PHY layer functions. In these embodiments, the PHY layer functions include the aforementioned radio control functions. In these embodiments, the protocol processing circuitry operates or implements various protocol layers/entities of one or more wireless communication protocols. In a first example, the protocol processing circuitry may operate LTE protocol entities and/or 5G/NR protocol entities when the baseband circuitry 4110 and/or RF circuitry 4106 are part of mmWave communication circuitry or some other suitable cellular communication circuitry. In the first example, the protocol processing circuitry would operate MAC, RLC, PDCP, SDAP, RRC, and NAS functions. In a second example, the protocol processing circuitry may operate one or more IEEE-based protocols when the baseband circuitry 4110 and/or RF circuitry 4106 are part of a Wi-Fi communication system. In the second example, the protocol processing circuitry would operate Wi-Fi MAC and logical link control (LLC) functions. The protocol processing circuitry may include one or more memory structures (e.g., 4104G) to store program code and data for operating the protocol functions, as well as one or more processing cores to execute the program code and perform various operations using the data. The baseband circuitry 4110 may also support radio communications for more than one wireless protocol.

[0158] The various hardware elements of the baseband circuitry 4110 discussed herein may be implemented, for example, as a solder-down substrate including one or more integrated circuits (ICs), a single packaged IC soldered to a main circuit board or a multi-chip module containing two or more ICs. In one example, the components of the baseband circuitry 4110 may be suitably combined in a single chip or chipset, or disposed on a same circuit board. In another example, some or all of the constituent components of the baseband circuitry 4110 and RF circuitry 4106 may be implemented together such as, for example, a system on a chip (SoC) or System-in-Package (SiP). In another example, some or all of the constituent components of the baseband circuitry 4110 may be implemented as a separate SoC that is communicatively coupled with and RF circuitry 4106 (or multiple instances of RF circuitry 4106). In yet another example, some or all of the constituent components of the baseband circuitry 4110 and the application circuitry 305/305 may be implemented together as individual SoCs mounted to a same circuit board (e.g., a “multi-chip package”).

[0159] In some embodiments, the baseband circuitry 4110 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 4110 may support communication with an E-UTRAN or other WMAN, a WLAN, a WPAN. Embodiments in which the baseband circuitry 4110 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[0160] RF circuitry 4106 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 4106 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 4106 may include a receive signal path, which may include circuitry to down-convert RF signals received from the FEM circuitry 4108 and provide baseband signals to the baseband circuitry 4110. RF circuitry 4106 may also include a transmit signal path, which may include circuitry to up-convert baseband signals provided by the baseband circuitry 4110 and provide RF output signals to the FEM circuitry 4108 for transmission.

[0161] In some embodiments, the receive signal path of the RF circuitry 4106 may include mixer circuitry 4106a, amplifier circuitry 4106b and filter circuitry 4106c. In some embodiments, the transmit signal path of the RF circuitry 4106 may include filter circuitry 4106c and mixer circuitry 4106a. RF circuitry 4106 may also include synthesizer circuitry 4106d for synthesizing a frequency for use by the mixer circuitry 4106a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 4106a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 4108 based on the synthesized frequency provided by synthesizer circuitry 4106d. The amplifier circuitry 4106b may be configured to amplify the down-converted signals and the filter circuitry 4106c 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 4110 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 4106a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[0162] In some embodiments, the mixer circuitry 4106a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 4106d to generate RF output signals for the FEM circuitry 4108. The baseband signals may be provided by the baseband circuitry 4110 and may be filtered by filter circuitry 4106c.

[0163] In some embodiments, the mixer circuitry 4106a of the receive signal path and the mixer circuitry 4106a of the transmit signal path may include two or more mixers and may be arranged for quadrature downconversion and upconversion, respectively. In some embodiments, the mixer circuitry 4106a of the receive signal path and the mixer circuitry

4106a 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 4106a of the receive signal path and the mixer circuitry 4106a of the transmit signal path may be arranged for direct downconversion and direct upconversion, respectively. In some embodiments, the mixer circuitry 4106a of the receive signal path and the mixer circuitry 4106a of the transmit signal path may be configured for super-heterodyne operation.

[0164] 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 4106 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 4110 may include a digital baseband interface to communicate with the RF circuitry 4106.

[0165] 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.

[0166] In some embodiments, the synthesizer circuitry 4106d 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 4106d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[0167] The synthesizer circuitry 4106d may be configured to synthesize an output frequency for use by the mixer circuitry 4106a of the RF circuitry 4106 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 4106d may be a fractional N/N+1 synthesizer.

[0168] 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 4110 or the application circuitry 305/305 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 application circuitry 305/305.

[0169] Synthesizer circuitry 4106d of the RF circuitry 4106 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or N+1 (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into Nd equal packets of phase, where Nd is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

[0170] In some embodiments, synthesizer circuitry 4106d 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 4106 may include an IQ/polar converter.

[0171] FEM circuitry 4108 may include a receive signal path, which may include circuitry configured to operate on RF signals received from antenna array 4111, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 4106 for further processing. FEM circuitry 4108 may also include a transmit signal path, which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 4106 for transmission by one or more of antenna elements of antenna array 4111. In various embodiments, the amplification through the transmit or receive signal paths may be done solely in the RF circuitry 4106, solely in the FEM circuitry 4108, or in both the RF circuitry 4106 and the FEM circuitry 4108.

[0172] In some embodiments, the FEM circuitry 4108 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry 4108 may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry 4108 may include an LNA to amplify received RF signals and provide the amplified received RF signals as an output (e.g., to the RF circuitry 4106). The transmit signal path of the FEM circuitry 4108 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 4106), and one or more filters to generate RF signals for subsequent transmission by one or more antenna elements of the antenna array 4111.

[0173] The antenna array 4111 comprises one or more antenna elements, each of which is configured convert electrical signals into radio waves to travel through the air and to convert received radio waves into electrical signals. For example, digital baseband signals provided by the baseband circuitry 4110 is converted into analog RF signals (e.g., modulated waveform) that will be amplified and transmitted via the antenna elements of the antenna array 4111 including one or more antenna elements (not shown). The antenna elements may be omnidirectional, direction, or a combination thereof. The antenna elements may be formed in a multitude of arranges as are known and/or discussed herein. The antenna array 4111 may comprise microstrip antennas or printed antennas that are fabricated on the surface of one or more printed circuit boards. The antenna array 4111 may be formed in as a patch of metal foil (e.g., a patch antenna) in a variety of shapes, and may be coupled with the RF circuitry 4106 and/or FEM circuitry 4108 using metal transmission lines or the like.

[0174] Processors of the application circuitry 305/305 and processors of the baseband circuitry 4110 may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry 4110, alone or in combination, may be used execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry 305/305 may utilize data (e.g., packet data) received from these layers and further execute Layer 4 functionality (e.g., TCP and UDP layers). As referred to herein, Layer 3 may comprise a RRC layer, described in further detail below. As referred to herein, Layer 2 may comprise a MAC layer, an RLC layer, and a PDCP layer, described in further detail below. As referred to herein, Layer 1 may comprise a PHY layer of a UE/RAN node, described in further detail below.

[0175] Figure 5 illustrates various protocol functions that may be implemented in a wireless communication device according to various embodiments. In particular, Figure 5 includes an arrangement 500 showing interconnections between various protocol layers/entities. The following description of Figure 5 is provided for various protocol layers/entities that operate in conjunction with the 5G/NR system standards and LTE system standards, but some or all of the aspects of Figure 5 may be applicable to other wireless communication network systems as well.

[0176] The protocol layers of arrangement 500 may include one or more of PHY 510, MAC 520, RLC 530, PDCP 540, SDAP 547, RRC 555, and NAS layer 557, in addition to other higher layer functions not illustrated. The protocol layers may include one or more service access points (e.g., items 559, 556, 550, 549, 545, 535, 525, and 515 in Figure 5) that may provide communication between two or more protocol layers.

[0177] The PHY 510 may transmit and receive physical layer signals 505 that may be received from or transmitted to one or more other communication devices. The physical layer signals 505 may comprise one or more physical channels, such as those discussed herein. The PHY 510 may further perform link adaptation or adaptive modulation and coding (AMC), power control, cell search (e.g., for initial synchronization and handover purposes), and other measurements used by higher layers, such as the RRC 555. The PHY 510 may still further perform error detection on the transport channels, forward error correction (FEC) coding/decoding of the transport channels, modulation/demodulation of physical channels, interleaving, rate matching, mapping onto physical channels, and MIMO antenna processing. In embodiments, an instance of PHY 510 may process requests from and provide indications to an instance of MAC 520 via one or more PHY-SAP 515. According to some embodiments, requests and indications communicated via PHY-SAP 515 may comprise one or more transport channels.

[0178] Instance(s) of MAC 520 may process requests from, and provide indications to, an instance of RLC 530 via one or more MAC-SAPs 525. These requests and indications communicated via the MAC-SAP 525 may comprise one or more logical channels. The MAC 520 may perform mapping between the logical channels and transport channels, multiplexing of MAC SDUs from one or more logical channels onto TBs to be delivered to PHY 510 via the transport channels, de-multiplexing MAC SDUs to one or more logical channels from TBs delivered from the PHY 510 via transport channels, multiplexing MAC SDUs onto TBs, scheduling information reporting, error correction through HARQ, and logical channel prioritization.

[0179] Instance(s) of RLC 530 may process requests from and provide indications to an instance of PDCP 540 via one or more radio link control service access points (RLC-

SAP) 535. These requests and indications communicated via RLC-SAP 535 may comprise one or more RLC channels. The RLC 530 may operate in a plurality of modes of operation, including: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM). The RLC 530 may execute transfer of upper layer protocol data units (PDUs), error correction through automatic repeat request (ARQ) for AM data transfers, and concatenation, segmentation and reassembly of RLC SDUs for UM and AM data transfers. The RLC 530 may also execute re-segmentation of RLC data PDUs for AM data transfers, reorder RLC data PDUs for UM and AM data transfers, detect duplicate data for UM and AM data transfers, discard RLC SDUs for UM and AM data transfers, detect protocol errors for AM data transfers, and perform RLC re-establishment.

[0180] Instance(s) of PDCP 540 may process requests from and provide indications to instance(s) of RRC 555 and/or instance(s) of SDAP 547 via one or more packet data convergence protocol service access points (PDCP-SAP) 545. These requests and indications communicated via PDCP-SAP 545 may comprise one or more radio bearers. The PDCP 540 may execute header compression and decompression of IP data, maintain PDCP Sequence Numbers (SNs), perform in-sequence delivery of upper layer PDUs at re-establishment of lower layers, eliminate duplicates of lower layer SDUs at re-establishment of lower layers for radio bearers mapped on RLC AM, cipher and decipher control plane data, perform integrity protection and integrity verification of control plane data, control timer-based discard of data, and perform security operations (e.g., ciphering, deciphering, integrity protection, integrity verification, etc.).

[0181] Instance(s) of SDAP 547 may process requests from and provide indications to one or more higher layer protocol entities via one or more SDAP-SAP 549. These requests and indications communicated via SDAP-SAP 549 may comprise one or more QoS flows. The SDAP 547 may map QoS flows to DRBs, and vice versa, and may also mark QFIs in DL and UL packets. A single SDAP entity 547 may be configured for an individual PDU session. In the UL direction, the NG-RAN 110 may control the mapping of QoS Flows to DRB(s) in two different ways, reflective mapping or explicit mapping. For reflective mapping, the SDAP 547 of a UE 101 may monitor the QFIs of the DL packets for each DRB, and may apply the same mapping for packets flowing in the UL direction. For a DRB, the SDAP 547 of the UE 101 may map the UL packets belonging to the QoS flows(s) corresponding to the QoS flow ID(s) and PDU session observed in the DL packets for that DRB. To enable reflective mapping, the NG-RAN 210B may mark DL packets over the Uu interface with a QoS flow ID. The explicit mapping may involve the RRC 555 configuring the SDAP 547 with an explicit QoS flow to DRB mapping rule, which may be stored and followed by the SDAP 547. In embodiments, the SDAP 547 may only be used in NR implementations and may not be used in LTE implementations.

[0182] The RRC 555 may configure, via one or more management service access points (M-SAP), aspects of one or more protocol layers, which may include one or more instances of PHY 510, MAC 520, RLC 530, PDCP 540 and SDAP 547. In embodiments, an instance of RRC 555 may process requests from and provide indications to one or more NAS entities 557 via one or more RRC-SAPs 556. The main services and functions of the RRC 555 may include broadcast of system information (e.g., included in MIBs or SIBs related to the NAS), broadcast of system information related to the access stratum (AS), paging, establishment, maintenance and release of an RRC connection between the UE 101 and RAN 110 (e.g., RRC connection paging, RRC connection establishment, RRC connection modification, and RRC connection release), establishment, configuration, maintenance and release of point to point Radio Bearers, security functions including key management, inter-RAT mobility, and measurement configuration for UE measurement reporting. The MIBs and SIBs may comprise one or more IEs, which may each comprise individual data fields or data structures.

[0183] The NAS 557 may form the highest stratum of the control plane between the UE 101 and the AMF 221B. The NAS 557 may support the mobility of the UEs 101 and the session management procedures to establish and maintain IP connectivity between the UE 101 and a P-GW in LTE systems.

[0184] According to various embodiments, one or more protocol entities of arrangement 500 may be implemented in UEs 101, RAN nodes 111, AMF 221B in NR implementations or MME 221A in LTE implementations, UPF 202 in NR implementations or S-GW 222A and P-GW 223A in LTE implementations, or the like to be used for control plane or user plane communications protocol stack between the aforementioned devices. In such embodiments, one or more protocol entities that may be implemented in one or more of UE 101, gNB 111, AMF 221B, etc. may communicate with a respective peer protocol entity that may be implemented in or on another device using the services of respective lower layer protocol entities to perform such communication. In some embodiments, a gNB-CU of the gNB 111 may host the RRC 555, SDAP 547, and PDCP 540 of the gNB that controls the operation of one or more gNB-DUs, and the gNB-DUs of the gNB 111 may each host the RLC 530, MAC 520, and PHY 510 of the gNB 111.

[0185] In a first example, a control plane protocol stack may comprise, in order from highest layer to lowest layer, NAS 557, RRC 555, PDCP 540, RLC 530, MAC 520, and PHY 510. In this example, upper layers 560 may be built on top of the NAS 557, which includes an IP layer 561, an SCTP 562, and an application layer signaling protocol (AP) 563.

[0186] In NR implementations, the AP 563 may be an NG application protocol layer (NGAP or NG-AP) 563 for the NG interface 113 defined between the NG-RAN node 111 and the AMF 221B, or the AP 563 may be an Xn application protocol layer (XnAP or Xn-AP) 563 for the Xn interface 112 that is defined between two or more RAN nodes 111.

[0187] The NG-AP 563 may support the functions of the NG interface 113 and may comprise Elementary Procedures (EPs). An NG-AP EP may be a unit of interaction between the NG-RAN node 111 and the AMF 221B. The NG-AP 563 services may comprise two groups: UE-associated services (e.g., services related to a UE 101, 102) and non-UE-associated services (e.g., services related to the whole NG interface instance between the NG-RAN node 111 and AMF 221B). These services may include functions including, but not limited to: a paging function for the sending of paging requests to NG-RAN nodes 111 involved in a particular paging area; a UE context management function for allowing the AMF 221B to establish, modify, and/or release a UE context in the AMF 221B and the NG-RAN node 111; a mobility function for UEs 101 in ECM-CONNECTED mode for intra-system HOs to support mobility within NG-RAN and inter-system HOs to support mobility from/to EPS systems; a NAS Signaling Transport function for transporting or rerouting NAS messages between UE 101 and AMF 221B; a NAS node selection function for determining an association between the AMF 221B and the UE 101; NG interface management function(s) for setting up the NG interface and monitoring for errors over the NG interface; a warning message transmission function for providing means to transfer warning messages via NG interface or cancel ongoing broadcast of warning messages; a Configuration Transfer function for requesting and transferring of RAN configuration information (e.g., SON information, performance measurement (PM) data, etc.) between two RAN nodes 111 via CN 120; and/or other like functions.

[0188] The XnAP 563 may support the functions of the Xn interface 112 and may comprise XnAP basic mobility procedures and XnAP global procedures. The XnAP basic mobility procedures may comprise procedures used to handle UE mobility within the NG RAN 111 (or E-UTRAN 210A), such as handover preparation and cancellation procedures, SN Status Transfer procedures, UE context retrieval and UE context release procedures, RAN paging procedures, dual connectivity related procedures, and the like. The XnAP global procedures may comprise procedures that are not related to a specific UE 101, such as Xn interface setup and reset procedures, NG-RAN update procedures, cell activation procedures, and the like.

[0189] In LTE implementations, the AP 563 may be an S1 Application Protocol layer (S1-AP) 563 for the S1 interface 113 defined between an E-UTRAN node 111 and an MME, or the AP 563 may be an X2 application protocol layer (X2AP or X2-AP) 563 for the X2 interface 112 that is defined between two or more E-UTRAN nodes 111.

[0190] The S1 Application Protocol layer (S1-AP) 563 may support the functions of the S1 interface, and similar to the NG-AP discussed previously, the S1-AP may comprise S1-AP EPs. An S1-AP EP may be a unit of interaction between the E-UTRAN node 111 and an MME 221A within an LTE CN 120. The S1-AP 563 services may comprise two groups: UE-associated services and non UE-associated services. These services perform functions including, but not limited to: E-UTRAN Radio Access Bearer (E-RAB) management, UE capability indication, mobility, NAS signaling transport, RAN Information Management (RIM), and configuration transfer.

[0191] The X2AP 563 may support the functions of the X2 interface 112 and may comprise X2AP basic mobility procedures and X2AP global procedures. The X2AP basic mobility procedures may comprise procedures used to handle UE mobility within the E-UTRAN 120, such as handover preparation and cancellation procedures, SN Status Transfer procedures, UE context retrieval and UE context release procedures, RAN paging procedures, dual connectivity related procedures, and the like. The X2AP global procedures may comprise procedures that are not related to a specific UE 101, such as X2 interface setup and reset procedures, load indication procedures, error indication procedures, cell activation procedures, and the like.

[0192] The SCTP layer (alternatively referred to as the SCTP/IP layer) 562 may provide guaranteed delivery of application layer messages (e.g., NGAP or XnAP messages in NR implementations, or S1-AP or X2AP messages in LTE implementations). The SCTP 562 may ensure reliable delivery of signaling messages between the RAN node 111 and the AMF 221B/MME 221A based, in part, on the IP protocol, supported by the IP 561. The Internet Protocol layer (IP) 561 may be used to perform packet addressing and routing functionality. In some implementations the IP layer 561 may use point-to-point transmission to deliver and convey PDUs. In this regard, the RAN node 111 may comprise L2 and L1 layer communication links (e.g., wired or wireless) with the MME/AMF to exchange information.

[0193] In a second example, a user plane protocol stack may comprise, in order from highest layer to lowest layer, SDAP 547, PDCP 540, RLC 530, MAC 520, and PHY 510. The user plane protocol stack may be used for communication between the UE 101, the RAN node 111, and UPF 202 in NR implementations or an S-GW 222A and P-GW 223A in LTE implementations. In this example, upper layers 551 may be built on top of the SDAP 547, and may include a user datagram protocol (UDP) and IP security layer (UDP/IP) 552, a General Packet Radio Service (GPRS) Tunneling Protocol for the user plane layer (GTP-U) 553, and a User Plane PDU layer (UP PDU) 563.

[0194] The transport network layer 554 (also referred to as a "transport layer") may be built on IP transport, and the GTP-U 553 may be used on top of the UDP/IP layer 552 (comprising a UDP layer and IP layer) to carry user plane PDUs (UP-PDUs). The IP layer (also referred to as the "Internet layer") may be used to perform packet addressing and routing functionality. The IP layer may assign IP addresses to user data packets in any of IPv4, IPv6, or PPP formats, for example.

[0195] The GTP-U 553 may be used for carrying user data within the GPRS core network and between the radio access network and the core network. The user data transported can be packets in any of IPv4, IPv6, or PPP formats, for example. The UDP/IP 552 may provide checksums for data integrity, port numbers for addressing different functions at the source and destination, and encryption and authentication on the selected data flows. The RAN node 111 and the S-GW 222A may utilize an S1-U interface to exchange user plane data via a protocol stack comprising an L1 layer (e.g., PHY 510), an L2 layer (e.g., MAC 520, RLC 530, PDCP 540, and/or SDAP 547), the UDP/IP layer 552, and the GTP-U 553. The S-GW 222A and the P-GW 223A may utilize an S5/S8a interface to exchange user plane data via a protocol stack comprising an L1 layer, an L2 layer, the UDP/IP layer 552, and the GTP-U 553. As discussed previously, NAS protocols may support the mobility of the UE 101 and the session management procedures to establish and maintain IP connectivity between the UE 101 and the P-GW 223A.

[0196] Moreover, although not shown by Figure 5, an application layer may be present above the AP 563 and/or the transport network layer 554. The application layer may be a layer in which a user of the UE 101, RAN node 111, or other network element interacts with software applications being executed, for example, by application circuitry 305 or application circuitry 305, respectively. The application layer may also provide one or more interfaces for software applications to interact with communications systems of the UE 101 or RAN node 111, such as the baseband circuitry 4110. In some implementations the IP layer and/or the application layer may provide the same or similar functionality as layers 5-7, or portions thereof, of the Open Systems Interconnection (OSI) model (e.g., OSI Layer 7 – the application layer, OSI Layer 6 – the presentation layer, and OSI Layer 5 – the session layer).

[0197] Figure 6 illustrates components of a core network in accordance with various embodiments. The components of the CN 220 may be implemented in one physical node or separate physical nodes including components to read and execute instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium). In embodiments, the components of CN 220 may be implemented in a same or similar manner as discussed herein with regard to the components of CN 220. In some embodiments, NFV is utilized to virtualize any or all of the above-described network node functions via executable instructions stored in one or more computer-readable storage mediums (described in further detail below). A logical instantiation of the CN 220 may be referred to as a network slice 601, and individual logical instantiations of the CN 220 may provide specific network capabilities and network characteristics. A logical instantiation of a portion of the CN 220 may be referred to as a network sub-slice 602 (e.g., the network sub-slice 602 is shown to include the P-GW 223A and the PCRF 226A).

[0198] As used herein, the terms “instantiate,” “instantiation,” and the like may refer to the creation of an instance, and an “instance” may refer to a concrete occurrence of an object, which may occur, for example, during execution of program code. A network instance may refer to information identifying a domain, which may be used for traffic detection and routing in case of different IP domains or overlapping IP addresses. A network slice instance may refer to a set of network functions (NFs) instances and the resources (e.g., compute, storage, and networking resources) required to deploy the network slice.

[0199] With respect to 5G systems (see, e.g., Figure 2B), a network slice always comprises a RAN part and a CN part. The support of network slicing relies on the principle that traffic for different slices is handled by different PDU sessions. The network can realize the different network slices by scheduling and also by providing different L1/L2 configurations. The UE 201 provides assistance information for network slice selection in an appropriate RRC message, if it has been provided by NAS. While the network can support large number of slices, the UE need not support more than 8 slices simultaneously.

[0200] A network slice may include the CN 220 control plane and user plane NFs, NG-RANs 210B in a serving PLMN, and a N3IWF functions in the serving PLMN. Individual network slices may have different S-NSSAI and/or may have different SSTs. NSSAI includes one or more S-NSSAIs, and each network slice is uniquely identified by an S-NSSAI. Network slices may differ for supported features and network functions optimizations, and/or multiple network slice instances may deliver the same service/features but for different groups of UEs 201 (e.g., enterprise users). For example, individual network slices may deliver different committed service(s) and/or may be dedicated to a particular customer or enterprise. In this example, each network slice may have different S-NSSAIs with the same SST but with different slice differentiators. Additionally, a single UE may be served with one or more network slice instances simultaneously via a 5G AN and associated with eight different S-NSSAIs. Moreover, an AMF 221B instance serving an individual UE 201 may belong to each of the network slice instances serving that UE.

[0201] Network Slicing in the NG-RAN 210B involves RAN slice awareness. RAN slice awareness includes differentiated handling of traffic for different network slices, which have been pre-configured. Slice awareness in the NG-RAN 210B is introduced at the PDU session level by indicating the S-NSSAI corresponding to a PDU session in all signaling that includes PDU session resource information. How the NG-RAN 210B supports the slice enabling in terms of NG-RAN functions (e.g., the set of network functions that comprise each slice) is implementation dependent. The NG-RAN 210B selects the RAN part of the network slice using assistance information provided by the UE 201 or the 5GC 220, which unambiguously identifies one or more of the pre-configured network slices in the PLMN. The NG-RAN 210B also supports resource management and policy enforcement between slices as per SLAs. A single NG-RAN node may support multiple slices, and the NG-RAN 210B may also apply an appropriate RRM policy for the SLA in place to each supported slice. The NG-RAN 210B may also support QoS differentiation within a slice.

[0202] The NG-RAN 210B may also use the UE assistance information for the selection of an AMF 221B during an initial attach, if available. The NG-RAN 210B uses the assistance information for routing the initial NAS to an AMF 221B. If the NG-RAN 210B is unable to select an AMF 221B using the assistance information, or the UE 201 does not provide any such information, the NG-RAN 210B sends the NAS signaling to a default AMF 221B, which may be among a pool of AMFs 221B. For subsequent accesses, the UE 201 provides a temp ID, which is assigned to the UE 201 by the 5GC 220, to enable the NG-RAN 210B to route the NAS message to the appropriate AMF 221B as long as the temp ID is valid. The NG-RAN 210B is aware of, and can reach, the AMF 221B that is associated with the temp ID. Otherwise, the method for initial attach applies.

[0203] The NG-RAN 210B supports resource isolation between slices. NG-RAN 210B resource isolation may be achieved by means of RRM policies and protection mechanisms that should avoid that shortage of shared resources if one slice breaks the service level agreement for another slice. In some implementations, it is possible to fully dedicate NG-RAN 210B resources to a certain slice. How NG-RAN 210B supports resource isolation is implementation dependent.

[0204] Some slices may be available only in part of the network. Awareness in the NG-RAN 210B of the slices supported in the cells of its neighbors may be beneficial for inter-frequency mobility in connected mode. The slice availability may not change within the UE's registration area. The NG-RAN 210B and the 5GC 220 are responsible to handle a service request for a slice that may or may not be available in a given area. Admission or rejection of access to a slice may depend on factors such as support for the slice, availability of resources, support of the requested service by NG-RAN 210B.

[0205] The UE 201 may be associated with multiple network slices simultaneously. In case the UE 201 is associated with multiple slices simultaneously, only one signaling connection is maintained, and for intra-frequency cell reselection, the UE 201 tries to camp on the best cell. For inter-frequency cell reselection, dedicated priorities can be used to control the frequency on which the UE 201 camps. The 5GC 220 is to validate that the UE 201 has the rights to access a network slice. Prior to receiving an Initial Context Setup Request message, the NG-RAN 210B may be allowed to apply some provisional/local policies, based on awareness of a particular slice that the UE 201 is requesting to access. During the initial context setup, the NG-RAN 210B is informed of the slice for which resources are being requested.

[0206] NFV architectures and infrastructures may be used to virtualize one or more NFs, alternatively performed by proprietary hardware, onto physical resources comprising a combination of industry-standard server hardware, storage hardware, or switches. In other words, NFV systems can be used to execute virtual or reconfigurable implementations of one or more EPC components/functions.

[0207] Figure 7 is a block diagram illustrating components, according to some example embodiments, of a system 700 to support NFV. The system 700 is illustrated as including a VIM 702, an NFVI 704, an VNFM 706, VNFs 708, an EM 710, an NFVO 712, and a NM 714.

[0208] The VIM 702 manages the resources of the NFVI 704. The NFVI 704 can include physical or virtual resources and applications (including hypervisors) used to execute the system 700. The VIM 702 may manage the life cycle of virtual resources with the NFVI 704 (e.g., creation, maintenance, and tear down of VMs associated with one or more physical resources), track VM instances, track performance, fault and security of VM instances and associated physical resources, and expose VM instances and associated physical resources to other management systems.

[0209] The VNFM 706 may manage the VNFs 708. The VNFs 708 may be used to execute EPC components/functions. The VNFM 706 may manage the life cycle of the VNFs 708 and track performance, fault and security of the virtual aspects of VNFs 708.

The EM 710 may track the performance, fault and security of the functional aspects of VNFs 708. The tracking data from the VNFM 706 and the EM 710 may comprise, for example, PM data used by the VIM 702 or the NFVI 704. Both the VNFM 706 and the EM 710 can scale up/down the quantity of VNFs of the system 700.

[0210] The NFVO 712 may coordinate, authorize, release and engage resources of the NFVI 704 in order to provide the requested service (e.g., to execute an EPC function, component, or slice). The NM 714 may provide a package of end-user functions with the responsibility for the management of a network, which may include network elements with VNFs, non-virtualized network functions, or both (management of the VNFs may occur via the EM 710).

[0211] Figure 8 is a block diagram illustrating components, according to some example embodiments, able to read instructions from a machine-readable or computer-readable medium (e.g., a non-transitory machine-readable storage medium) and perform any one or more of the methodologies discussed herein. Specifically, Figure 8 shows a diagrammatic representation of hardware resources 800 including one or more processors (or processor cores) 810, one or more memory/storage devices 820, and one or more communication resources 830, each of which may be communicatively coupled via a bus 840. For embodiments where node virtualization (e.g., NFV) is utilized, a hypervisor 802 may be executed to provide an execution environment for one or more network slices/sub-slices to utilize the hardware resources 800.

[0212] The processors 810 may include, for example, a processor 812 and a processor 814. The processor(s) 810 may be, for example, a central processing unit (CPU), a reduced instruction set computing (RISC) processor, a complex instruction set computing (CISC) processor, a graphics processing unit (GPU), a DSP such as a baseband processor, an ASIC, an FPGA, a radio-frequency integrated circuit (RFIC), another processor (including those discussed herein), or any suitable combination thereof.

[0213] The memory/storage devices 820 may include main memory, disk storage, or any suitable combination thereof. The memory/storage devices 820 may include, but are not limited to, any type of volatile or nonvolatile memory such as dynamic random access memory (DRAM), static random access memory (SRAM), erasable programmable read-only memory (EPROM), electrically erasable programmable read-only memory (EEPROM), Flash memory, solid-state storage, etc.

[0214] The communication resources 830 may include interconnection or network interface components or other suitable devices to communicate with one or more peripheral devices 804 or one or more databases 806 via a network 808. For example, the communication resources 830 may include wired communication components (e.g., for coupling via USB), cellular communication components, NFC components, Bluetooth® (or Bluetooth® Low Energy) components, Wi-Fi® components, and other communication components.

[0215] Instructions 850 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 810 to perform any one or more of the methodologies discussed herein. The instructions 850 may reside, completely or partially, within at least one of the processors 810 (e.g., within the processor's cache memory), the memory/storage devices 820, or any suitable combination thereof. Furthermore, any portion of the instructions 850 may be transferred to the hardware resources 800 from any combination of the peripheral devices 804 or the databases 806. Accordingly, the memory of processors 810, the memory/storage devices 820, the peripheral devices 804, and the databases 806 are examples of computer-readable and machine-readable media.

EXAMPLE PROCEDURES

[0216] In some embodiments, the electronic device(s), network(s), system(s), chip(s) or component(s), or portions or implementations thereof, of Figures 1-8 or some other figure herein, may be configured to perform one or more processes, techniques, or methods as described herein, or portions thereof. One such process is depicted in Figure 9. For example, the process may include a method of supporting edge computing in a 3GPP network, comprising: receiving or causing to receive a request to provide information indicating that an edge computing related resource in a local data network (DN) is to be coupled to one or more user plane functions (UPFs), wherein the request comprises a location of the local DN and a quality of service (QoS) requirement on an N6 interface (step 902); and identifying or causing to identify, from the one or more preexisting UPFs, a first UPF, wherein data transport between the first UPF and the local DN meets the QoS requirement on the N6 interface (step 904); deploying or causing to deploy a second UPF in response to determining that the first UPF cannot be identified from the one or more

UPFs, wherein data transport between the second UPF and the local DN meets the QoS requirement on the N6 interface (step 906); and communicating or causing to communicate information associated with one or more of the first UPF and the second UPF to the edge computing management system (step 908).

[0217] It is to be appreciated that Figure 9 is an illustration of one example of a process set forth herein. There may be other processes, methods, or techniques set forth herein that have not be shown using an illustration (e.g., a flow chart, etc.).

[0218] For one or more embodiments, at least one of the component(s), device(s), system(s), or portions thereof that are set forth in one or more of the preceding figures may be configured to perform one or more operations, techniques, processes, and/or methods as set forth in the example section below. For example, the baseband circuitry as described above in connection with one or more of the preceding figures may be configured to operate in accordance with one or more of the examples set forth below. For another example, circuitry associated with a UE, base station, network element, etc. as described above in connection with one or more of the preceding figures may be configured to operate in accordance with one or more of the examples set forth below in the example section. For yet another example, an apparatus may be configured to operate in accordance with one or more of the examples set forth below. For one more example, an apparatus may comprise means for operating in accordance with one or more of the examples set forth below in the example section.

EXAMPLES

[0219] The examples set forth herein are illustrative and not exhaustive.

[0220] Example 1 may include the 3GPP management system comprising one or more processors that are configured to:

receive a request from edge computing management system to provide the information of UPF to which the edge computing related resources in the local data network can be connected; and

identify the UPF where the data transport between UPF and local data network can meet the QoS requirements on the N6 interface; and

deploy a new UPF, if such UPF cannot be located from the above step; and

provide the information of UPF(s) to the edge computing management system.

[0221] Example 2 may include the method of example 1 or some other example herein, wherein the request edge computing management system sent are with the location of local data network and the QoS requirements on the N6 interface.

[0222] Example 3 may include the method of examples 1 and 2 or some other example herein, wherein 3GPP management system uses the local data network location to find the UPF where the data transport between UPF and local data network can meet the QoS requirements on the N6 interface.

[0223] Example 4 may include the 3GPP management system comprising one or more processors is configured:

receive a request from edge computing management system to provide the 3GPP performance measurements that are relevant to edge computing; and

collect and reports the 3GPP performance measurements to the Edge computing management system; and

receive a request from edge computing management system to subscribe to the alarm notifications that are relevant to the edge computing.

detect an alarm, and send the alarm notifications related to the edge computing to the edge computing management system; and

receive a request from edge computing management system to provide the connection information (e.g. IP address) of the PCF or NEF to which the AF can communicate to influence traffic routing; and

provide the connection information (e.g. IP address) of the PCF or NEF to the edge computing management system.

[0224] Example 5 may include the edge computing management system comprising one or more processors is configured:

send a request to 3GPP management system to provide the 3GPP performance measurements that are relevant to edge computing; and

receive the 3GPP performance measurements from the 3GPP management system; and

send a request to 3GPP management system to subscribe to the alarm notifications that are relevant to the edge computing.

detect an alarm, and send the alarm notifications related to the edge computing to the 3GPP management system; and send a request to 3GPP management system to provide the connection information (e.g. IP address) of the PCF or NEF to which the AF can communicate to influence traffic routing; and

receive the connection information (e.g. IP address) of the PCF or NEF from the 3GPP management system.

[0225] Example 6 may include the 3GPP management system comprising one or more processors is configured:

send a request to NFVO to instantiate the NS identified by nsInstanceId, with the parameter additionalParamForVnf providing the information for the UPF, and parameter locationConstraints indicating the constraints on where the UPF will be located; and

receive from NFVO a NS LCM Operation Occurrence Notification indicating the start of NS instantiation procedure; and

receive from NFVO a NS LCM Operation Occurrence Notification with the result of NS instantiation, including vnfInstanceId to indicate the UPF instance that has been instantiated.

[0226] Example 7 may include the method of example 6 or some other example herein, wherein upon receiving from NFVO a notification indicating the UPF instance that has been instantiated, 3GPP management system consumes Provisioning for NF service with createMOIAttributes operation to create the UPFFunction IOC for the UPF instance.

[0227] Example 8 may include the 3GPP management system comprising one or more processors is configured:

use Provisioning for NF service with modifyMOIAttributes operation to configure the SMF – SMFFunction with the UPF provisioning information in order to add the UPF to the available UPF list;

use Provisioning for NF service with modifyMOIAttributes operation to configure SMF with the UPF identifier of the UPF to be removed from the available UPF list;

use Provisioning for NF service with modifyMOIAttributes operation to configure the NRF – NRFFunction with the available UPF; and

use Provisioning for NF service with createMOIAttributes operation to create EP_SBI_X IOC contained by UPFFunction IOC that is used by UPF to communicate with NRF.

[0228] Example 9 may include a method of supporting edge computing in a Third Generation Partnership Project (3GPP) network, comprising:

receiving or causing to receive a request to provide information indicating that an edge computing related resource in a local data network (DN) is to be coupled to one or more user plane functions (UPFs), wherein the request comprises a location of the local DN and a quality of service (QoS) requirement on an N6 interface;

identifying or causing to identify, from the one or more UPFs, a first UPF, wherein data transport between the first UPF and the local DN meets the QoS requirement on the N6 interface;

deploying or causing to deploy a second UPF in response to determining that the first UPF cannot be identified from the one or more UPFs, wherein data transport between the second UPF and the local DN meets the QoS requirement on the N6 interface; and

communicating or causing to communicate information associated with one or more of the first UPF and the second UPF to the edge computing management system.

[0229] Example 10 may include the method of example 9 or some other example herein, wherein the request is provided within the location of the local DN and wherein the request is in compliance with the QoS requirement on the N6 interface.

[0230] Example 11 may include the method of example 9 or some other example herein, further comprising:

locating or causing to locate the first UPF based on the location of the local DN.

[0231] Example 12 may include a method of supporting edge computing in a 3GPP network, comprising:

receiving or causing to receive a request to provide a 3GPP performance measurement that is associated with edge computing;

transmitting or causing to transmit the 3GPP performance measurement; and

receiving or causing to receive a request to subscribe to an alarm notification associated with edge computing;

detecting or causing to detect an alarm;

transmitting or causing to transmit the alarm notification;

receiving or causing to receive a request to provide connection information of a policy function (PCF) or a network exposure function (NEF) to which an AF can communicate to influence traffic routing; and

transmitting or causing to transmit the connection information of the PCF or the NEF to the edge computing management system.

[0232] Example 13 may include a method of supporting edge computing in a 3GPP network, comprising:

transmitting or causing to transmit a request to provide a 3GPP performance measurement that is associated with edge computing;

receiving or causing to receive the 3GPP performance measurement;

transmitting or causing to transmit a request to subscribe to an alarm notification associated with edge computing;

receiving or causing to receive the alarm notification;

transmitting or causing to transmit a request to provide connection information of a policy function (PCF) or a network exposure function (NEF) to which an AF can communicate to influence traffic routing; and

receiving or causing to receive the connection information of the PCF or the NEF from the 3GPP management system.

[0233] Example 14 may include a method of supporting edge computing in a 3GPP network, comprising:

transmitting or causing to transmit a request to a network functions virtualization (NFV) orchestrator (NFVO) to instantiate a network service (NS) with a first parameter that provides information for a user plane function (UPF) and a second parameter that indicates a constraint on where the UPF can be located;

receiving or causing to receive, from the NFVO, a first notification indicating a start of an NS instantiation procedure; and

receiving or causing to receive, from the NFVO, a second notification with a result of the NS instantiation procedure to indicate that the UPF has been instantiated.

[0234] Example 15 may include the method of example 14 or some other example herein, further comprising:

creating or causing to create a UPFFunction IOC for the UPF in response to receiving the second notification.

[0235] Example 16 may include the method of example 14 or some other example herein, further comprising:

transmitting or causing to transmit a request to the NFVO to terminate the instantiated UPF;

receiving or causing to receive, from the NFVO, a third notification indicating a start of an NS termination procedure; and

receiving or causing to receive, from the NFVO, a fourth notification with a result of the NS termination procedure to indicate the UPF has been terminated.

[0236] Example 17 may include a method of supporting edge computing in a 3GPP network, comprising:

configuring or causing to configure a session management function (SMF) with provisioning information associated with a UPF; and

adding or causing to add the UPF to a list of UPFs.

[0237] Example 18 may include the method of example 17 or some other example herein, further comprising:

configuring or causing configure the SMF with an identifier of a second UPF; and

removing or causing to remove the second UPF from the list of UPFs.

[0238] Example 19 may include a method of supporting edge computing in a 3GPP network, comprising:

configuring or causing configure a NF Repository Function (NRF) with an available UPF;

connecting or causing to connect the available UPF with the NRF; and

transmitting or causing to transmit a notification message to one or more SMFs having a subscription to the NRF, the subscription matching UPF provisioning information of the available UPF.

[0239] Example 20 may include an apparatus for use in supporting edge computing in a 3GPP network, comprising:

means for receiving a request to provide information indicating that an edge computing related resource in a local data network (DN) is to be coupled to one or more user plane functions (UPFs), wherein the request comprises a location of the local DN and a quality of service (QoS) requirement on an N6 interface;

means for identifying, from the one or more UPFs, a first UPF, wherein data transport between the first UPF and the local DN meets the QoS requirement on the N6 interface;

means for deploying a second UPF in response to determining that the first UPF cannot be identified from the one or more UPFs, wherein data transport between the second UPF and the local DN meets the QoS requirement on the N6 interface; and

means for communicating information associated with one or more of the first UPF and the second UPF to the edge computing management system.

[0240] Example 21 may include the apparatus of example 20 or some other example herein, wherein the request is provided within the location of the local DN and wherein the request is in compliance with the QoS requirement on the N6 interface.

[0241] Example 22 may include the apparatus of example 20 or some other example herein, further comprising:

means for locating the first UPF based on the location of the local DN.

[0242] Example 23 may include an apparatus for use in supporting edge computing in a 3GPP network, comprising:

means for receiving a request to provide a 3GPP performance measurement that is associated with edge computing;

means for transmitting the 3GPP performance measurement;

means for receiving a request to subscribe to an alarm notification associated with edge computing;

means for detecting an alarm;

means for transmitting the alarm notification;

means for receiving a request to provide connection information of a policy function (PCF) or a network exposure function (NEF) to which an AF can communicate to influence traffic routing; and

means for transmitting the connection information of the PCF or the NEF to the edge computing management system.

[0243] Example 24 may include an apparatus for use in supporting edge computing in a 3GPP network, comprising:

means for transmitting a request to provide a 3GPP performance measurement that is associated with edge computing;

means for receiving the 3GPP performance measurement;

means for transmitting a request to subscribe to an alarm notification associated with edge computing;

means for receiving the alarm notification;

means for transmitting a request to provide connection information of a policy function (PCF) or a network exposure function (NEF) to which an AF can communicate to influence traffic routing; and

means for receiving the connection information of the PCF or the NEF from the 3GPP management system.

[0244] Example 25 may include an apparatus for use in supporting edge computing in a 3GPP network, comprising:

means for transmitting a request to a network functions virtualization (NFV) orchestrator (NFVO) to instantiate a network service (NS) with a first parameter that provides information for a user plane function (UPF) and a second parameter that indicates a constraint on where the UPF can be located;

means for receiving, from the NFVO, a first notification indicating a start of an NS instantiation procedure; and

means for receiving, from the NFVO, a second notification with a result of the NS instantiation procedure to indicate that the UPF has been instantiated.

[0245] Example 26 may include the apparatus of example 25 or some other example herein, further comprising:

means for creating or causing to create a UPFFunction IOC for the UPF in response to receiving the second notification.

[0246] Example 27 may include the apparatus of example 25 or some other example herein, further comprising:

means for transmitting a request to the NFVO to terminate the instantiated UPF;

means for receiving, from the NFVO, a third notification indicating a start of an NS termination procedure; and

means for receiving, from the NFVO, a fourth notification with a result of the NS termination procedure to indicate the UPF has been terminated.

[0247] Example 28 may include an apparatus for use in supporting edge computing in a 3GPP network, comprising:

means for configuring a session management function (SMF) with provisioning information associated with a UPF; and

means for adding the UPF to a list of UPFs.

[0248] Example 29 may include the apparatus of example 28 or some other example herein, further comprising:

means for configuring the SMF with an identifier of a second UPF; and

means for removing the second UPF from the list of UPFs.

[0249] Example 30 may include an apparatus for use in supporting edge computing in a 3GPP network, comprising:

means for configuring a NF Repository Function (NRF) with an available UPF;

means for connecting the available UPF with the NRF; and

means for transmitting a notification message to one or more SMFs having a subscription to the NRF, the subscription matching UPF provisioning information of the available UPF.

[0250] Example 31 may include an apparatus for use in supporting edge computing in a 3GPP network, configured to:

receive a request to provide information indicating that an edge computing related resource in a local data network (DN) is to be coupled to one or more user plane functions (UPFs), wherein the request comprises a location of the local DN and a quality of service (QoS) requirement on an N6 interface;

identify, from the one or more UPFs, a first UPF, wherein data transport between the first UPF and the local DN meets the QoS requirement on the N6 interface;

deploy a second UPF in response to determining that the first UPF cannot be identified from the one or more UPFs, wherein data transport between the second UPF and the local DN meets the QoS requirement on the N6 interface; and

communicate information associated with one or more of the first UPF and the second UPF to the edge computing management system.

[0251] Example 32 may include the apparatus of example 20 or some other example herein, wherein the request is provided within the location of the local DN and wherein the request is in compliance with the QoS requirement on the N6 interface.

[0252] Example 33 may include the apparatus of example 20 or some other example herein, wherein the apparatus is further configured to:

locate the first UPF based on the location of the local DN.

[0253] Example 34 may include an apparatus for use in supporting edge computing in a 3GPP network, configured to:

receive a request to provide a 3GPP performance measurement that is associated with edge computing; and

transmit the 3GPP performance measurement; and

receive a request to subscribe to an alarm notification associated with edge computing.

detect an alarm;

transmit the alarm notification;

receive a request to provide connection information of a policy function (PCF) or a network exposure function (NEF) to which an AF can communicate to influence traffic routing; and

transmit the connection information of the PCF or the NEF to the edge computing management system.

[0254] Example 35 may include an apparatus for use in supporting edge computing in a 3GPP network, configured to:

transmit a request to provide a 3GPP performance measurement that is associated with edge computing; and

receive the 3GPP performance measurement;

transmit a request to subscribe to an alarm notification associated with edge computing;

receive the alarm notification;

transmit a request to provide connection information of a policy function (PCF) or a network exposure function (NEF) to which an AF can communicate to influence traffic routing; and

receive the connection information of the PCF or the NEF from the 3GPP management system.

[0255] Example 36 may include an apparatus for use in supporting edge computing in a 3GPP network, configured to:

transmit a request to a network functions virtualization (NFV) orchestrator (NFVO) to instantiate a network service (NS) with a first parameter that provides information for a user plane function (UPF) and a second parameter that indicates a constraint on where the UPF can be located;

receive, from the NFVO, a first notification indicating a start of an NS instantiation procedure; and

receive, from the NFVO, a second notification with a result of the NS instantiation procedure to indicate that the UPF has been instantiated.

[0256] Example 37 may include the apparatus of example 25 or some other example herein, wherein the apparatus is further configured to:

create a UPFFunction IOC for the UPF in response to receiving the second notification.

[0257] Example 38 may include the apparatus of example 25 or some other example herein, wherein the apparatus is further configured to:

transmit a request to the NFVO to terminate the instantiated UPF;

receive, from the NFVO, a third notification indicating a start of an NS termination procedure; and

receive, from the NFVO, a fourth notification with a result of the NS termination procedure to indicate the UPF has been terminated.

[0258] Example 39 may include an apparatus for use in supporting edge computing in a 3GPP network, configured to:

configure a session management function (SMF) with provisioning information associated with a UPF; and

add the UPF to a list of UPFs.

[0259] Example 40 may include the apparatus of example 28 or some other example herein, wherein the apparatus is further configured to:

configure the SMF with an identifier of a second UPF; and

remove the second UPF from the list of UPFs.

[0260] Example 41 may include an apparatus for use in supporting edge computing in a 3GPP network, configured to:

configure a NF Repository Function (NRF) with an available UPF;

connect the available UPF with the NRF; and

transmit a notification message to one or more SMFs having a subscription to the NRF, the subscription matching UPF provisioning information of the available UPF.

[0261] Example 42 may include an apparatus comprising means to perform one or more elements of a method described in or related to any of examples 1-41, or any other method or process described herein.

[0262] Example 43 may include one or more non-transitory computer-readable media comprising instructions to cause an electronic device, upon execution of the instructions by one or more processors of the electronic device, to perform one or more elements of a method described in or related to any of examples 1-41, or any other method or process described herein.

[0263] Example 44 may include an apparatus comprising logic, modules, or circuitry to perform one or more elements of a method described in or related to any of examples 1-41, or any other method or process described herein.

[0264] Example 45 may include a method, technique, or process as described in or related to any of examples 1-41, or portions or parts thereof.

[0265] Example 46 may include an apparatus comprising: one or more processors and one or more computer-readable media comprising instructions that, when executed by the one or more processors, cause the one or more processors to perform the method, techniques, or process as described in or related to any of examples 1-41, or portions thereof.

[0266] Example 47 may include a signal as described in or related to any of examples 1-41, or portions or parts thereof.

[0267] Example 48 may include a signal in a wireless network as shown and described herein.

[0268] Example 49 may include a method of communicating in a wireless network as shown and described herein.

[0269] Example 50 may include a system for providing wireless communication as shown and described herein.

[0270] Example 51 may include a device for providing wireless communication as shown and described herein.

[0271] Example 52 may include an apparatus comprising means for performing one or more of the methods described above in connection with examples 1-51.

[0272] Example 53 may include an apparatus comprising circuitry configured to perform one or more of the methods described above in connection with examples 1-51.

[0273] Example 54 may include an apparatus according to any of any one of examples 1-51, wherein the apparatus or any portion thereof is implemented in or by a user equipment (UE).

[0274] Example 55 may include a method according to any of any one of examples 1-51, wherein the method or any portion thereof is implemented in or by a user equipment (UE).

[0275] Example 56 may include an apparatus according to any of any one of examples 1-51, wherein the apparatus or any portion thereof is implemented in or by a base station (BS).

[0276] Example 57 may include a method according to any of any one of examples 1-51, wherein the method or any portion thereof is implemented in or by a BS.

[0277] Example 58 may include the method of example 7, wherein the UPFFunction IOC in NRM should contain the NRF identity to contact for registration and UPF Provisioning Information.

[0278] Example 59 may include the method of example 8, wherein the SMFFunction IOC in NRM should contain a list of (S-NSSAI, DNN) and a SMF Area Identity the UPF can serve.

[0279] Any of the above-described examples may be combined with any other example (or combination of examples), unless explicitly stated otherwise. The foregoing description of one or more implementations provides illustration and description, but is not intended to be exhaustive or to limit the scope of embodiments to the precise form disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from practice of various embodiments.

[0280] Any of the above-described examples may be combined with any other example (or combination of examples), unless explicitly stated otherwise. The foregoing description of one or more implementations provides illustration and description, but is not intended to be exhaustive or to limit the scope of embodiments to the precise form disclosed. Modifications and variations are possible in light of the above teachings or may be acquired from practice of various embodiments.

Abbreviations

[0281] For the purposes of the present document, the following abbreviations may apply to the examples and embodiments discussed herein.

3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
5GC	5G Core network
ACK	Acknowledgement
AF	Application Function
AM	Acknowledged Mode
AMBR	Aggregate Maximum Bit Rate
AMF	Access and Mobility Management Function
AN	Access Network
ANR	Automatic Neighbour Relation
AP	Application Protocol, Antenna Port, Access Point
API	Application Programming Interface
APN	Access Point Name
ARP	Allocation and Retention Priority
ARQ	Automatic Repeat Request
AS	Access Stratum
ASN.1	Abstract Syntax Notation One
AUSF	Authentication Server Function
AWGN	Additive White Gaussian Noise
BCH	Broadcast Channel
BER	Bit Error Ratio
BFD	Beam Failure Detection
BLER	Block Error Rate
BPSK	Binary Phase Shift Keying
BRAS	Broadband Remote Access Server
BSS	Business Support System
BS	Base Station
BSR	Buffer Status Report
BW	Bandwidth
BWP	Bandwidth Part
C-RNTI	Cell Radio Network Temporary Identity

CA	Carrier Aggregation, Certification Authority
CAPEX	CAPital EXpenditureCBRA Contention Based Random Access
CC	Component Carrier, Country Code, Cryptographic Checksum
CCA	Clear Channel Assessment
CCE	Control Channel Element
CCCH	Common Control Channel
CE	Coverage Enhancement
CDM	Content Delivery Network
CDMA	Code-Division Multiple Access
CFRA	Contention Free Random Access
CG	Cell Group
CI	Cell Identity
CID	Cell-ID (e.g., positioning method)
CIM	Common Information Model
CIR	Carrier to Interference Ratio
CK	Cipher Key
CM	Connection Management, Conditional Mandatory
CMAS	Commercial Mobile Alert Service
CMD	Command
CMS	Cloud Management System
CO	Conditional Optional
CoMP	Coordinated Multi-Point
CORESET	Control Resource Set
COTS	Commercial Off-The-Shelf
CP	Control Plane, Cyclic Prefix, Connection Point
CPD	Connection Point Descriptor
CPE	Customer Premise Equipment
CPICH	Common Pilot Channel
CQI	Channel Quality Indicator
CPU	CSI processing unit, Central Processing Unit
C/R	Command/Response field bit
CRAN	Cloud Radio Access Network, Cloud RAN

CRB	Common Resource Block
CRC	Cyclic Redundancy Check
CRI	Channel-State Information Resource Indicator, CSI-RS Resource Indicator
C-RNTI	Cell RNTI
CS	Circuit Switched
CSAR	Cloud Service Archive
CSI	Channel-State Information
CSI-IM	CSI Interference Measurement
CSI-RS	CSI Reference Signal
CSI-RSRP	CSI reference signal received power
CSI-RSRQ	CSI reference signal received quality
CSI-SINR	CSI signal-to-noise and interference ratio
CSMA	Carrier Sense Multiple Access
CSMA/CA	CSMA with collision avoidance
CSS	Common Search Space, Cell-specific Search Space
CTS	Clear-to-Send
CW	Codeword
CWS	Contention Window Size
D2D	Device-to-Device
DC	Dual Connectivity, Direct Current
DCI	Downlink Control Information
DF	Deployment Flavour
DL	Downlink
DMTF	Distributed Management Task Force
DPDK	Data Plane Development Kit
DM-RS, DMRS	Demodulation Reference Signal
DN	Data network
DRB	Data Radio Bearer
DRS	Discovery Reference Signal
DRX	Discontinuous Reception
DSL	Domain Specific Language. Digital Subscriber Line

DSLAM	DSL Access Multiplexer
DwPTS	Downlink Pilot Time Slot
E-LAN	Ethernet Local Area Network
E2E	End-to-End
ECCA	extended clear channel assessment, extended CCA
ECCE	Enhanced Control Channel Element, Enhanced CCE
ED	Energy Detection
EDGE	Enhanced Datarates for GSM Evolution (GSM Evolution)
EGMF	Exposure Governance Management Function
EGPRS	Enhanced GPRS
EIR	Equipment Identity Register
eLAA	enhanced Licensed Assisted Access, enhanced LAA
EM	Element Manager
eMBB	Enhanced Mobile Broadband
EMS	Element Management System
eNB	evolved NodeB, E-UTRAN Node B
EN-DC	E-UTRA-NR Dual Connectivity
EPC	Evolved Packet Core
EPDCCH	enhanced PDCCH, enhanced Physical Downlink Control Cannel
EPRE	Energy per resource element
EPS	Evolved Packet System
EREG	enhanced REG, enhanced resource element groups
ETSI	European Telecommunications Standards Institute
ETWS	Earthquake and Tsunami Warning System
eUICC	embedded UICC, embedded Universal Integrated Circuit Card
E-UTRA	Evolved UTRA
E-UTRAN	Evolved UTRAN
EV2X	Enhanced V2X
F1AP	F1 Application Protocol
F1-C	F1 Control plane interface
F1-U	F1 User plane interface
FACCH	Fast Associated Control CHannel

FACCH/F	Fast Associated Control Channel/Full rate
FACCH/H	Fast Associated Control Channel/Half rate
FACH	Forward Access Channel
FAUSCH	Fast Uplink Signalling Channel
FB	Functional Block
FBI	Feedback Information
FCC	Federal Communications Commission
FCCH	Frequency Correction CHannel
FDD	Frequency Division Duplex
FDM	Frequency Division Multiplex
FDMA	Frequency Division Multiple Access
FE	Front End
FEC	Forward Error Correction
FFS	For Further Study
FFT	Fast Fourier Transformation
feLAA	further enhanced Licensed Assisted Access, further enhanced LAA
FN	Frame Number
FPGA	Field-Programmable Gate Array
FR	Frequency Range
G-RNTI	GERAN Radio Network Temporary Identity
GERAN	GSM EDGE RAN, GSM EDGE Radio Access Network
GGSN	Gateway GPRS Support Node
GLONASS	GLObal'naya NAvigatsionnaya Sputnikovaya Sistema (Engl.: Global Navigation Satellite System)
gNB	Next Generation NodeB
gNB-CU	gNB-centralized unit, Next Generation NodeB centralized unit
gNB-DU	gNB-distributed unit, Next Generation NodeB distributed unit
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications, Groupe Spécial Mobile
GTP	GPRS Tunneling Protocol

GTP-U	GPRS Tunnelling Protocol for User Plane
GTS	Go To Sleep Signal (related to WUS)
GUMMEI	Globally Unique MME Identifier
GUTI	Globally Unique Temporary UE Identity
HARQ	Hybrid ARQ, Hybrid Automatic Repeat Request
HANDO, HO	Handover
HFN	HyperFrame Number
HHO	Hard Handover
HLR	Home Location Register
HN	Home Network
HO	Handover
HPLMN	Home Public Land Mobile Network
HSDPA	High Speed Downlink Packet Access
HSN	Hopping Sequence Number
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
HTTP	Hyper Text Transfer Protocol
HTTPS	Hyper Text Transfer Protocol Secure (https is http/1.1 over SSL, i.e. port 443)
I-Block	Information Block
ICCID	Integrated Circuit Card Identification
ICIC	Inter-Cell Interference Coordination
ID	Identity, identifier
IDFT	Inverse Discrete Fourier Transform
IE	Information element
IBE	In-Band Emission
IEEE	Institute of Electrical and Electronics Engineers
IEI	Information Element Identifier
IEIDL	Information Element Identifier Data Length
IETF	Internet Engineering Task Force
IF	Infrastructure

IM	Interference Measurement, Intermodulation, IP Multimedia
IMC	IMS Credentials
IMEI	International Mobile Equipment Identity
IMGI	International mobile group identity
IMPI	IP Multimedia Private Identity
IMPU	IP Multimedia PUblic identity
IMS	IP Multimedia Subsystem
IMSI	International Mobile Subscriber Identity
IoT	Internet of Things
IP	Internet Protocol
Ipsec	IP Security, Internet Protocol Security
IP-CAN	IP-Connectivity Access Network
IP-M	IP Multicast
IPv4	Internet Protocol Version 4
IPv6	Internet Protocol Version 6
IR	Infrared
IS	In Sync
IRP	Integration Reference Point
ISDN	Integrated Services Digital Network
ISIM	IM Services Identity Module
ISO	International Organisation for Standardisation
ISP	Internet Service Provider
IWF	Interworking-Function
I-WLAN	Interworking WLAN
K	Constraint length of the convolutional code, USIM Individual key
kB	Kilobyte (1000 bytes)
kbps	kilo-bits per second
Kc	Ciphering key
Ki	Individual subscriber authentication key
KPI	Key Performance Indicator
KQI	Key Quality Indicator
KSI	Key Set Identifier

ksps	kilo-symbols per second
KVM	Kernel Virtual Machine
L1	Layer 1 (physical layer)
L1-RSRP	Layer 1 reference signal received power
L2	Layer 2 (data link layer)
L3	Layer 3 (network layer)
LAA	Licensed Assisted Access
LAN	Local Area Network
LBT	Listen Before Talk
LCM	LifeCycle Management
LCR	Low Chip Rate
LCS	Location Services
LCID	Logical Channel ID
LI	Layer Indicator
LLC	Logical Link Control, Low Layer Compatibility
LPLMN	Local PLMN
LPP	LTE Positioning Protocol
LSB	Least Significant Bit
LTE	Long Term Evolution
LWA	LTE-WLAN aggregation
LWIP	LTE/WLAN Radio Level Integration with IPsec Tunnel
LTE	Long Term Evolution
M2M	Machine-to-Machine
MAC	Medium Access Control (protocol layering context)
MAC	Message authentication code (security/encryption context)
MAC-A	MAC used for authentication and key agreement (TSG T WG3 context)
MAC-I	MAC used for data integrity of signalling messages (TSG T WG3 context)
MANO	Management and Orchestration
MBMS	Multimedia Broadcast and Multicast Service
MBSFN	Multimedia Broadcast multicast service Single Frequency Network

MCC	Mobile Country Code
MCG	Master Cell Group
MCOT	Maximum Channel Occupancy Time
MCS	Modulation and coding scheme
MDAF	Management Data Analytics Function
MDAS	Management Data Analytics Service
MDT	Minimization of Drive Tests
ME	Mobile Equipment
MeNB	master eNB
MER	Message Error Ratio
MGL	Measurement Gap Length
MGRP	Measurement Gap Repetition Period
MIB	Master Information Block, Management Information Base
MIMO	Multiple Input Multiple Output
MLC	Mobile Location Centre
MM	Mobility Management
MME	Mobility Management Entity
MN	Master Node
MO	Measurement Object, Mobile Originated
MPBCH	MTC Physical Broadcast CHannel
MPDCCH	MTC Physical Downlink Control CHannel
MPDSCH	MTC Physical Downlink Shared CHannel
MPRACH	MTC Physical Random Access CHannel
MPUSCH	MTC Physical Uplink Shared Channel
MPLS	MultiProtocol Label Switching
MS	Mobile Station
MSB	Most Significant Bit
MSC	Mobile Switching Centre
MSI	Minimum System Information, MCH Scheduling Information
MSID	Mobile Station Identifier
MSIN	Mobile Station Identification Number
MSISDN	Mobile Subscriber ISDN Number

MT	Mobile Terminated, Mobile Termination
MTC	Machine-Type Communications
mMTC	massive MTC, massive Machine-Type Communications
MU-MIMO	Multi User MIMO
MWUS	MTC wake-up signal, MTC WUS
NACK	Negative Acknowledgement
NAI	Network Access Identifier
NAS	Non-Access Stratum, Non-Access Stratum layer
NCT	Network Connectivity Topology
NEC	Network Capability Exposure
NE-DC	NR-E-UTRA Dual Connectivity
NEF	Network Exposure Function
NF	Network Function
NFP	Network Forwarding Path
NFPD	Network Forwarding Path Descriptor
NFV	Network Functions Virtualization
NFVI	NFV Infrastructure
NFVO	NFV Orchestrator
NG	Next Generation, Next Gen
NGEN-DC	NG-RAN E-UTRA-NR Dual Connectivity
NM	Network Manager
NMS	Network Management System
N-PoP	Network Point of Presence
NMIB, N-MIB	Narrowband MIB
NPBCH	Narrowband Physical Broadcast CHannel
NPDCCH	Narrowband Physical Downlink Control CHannel
NPDSCH	Narrowband Physical Downlink Shared CHannel
NPRACH	Narrowband Physical Random Access CHannel
NPUSCH	Narrowband Physical Uplink Shared CHannel
NPSS	Narrowband Primary Synchronization Signal
NSSS	Narrowband Secondary Synchronization Signal
NR	New Radio, Neighbour Relation

NRF	NF Repository Function
NRS	Narrowband Reference Signal
NS	Network Service
NSA	Non-Standalone operation mode
NSD	Network Service Descriptor
NSR	Network Service Record
NSSAI	Network Slice Selection Assistance Information
S-NNSAI	Single-NSSAI
NSSF	Network Slice Selection Function
NW	Network
NWUS	Narrowband wake-up signal, Narrowband WUS
NZP	Non-Zero Power
O&M	Operation and Maintenance
ODU2	Optical channel Data Unit - type 2
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OOB	Out-of-band
OOS	Out of Sync
OPEX	OPerating EXpense
OSI	Other System Information
OSS	Operations Support System
OTA	over-the-air
PAPR	Peak-to-Average Power Ratio
PAR	Peak to Average Ratio
PBCH	Physical Broadcast Channel
PC	Power Control, Personal Computer
PCC	Primary Component Carrier, Primary CC
PCell	Primary Cell
PCI	Physical Cell ID, Physical Cell Identity
PCEF	Policy and Charging Enforcement Function
PCF	Policy Control Function
PCRF	Policy Control and Charging Rules Function

PDCP	Packet Data Convergence Protocol, Packet Data Convergence Protocol layer
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network, Public Data Network
PDSCH	Physical Downlink Shared Channel
PDU	Protocol Data Unit
PEI	Permanent Equipment Identifiers
PFD	Packet Flow Description
P-GW	PDN Gateway
PHICH	Physical hybrid-ARQ indicator channel
PHY	Physical layer
PLMN	Public Land Mobile Network
PIN	Personal Identification Number
PM	Performance Measurement
PMI	Precoding Matrix Indicator
PNF	Physical Network Function
PNFD	Physical Network Function Descriptor
PNFR	Physical Network Function Record
POC	PTT over Cellular
PP, PTP	Point-to-Point
PPP	Point-to-Point Protocol
PRACH	Physical RACH
PRB	Physical resource block
PRG	Physical resource block group
ProSe	Proximity Services, Proximity-Based Service
PRS	Positioning Reference Signal
PRR	Packet Reception Radio
PS	Packet Services
PSBCH	Physical Sidelink Broadcast Channel
PSDCH	Physical Sidelink Downlink Channel
PSCCH	Physical Sidelink Control Channel

PSSCH	Physical Sidelink Shared Channel
PSCell	Primary SCell
PSS	Primary Synchronization Signal
PSTN	Public Switched Telephone Network
PT-RS	Phase-tracking reference signal
PTT	Push-to-Talk
PUCCH	Physical Uplink Control Channel
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QCI	QoS class of identifier
QCL	Quasi co-location
QFI	QoS Flow ID, QoS Flow Identifier
QoS	Quality of Service
QPSK	Quadrature (Quaternary) Phase Shift Keying
QZSS	Quasi-Zenith Satellite System
RA-RNTI	Random Access RNTI
RAB	Radio Access Bearer, Random Access Burst
RACH	Random Access Channel
RADIUS	Remote Authentication Dial In User Service
RAN	Radio Access Network
RAND	RANDom number (used for authentication)
RAR	Random Access Response
RAT	Radio Access Technology
RAU	Routing Area Update
RB	Resource block, Radio Bearer
RBG	Resource block group
REG	Resource Element Group
Rel	Release
REQ	REQuest
RF	Radio Frequency
RI	Rank Indicator
RIV	Resource indicator value

RL	Radio Link
RLC	Radio Link Control, Radio Link Control layer
RLC AM	RLC Acknowledged Mode
RLC UM	RLC Unacknowledged Mode
RLF	Radio Link Failure
RLM	Radio Link Monitoring
RLM-RS	Reference Signal for RLM
RM	Registration Management
RMC	Reference Measurement Channel
RMSI	Remaining MSI, Remaining Minimum System Information
RN	Relay Node
RNC	Radio Network Controller
RNL	Radio Network Layer
RNTI	Radio Network Temporary Identifier
ROHC	RObust Header Compression
RRC	Radio Resource Control, Radio Resource Control layer
RRM	Radio Resource Management
RS	Reference Signal
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indicator
RSU	Road Side Unit
RSTD	Reference Signal Time difference
RTP	Real Time Protocol
RTS	Ready-To-Send
RTT	Round Trip Time
Rx	Reception, Receiving, Receiver
S1AP	S1 Application Protocol
S1-MME	S1 for the control plane
S1-U	S1 for the user plane
S-GW	Serving Gateway
S-RNTI	SRNC Radio Network Temporary Identity

S-TMSI	SAE Temporary Mobile Station Identifier
SA	Standalone operation mode
SAE	System Architecture Evolution
SAP	Service Access Point
SAPD	Service Access Point Descriptor
SAPI	Service Access Point Identifier
SCC	Secondary Component Carrier, Secondary CC
SCell	Secondary Cell
SC-FDMA	Single Carrier Frequency Division Multiple Access
SCG	Secondary Cell Group
SCM	Security Context Management
SCS	Subcarrier Spacing
SCTP	Stream Control Transmission Protocol
SDAP	Service Data Adaptation Protocol, Service Data Adaptation Protocol layer
SDL	Supplementary Downlink
SDNF	Structured Data Storage Network Function
SDP	Service Discovery Protocol (Bluetooth related)
SDSF	Structured Data Storage Function
SDU	Service Data Unit
SEAF	Security Anchor Function
SeNB	secondary eNB
SEPP	Security Edge Protection Proxy
SFI	Slot format indication
SFTD	Space-Frequency Time Diversity, SFN and frame timing difference
SFN	System Frame Number
SgNB	Secondary gNB
SGSN	Serving GPRS Support Node
S-GW	Serving Gateway
SI	System Information
SI-RNTI	System Information RNTI
SIB	System Information Block

SIM	Subscriber Identity Module
SIP	Session Initiated Protocol
SiP	System in Package
SL	Sidelink
SLA	Service Level Agreement
SM	Session Management
SMF	Session Management Function
SMS	Short Message Service
SMSF	SMS Function
SMTC	SSB-based Measurement Timing Configuration
SN	Secondary Node, Sequence Number
SoC	System on Chip
SON	Self-Organizing Network
SpCell	Special Cell
SP-CSI-RNTI	Semi-Persistent CSI RNTI
SPS	Semi-Persistent Scheduling
SQN	Sequence number
SR	Scheduling Request
SRB	Signalling Radio Bearer
SRS	Sounding Reference Signal
SS	Synchronization Signal
SSB	Synchronization Signal Block, SS/PBCH Block
SSBRI	SS/PBCH Block Resource Indicator, Synchronization Signal Block Resource Indicator
SSC	Session and Service Continuity
SS-RSRP	Synchronization Signal based Reference Signal Received Power
SS-RSRQ	Synchronization Signal based Reference Signal Received Quality
SS-SINR Ratio	Synchronization Signal based Signal to Noise and Interference
SSS	Secondary Synchronization Signal
SSSG	Search Space Set Group
SSSIF	Search Space Set Indicator

SST	Slice/Service Types
SU-MIMO	Single User MIMO
SUL	Supplementary Uplink
TA	Timing Advance, Tracking Area
TAC	Tracking Area Code
TAG	Timing Advance Group
TAU	Tracking Area Update
TB	Transport Block
TBS	Transport Block Size
TBD	To Be Defined
TCI	Transmission Configuration Indicator
TCP	Transmission Communication Protocol
TDD	Time Division Duplex
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TE	Terminal Equipment
TEID	Tunnel End Point Identifier
TFT	Traffic Flow Template
TMSI	Temporary Mobile Subscriber Identity
TNL	Transport Network Layer
TPC	Transmit Power Control
TPMI	Transmitted Precoding Matrix Indicator
TR	Technical Report
TRP, TRxP	Transmission Reception Point
TRS	Tracking Reference Signal
TRx	Transceiver
TS	Technical Specifications, Technical Standard
TTI	Transmission Time Interval
Tx	Transmission, Transmitting, Transmitter
U-RNTI	UTRAN Radio Network Temporary Identity
UART	Universal Asynchronous Receiver and Transmitter
UCI	Uplink Control Information

UE	User Equipment
UDM	Unified Data Management
UDP	User Datagram Protocol
UDSF	Unstructured Data Storage Network Function
UICC	Universal Integrated Circuit Card
UL	Uplink
UM	Unacknowledged Mode
UML	Unified Modelling Language
UMTS	Universal Mobile Telecommunications System
UP	User Plane
UPF	User Plane Function
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
URLLC	Ultra-Reliable and Low Latency
USB	Universal Serial Bus
USIM	Universal Subscriber Identity Module
USS	UE-specific search space
UTRA	UMTS Terrestrial Radio Access
UTRAN	Universal Terrestrial Radio Access Network
UwPTS	Uplink Pilot Time Slot
V2I	Vehicle-to-Infrastruction
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-everything
VIM	Virtualized Infrastructure Manager
VL	Virtual Link,
VLAN	Virtual LAN, Virtual Local Area Network
VM	Virtual Machine
VNF	Virtualized Network Function
VNFFG	VNF Forwarding Graph
VNFFGD	VNF Forwarding Graph Descriptor
VNFM	VNF Manager

VoIP	Voice-over-IP, Voice-over-Internet Protocol
VPLMN	Visited Public Land Mobile Network
VPN	Virtual Private Network
VRB	Virtual Resource Block
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WPAN	Wireless Personal Area Network
X2-C	X2-Control plane
X2-U	X2-User plane
XML	eXtensible Markup Language
XRES	EXpected user RESponse
XOR	eXclusive OR
ZC	Zadoff-Chu
ZP	Zero Power

Terminology

[0282] For the purposes of the present document, the following terms and definitions are applicable to the examples and embodiments discussed herein. However, these terms and definitions are not limiting.

[0283] The term "circuitry" as used herein refers to, is part of, or includes hardware components such as an electronic circuit, a logic circuit, a processor (shared, dedicated, or group) and/or memory (shared, dedicated, or group), an Application Specific Integrated Circuit (ASIC), a field-programmable device (FPD) (e.g., a field-programmable gate array (FPGA), a programmable logic device (PLD), a complex PLD (CPLD), a high-capacity PLD (HCPLD), a structured ASIC, or a programmable SoC), digital signal processors (DSPs), etc., that are configured to provide the described functionality. In some embodiments, the circuitry may execute one or more software or firmware programs to provide at least some of the described functionality. The term "circuitry" may also refer to a combination of one or more hardware elements (or a combination of circuits used in an electrical or electronic system) with the program code used to carry out the functionality of that program code. In these embodiments, the combination of hardware elements and program code may be referred to as a particular type of circuitry.

[0284] The term "processor circuitry" as used herein refers to, is part of, or includes circuitry capable of sequentially and automatically carrying out a sequence of arithmetic or logical operations, or recording, storing, and/or transferring digital data. The term "processor circuitry" may refer to one or more application processors, one or more baseband processors, a physical central processing unit (CPU), a single-core processor, a dual-core processor, a triple-core processor, a quad-core processor, and/or any other device capable of executing or otherwise operating computer-executable instructions, such as program code, software modules, and/or functional processes. The terms "application circuitry" and/or "baseband circuitry" may be considered synonymous to, and may be referred to as, "processor circuitry."

[0285] The term "interface circuitry" as used herein refers to, is part of, or includes circuitry that enables the exchange of information between two or more components or devices. The term "interface circuitry" may refer to one or more hardware interfaces, for example, buses, I/O interfaces, peripheral component interfaces, network interface cards, and/or the like.

[0286] The term "user equipment" or "UE" as used herein refers to a device with radio communication capabilities and may describe a remote user of network resources in a communications network. The term "user equipment" or "UE" may be considered synonymous to, and may be referred to as, client, mobile, mobile device, mobile terminal, user terminal, mobile unit, mobile station, mobile user, subscriber, user, remote station, access agent, user agent, receiver, radio equipment, reconfigurable radio equipment, reconfigurable mobile device, etc. Furthermore, the term "user equipment" or "UE" may include any type of wireless/wired device or any computing device including a wireless communications interface.

[0287] The term "network element" as used herein refers to physical or virtualized equipment and/or infrastructure used to provide wired or wireless communication network services. The term "network element" may be considered synonymous to and/or referred to as a networked computer, networking hardware, network equipment, network node, router, switch, hub, bridge, radio network controller, RAN device, RAN node, gateway, server, virtualized VNF, NFVI, and/or the like.

[0288] The term "computer system" as used herein refers to any type interconnected electronic devices, computer devices, or components thereof. Additionally, the term "computer system" and/or "system" may refer to various components of a computer that are communicatively coupled with one another. Furthermore, the term "computer system" and/or "system" may refer to multiple computer devices and/or multiple computing systems that are communicatively coupled with one another and configured to share computing and/or networking resources.

[0289] The term "appliance," "computer appliance," or the like, as used herein refers to a computer device or computer system with program code (e.g., software or firmware) that is specifically designed to provide a specific computing resource. A "virtual appliance" is a virtual machine image to be implemented by a hypervisor-equipped device that virtualizes or emulates a computer appliance or otherwise is dedicated to provide a specific computing resource.

[0290] The term "resource" as used herein refers to a physical or virtual device, a physical or virtual component within a computing environment, and/or a physical or virtual component within a particular device, such as computer devices, mechanical devices, memory space, processor/CPU time, processor/CPU usage, processor and accelerator loads, hardware time or usage, electrical power, input/output operations, ports or network sockets, channel/link allocation, throughput, memory usage, storage, network, database and applications, workload units, and/or the like. A "hardware resource" may refer to compute, storage, and/or network resources provided by physical hardware element(s). A "virtualized resource" may refer to compute, storage, and/or network resources provided by virtualization infrastructure to an application, device, system, etc. The term "network resource" or "communication resource" may refer to resources that are accessible by computer devices/systems via a communications network. The term "system resources" may refer to any kind of shared entities to provide services, and may include computing and/or network resources. System resources may be considered as a set of coherent functions, network data objects or services, accessible through a server where such system resources reside on a single host or multiple hosts and are clearly identifiable.

[0291] The term "channel" as used herein refers to any transmission medium, either tangible or intangible, which is used to communicate data or a data stream. The term "channel" may be synonymous with and/or equivalent to "communications channel," "data communications channel," "transmission channel," "data transmission channel," "access channel," "data access channel," "link," "data link," "carrier," "radiofrequency carrier," and/or any other like term denoting a pathway or medium through which data is communicated. Additionally, the term "link" as used herein refers to a connection between two devices through a RAT for the purpose of transmitting and receiving information.

[0292] The terms "instantiate," "instantiation," and the like as used herein refers to the creation of an instance. An "instance" also refers to a concrete occurrence of an object, which may occur, for example, during execution of program code.

[0293] The terms "coupled," "communicatively coupled," along with derivatives thereof are used herein. The term "coupled" may mean two or more elements are in direct physical or electrical contact with one another, may mean that two or more elements indirectly contact each other but still cooperate or interact with each other, and/or may mean that one or more other elements are coupled or connected between the elements that are said to be coupled with each other. The term "directly coupled" may mean that two or more elements are in direct contact with one another. The term "communicatively coupled" may mean that two or more elements may be in contact with one another by a means of communication including through a wire or other interconnect connection, through a wireless communication channel or ink, and/or the like.

[0294] The term "information element" refers to a structural element containing one or more fields. The term "field" refers to individual contents of an information element, or a data element that contains content.

[0295] The term "SMTC" refers to an SSB-based measurement timing configuration configured by *SSB-MeasurementTimingConfiguration*.

[0296] The term "SSB" refers to an SS/PBCH block.

[0297] The term "a "Primary Cell" refers to the MCG cell, operating on the primary frequency, in which the UE either performs the initial connection establishment procedure or initiates the connection re-establishment procedure.

[0298] The term "Primary SCG Cell" refers to the SCG cell in which the UE performs random access when performing the Reconfiguration with Sync procedure for DC operation.

[0299] The term "Secondary Cell" refers to a cell providing additional radio resources on top of a Special Cell for a UE configured with CA.

[0300] The term “Secondary Cell Group” refers to the subset of serving cells comprising the PSCell and zero or more secondary cells for a UE configured with DC.

[0301] The term “Serving Cell” refers to the primary cell for a UE in RRC_CONNECTED not configured with CA/DC there is only one serving cell comprising of the primary cell.

[0302] The term “serving cell” or “serving cells” refers to the set of cells comprising the Special Cell(s) and all secondary cells for a UE in RRC_CONNECTED configured with CA/.

[0303] The term “Special Cell” refers to the PCell of the MCG or the PSCell of the SCG for DC operation; otherwise, the term “Special Cell” refers to the Pcell.

WHAT IS CLAIMED IS:

1. A wireless communication management system, for use in a Third Generation Partnership Program (3GPP) wireless communication environment, comprising:

one or more processors configured to:

receive a request, from an edge computing management system, to provide information of a user plane function to which edge computing related resources in a local data network can be connected;

select a satisfactory user plane function based on the request, including:

select a preexisting user plane function that satisfies the request; or

deploy a new user plane function in response to determining that no preexisting user plane function exists that satisfies the request; and

provide information of the selected satisfactory user plane function to the edge computing management system.

2. The wireless communication management system of claim 1, wherein the preexisting user plane function is determined to satisfy the request when a data transport between the preexisting user plane function and a local data network is capable of meeting quality of service requirements on a predetermined interface.

3. The wireless communication management system of claim 2, wherein the request includes an identification of a location of the local data network and the quality of service requirements on the predetermined interface.

4. The wireless communication management system of claim 1, wherein the one or more processors are configured to perform the determining using the local data network.

5. The wireless communication management system of claim 1, wherein the new user plane function is deployed to a location where the data transported between user equipment and user plane function should meet 5G quality of service requirements.

6. The wireless communication management system of claim 5, wherein the deploying includes:

requesting a Network Functions Virtualization Orchestrator to instantiate the new user plane function with one or more location restraints; and

receiving confirmation from the Network Functions Virtualization Orchestrator that the new user plane function has been instantiated successfully.

7. The wireless communication management system of claim 6, wherein the one or more processors are further configured to configure at least one of a Session Management Function or a Network Functions Repository Function to add the newly instantiated user plane function.

8. A wireless communication management system, for supporting edge computing in a Third Generation Partnership Project (3GPP) network, comprising:

one or more processors configured to:

collect data relating to performance from a plurality of network components associated with edge computing in the 3GPP network;

receive a request from an edge computing management system to provide a 3GPP performance measurement associated with edge computing;

calculate the requested 3GPP performance measurement based on the request and the collected data; and

transmit the calculated 3GPP performance measurement to the edge computing management system in response to the request.

9. The wireless communication management system of claim 8, wherein the one or more processors are further configured to transmit the calculated 3GPP performance measurement using a Configuration Transfer function.

10. The wireless communication management system of claim 8, wherein the one or more processors are further configured to:

receive a request, from a network component, to subscribe to an alarm notification associated with edge computing; and add the network component to a list of alarm subscribers.

11. The wireless communication management system of claim 10, wherein the one or more processors are further configured to:

detect a system fault based on the collected data; and

transmit an alarm notification to the network component based on the list of alarm subscribers.

12. The wireless communication management system of claim 8, wherein the one or more circuits are further configured to:

receive a request, from the edge computing management system, to provide connection information of at least one of a policy function or a network exposure function to which an application function can communicate to influence traffic routing; and

transmit, in response to the request, the connection information of the at least one of the policy function or the network exposure function to the edge computing management system.

13. The wireless communication management system of claim 12, wherein the connection information includes an IP address.

14. A method of identifying a satisfactory user plane function for use with edge computing, comprising:

receiving a request, from an edge computing management system, to provide information of a user plane function to which edge computing related resources in a local data network can be connected;

selecting a satisfactory user plane function based on the request, including:

selecting a preexisting user plane function that satisfies the request; or

deploying a new user plane function in response to determining that no preexisting user plane function exists that satisfies the request; and

providing information of the selected satisfactory user plane function to the edge computing management system.

15. The method of claim 14, wherein selecting the preexisting user plane function includes determining that a data transport between the preexisting user plane function and a local data network is capable of meeting quality of service requirements on an predetermined interface.

16. The method of claim 15, wherein the request includes an identification of a location of the local data network and the quality of service requirements on the predetermined interface.

17. The method of claim 14, wherein the determining is performed using the local data network.

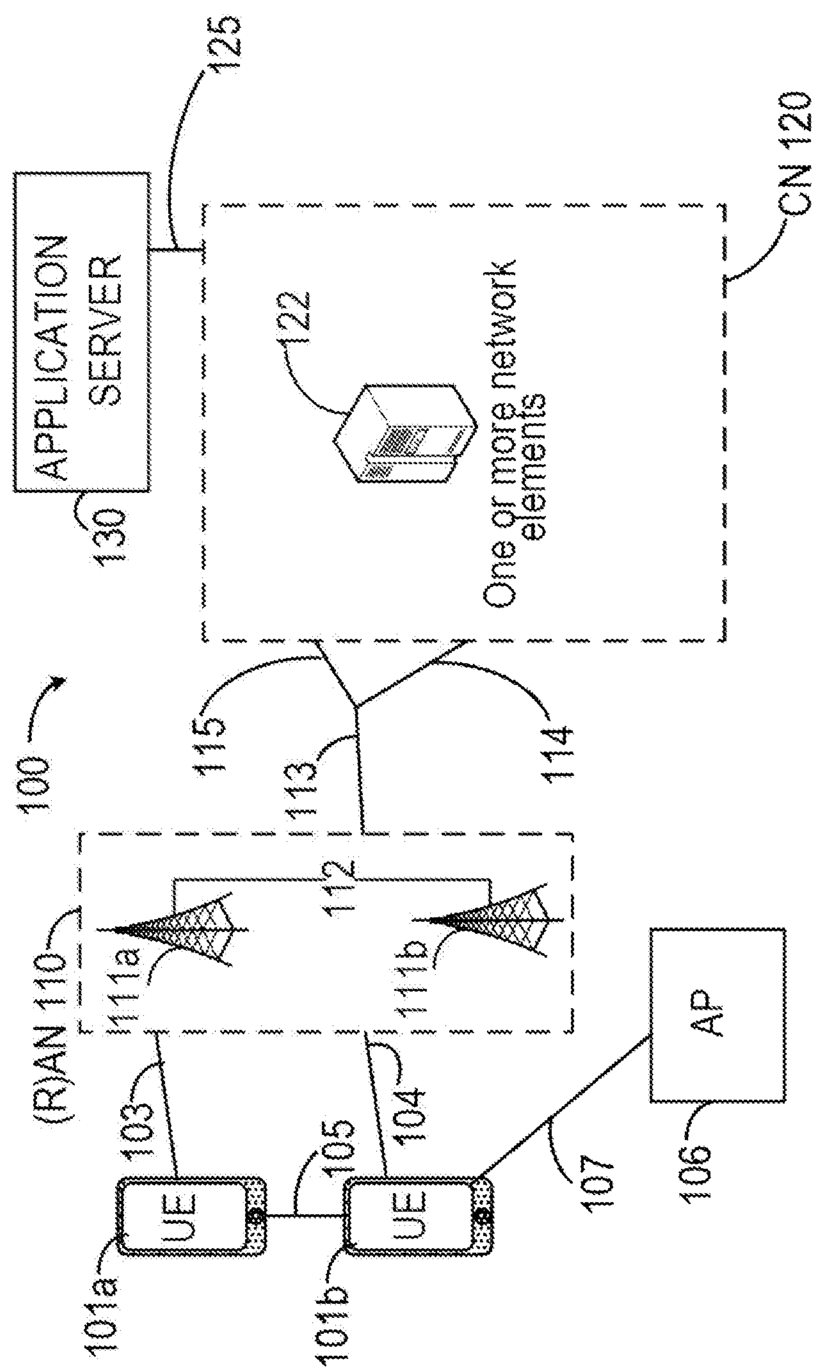
18. The method of claim 14, wherein the new user plane function is deployed to a location where the data transported between user equipment and user plane function should meet 5G quality of service requirements.

19. The method of claim 14, wherein the deploying includes:

requesting a Network Functions Virtualization Orchestrator to instantiate the new user plane functions with one or more location restraints; and

receiving confirmation from the Network Functions Virtualization Orchestrator that the new user plane function has been instantiated successfully.

20. The method of claim 19, further comprising configuring at least one of a Session Management Function or a Network Functions Repository Function to add the newly instantiated user plane function.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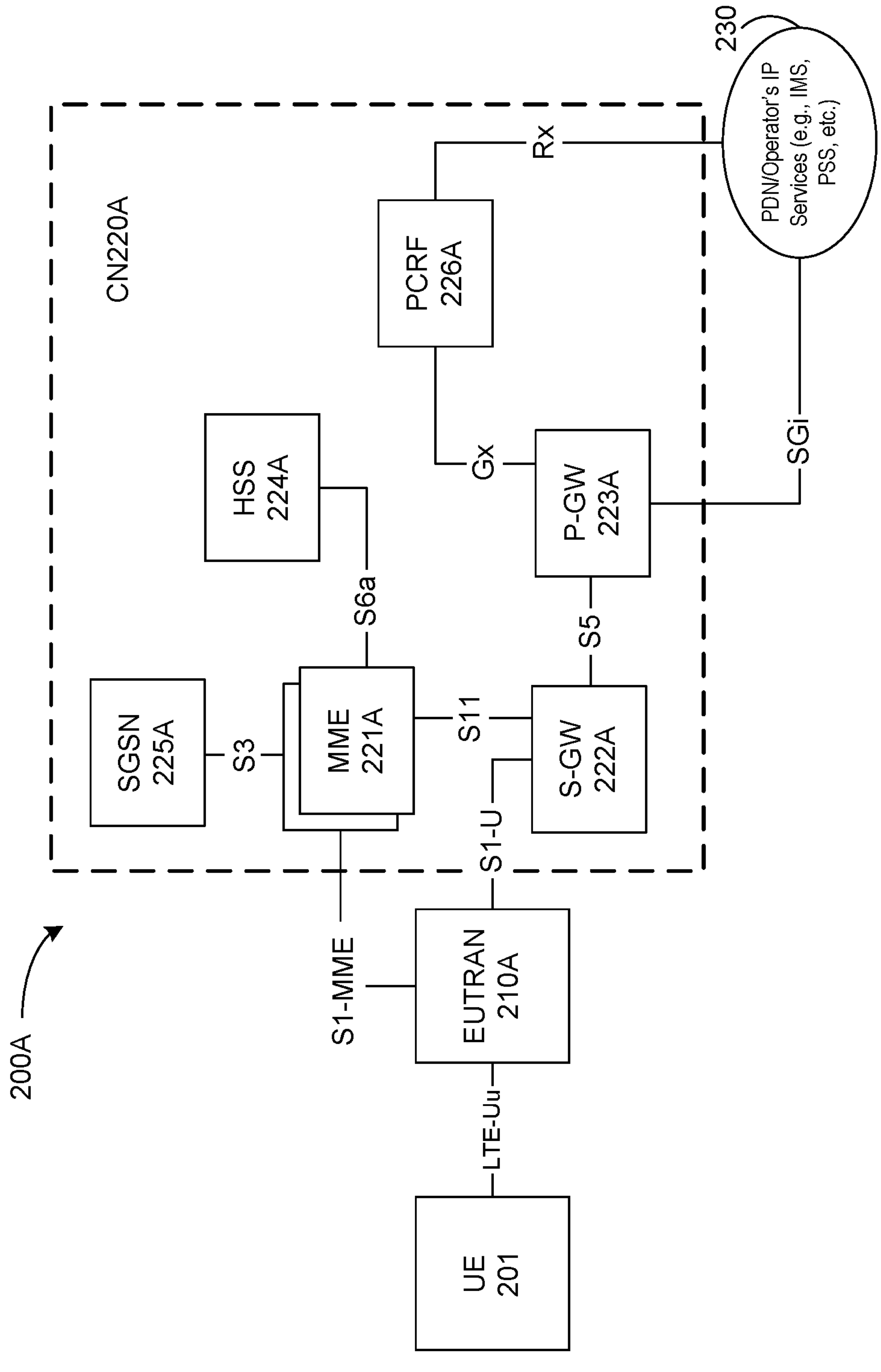
APPLICATION SERVER
130
125
CN 120
122
One or more network elements
115
113
114
(R)AN 110
111a
112
111b
103
104
105
UE
UE
101a
101b
AP
106
107

FIG. 1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CN220A
UE
201
LTE-Uu
EUTRAN
210A
S1-MME
S1-U
SGSN
225A
S3
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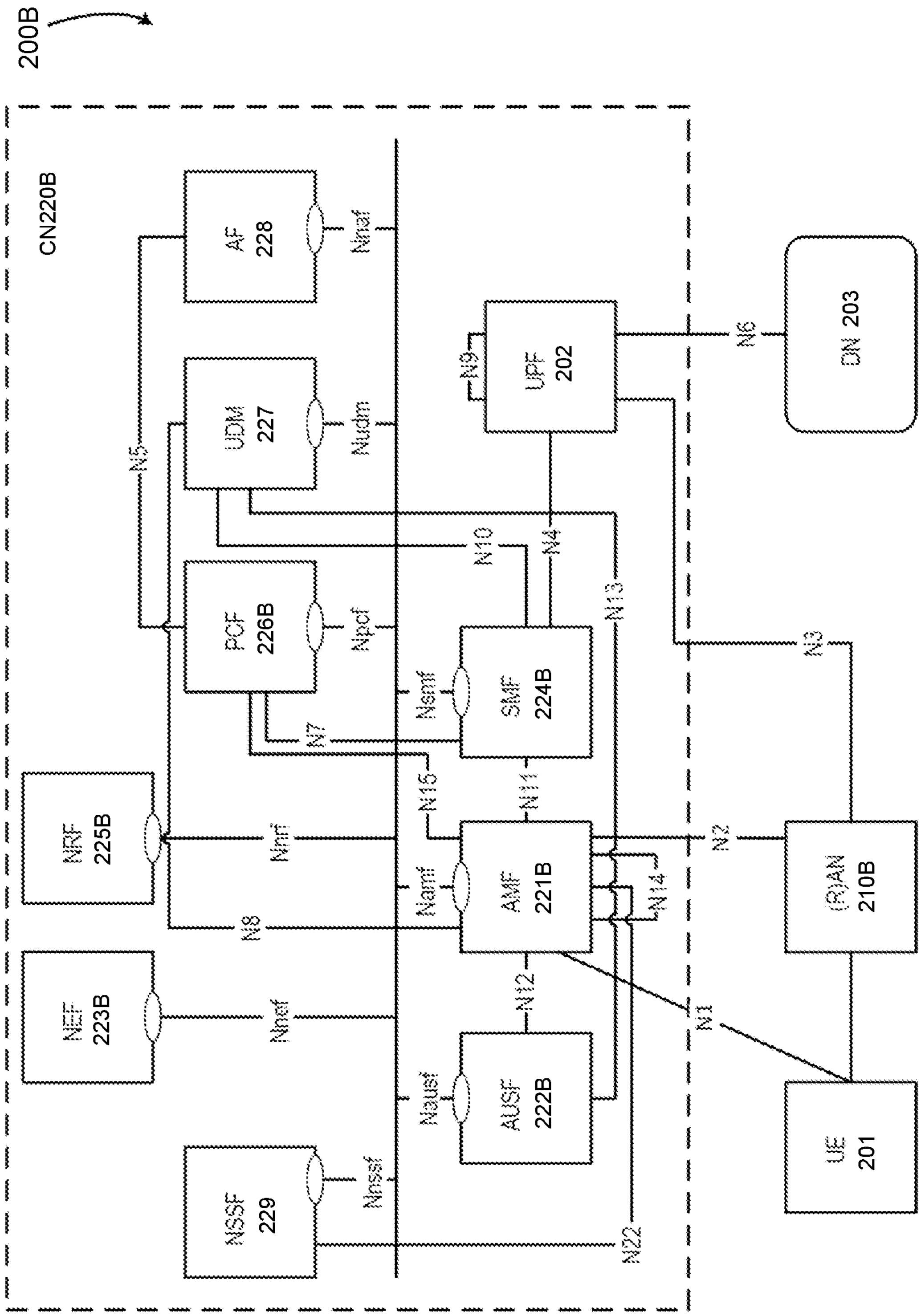
221A
S11
S-GW
222A
S5
S6a
HSS
224A
P-GW
223A
Gx
PCRF
226A
Rx
SGi
PDN/Operator's IP
Services (e.g., IMS,
PSS, etc.)
230

FIG. 2A


200B
CN220B
AF 228
UDM 227
PCF 226B
NRF 225B
NEF 223B
NSSF 229
SMF 224B
AMF 221B
AUSF 222B
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DN 203
(R)AN 210B
UE 201
Naf
Nudm
Npcf
Nnrf
Nnef
Nnssf
Nsmf
Namf
Nausf
N1
N2
N3
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N14
N15
N22

FIG. 2B

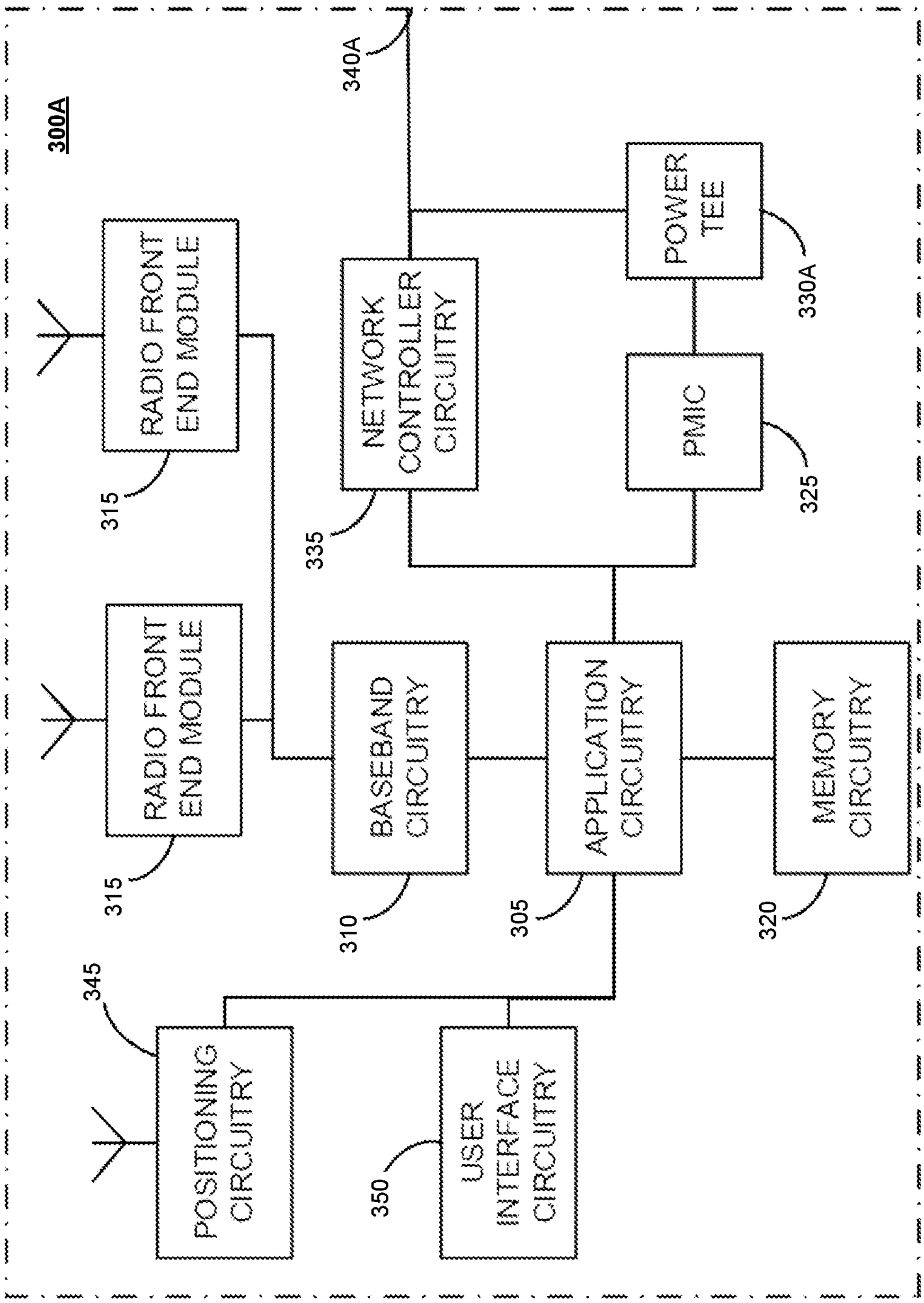

300A
340A
RADIO FRONT END MODULE
315
NETWORK CONTROLLER CIRCUITRY
335
POWER TEE
330A
PMIC
325
RADIO FRONT END MODULE
315
BASEBAND CIRCUITRY
310
APPLICATION CIRCUITRY
305
MEMORY CIRCUITRY
320
345
POSITIONING CIRCUITRY
USER INTERFACE CIRCUITRY
350

FIG. 3A

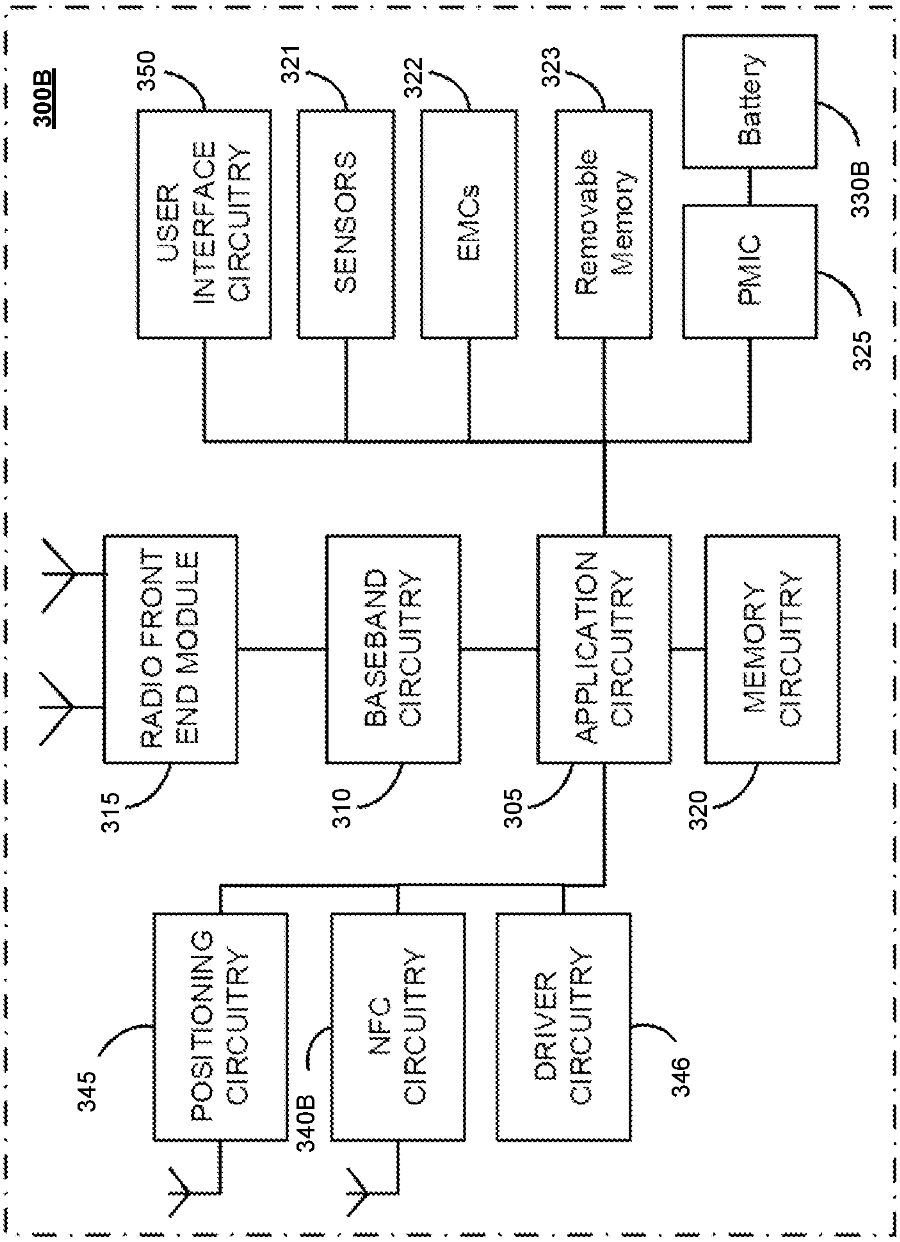

300B
USER INTERFACE CIRCUITRY
350
SENSORS
321
EMCs
322
Removable Memory
323
Battery
330B
PMIC
325
RADIO FRONT END MODULE
315
BASEBAND CIRCUITRY
310
APPLICATION CIRCUITRY
305
MEMORY CIRCUITRY
320
POSITIONING CIRCUITRY
345
NFC CIRCUITRY
340B
DRIVER CIRCUITRY
346

FIG. 3B

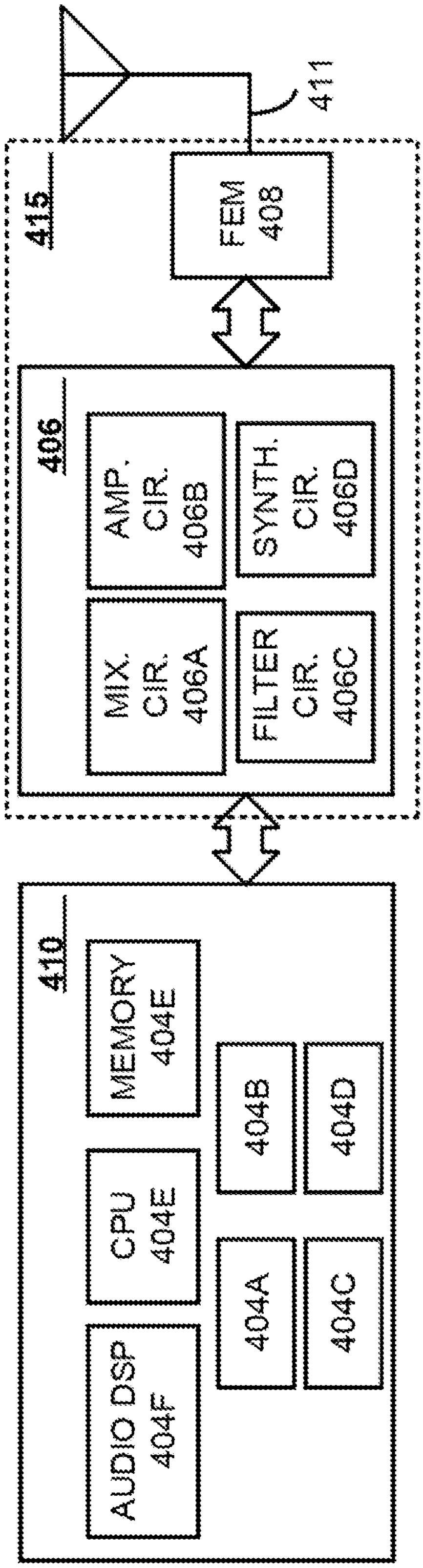

411
415
FEM
408
406
AMP.
CIR.
406B
SYNTH.
CIR.
406D
MIX.
CIR.
406A
FILTER
CIR.
406C
410
MEMORY
404E
404B
404D
CPU
404E
404A
404C
AUDIO DSP
404F

FIG. 4

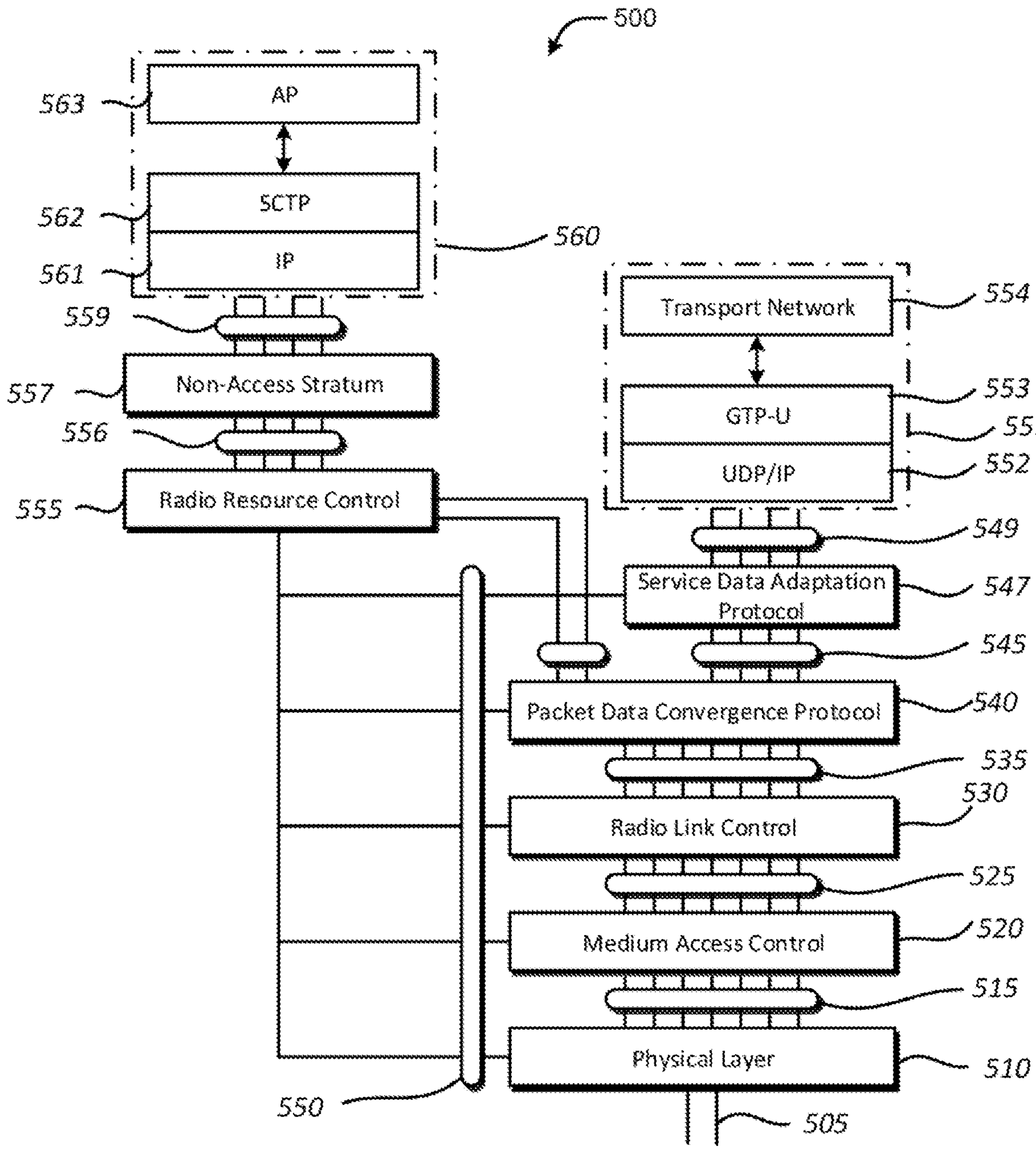

500
AP
SCTP
IP
563
562
561
560
559
Non-Access Stratum
557
556
Radio Resource Control
555
Transport Network
554
GTP-U
553
551
UDP/IP
552
549
Service Data Adaptation Protocol
547
545
Packet Data Convergence Protocol
540
535
Radio Link Control
530
525
Medium Access Control
520
515
Physical Layer
510
550
505

FIG. 5

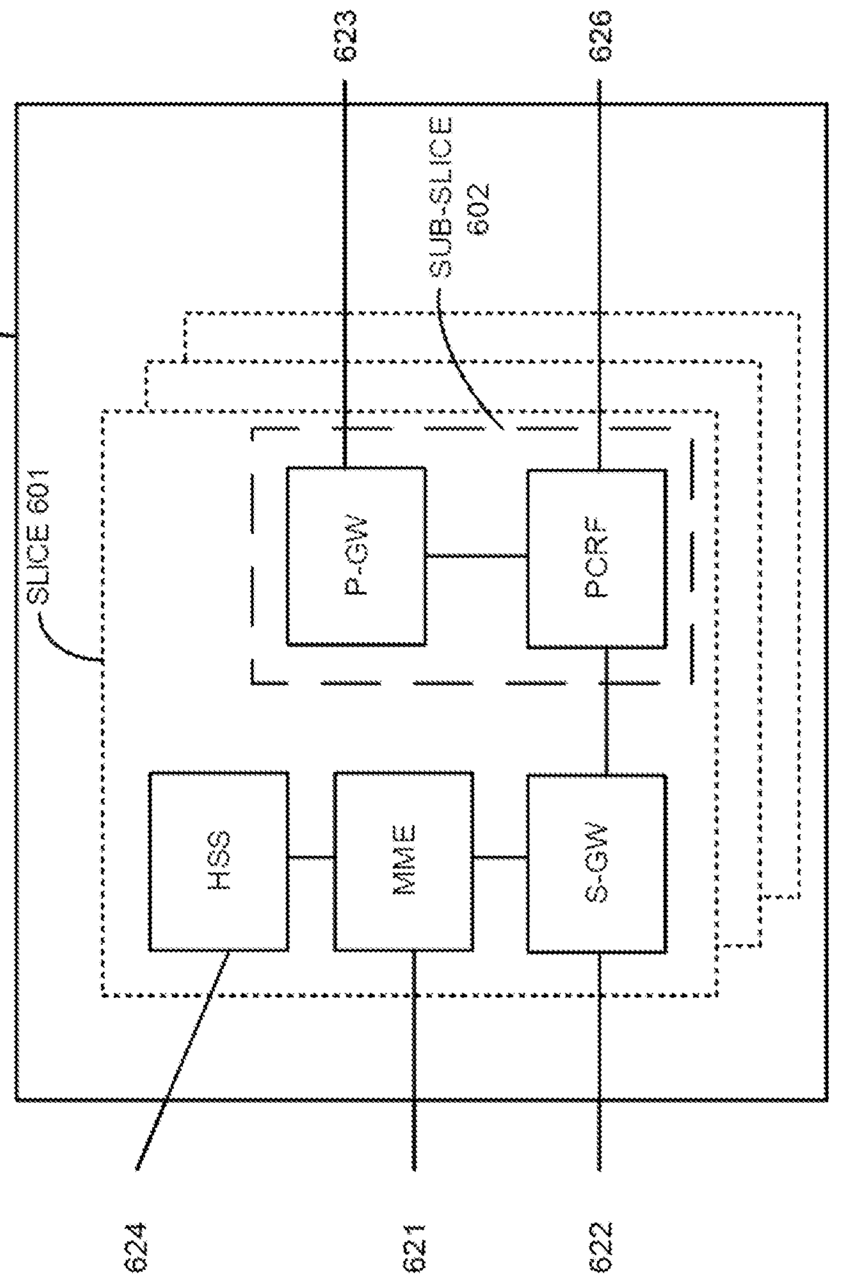

620
SLICE 601
SUB-SLICE 602
HSS
MME
S-GW
P-GW
PCRF
623
626
624
621
622

FIG. 6

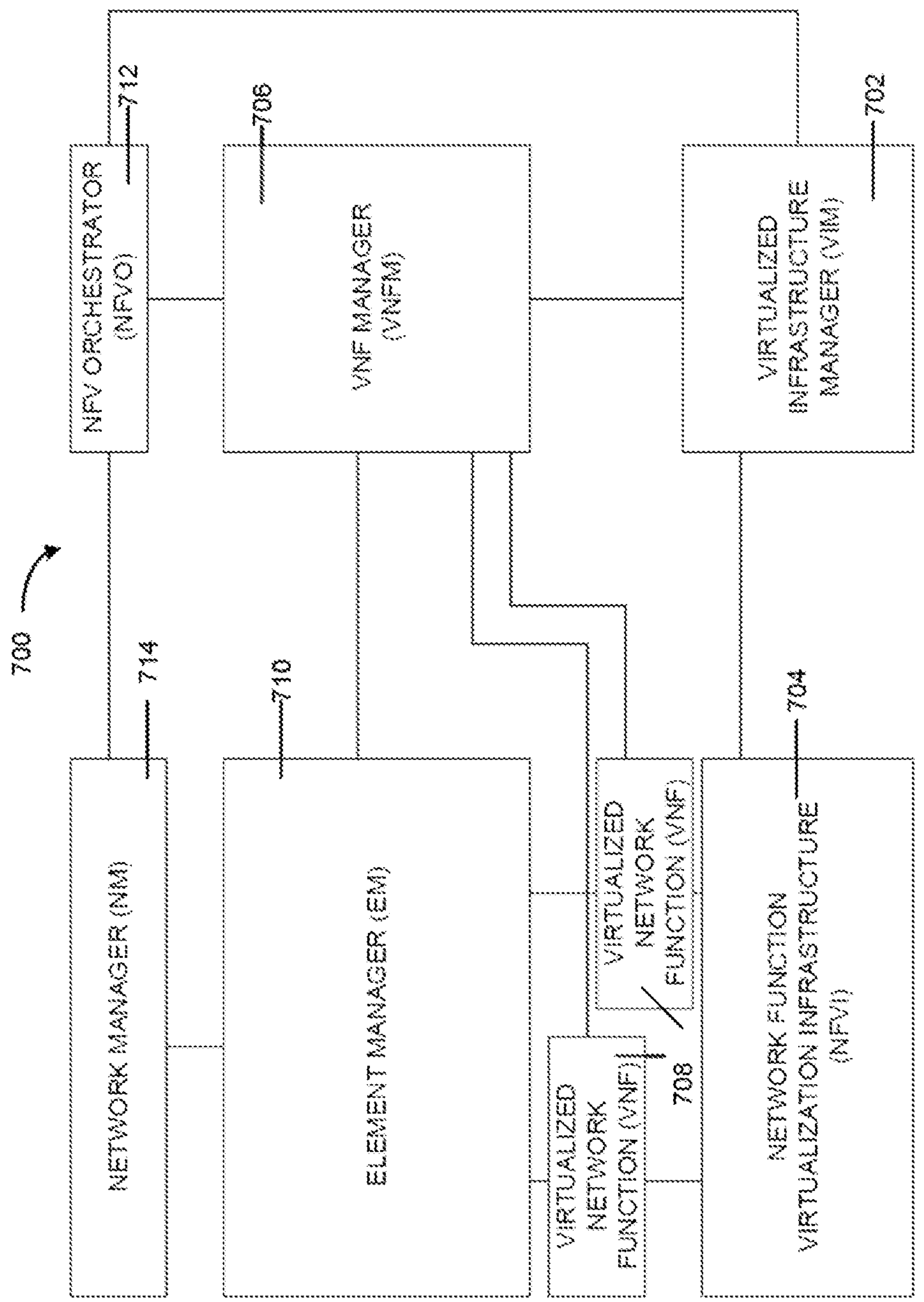
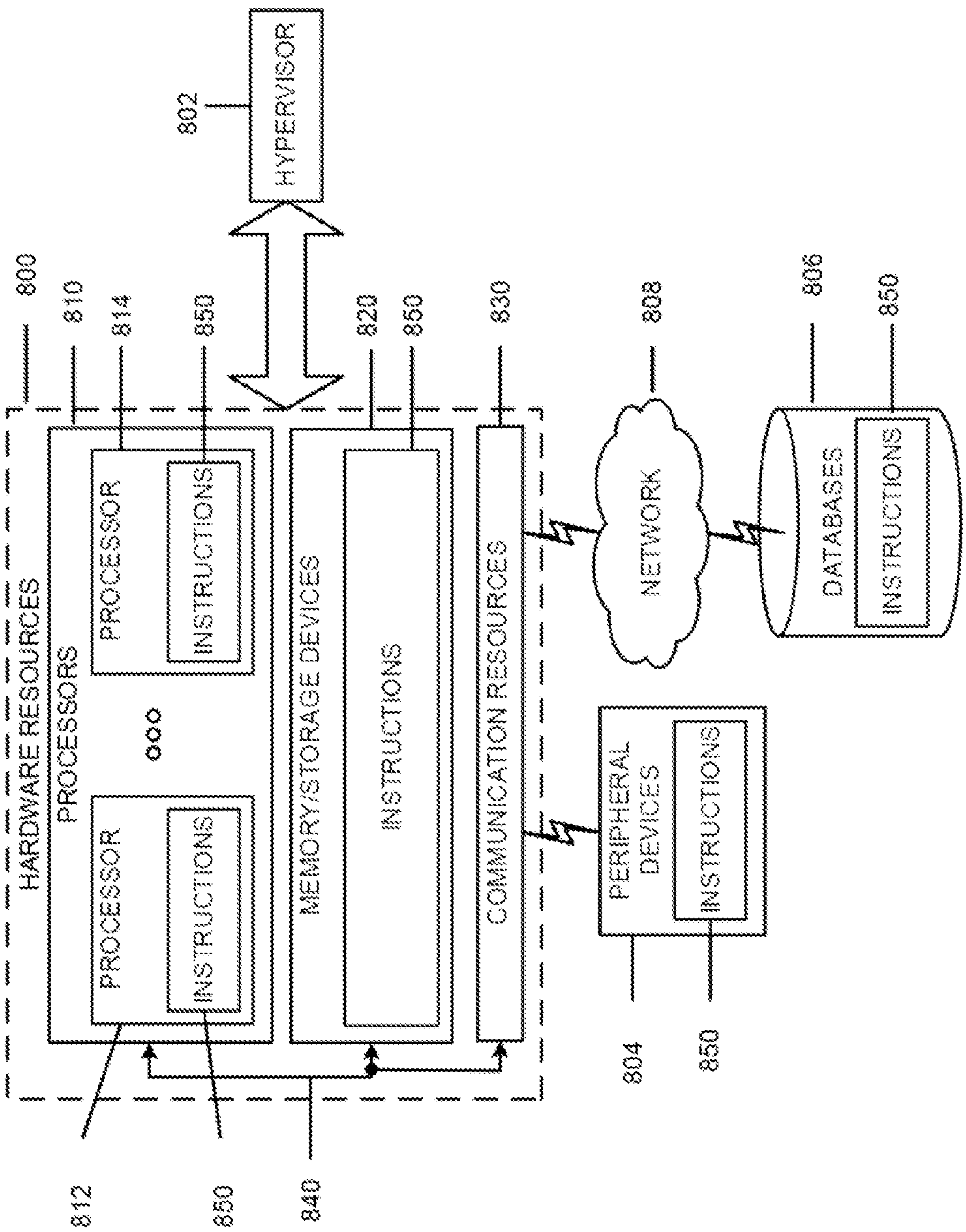

700
NFV ORCHESTRATOR (NFVO)
712
VNF MANAGER (VNFM)
706
VIRTUALIZED INFRASTRUCTURE MANAGER (VIM)
702
NETWORK MANAGER (NM)
714
ELEMENT MANAGER (EM)
710
VIRTUALIZED NETWORK FUNCTION (VNF)
VIRTUALIZED NETWORK FUNCTION (VNF)
708
NETWORK FUNCTION VIRTUALIZATION INFRASTRUCTURE (NFVI)
704

FIG. 7



HYPERVISOR
802
800
810
814
850
820
850
830
808
806
850
HARDWARE RESOURCES
PROCESSORS
PROCESSOR
INSTRUCTIONS
PROCESSOR
INSTRUCTIONS
MEMORY/STORAGE DEVICES
INSTRUCTIONS
COMMUNICATION RESOURCES
NETWORK
DATABASES
INSTRUCTIONS
PERIPHERAL DEVICES
INSTRUCTIONS
804
850
812
850
840

FIG. 8

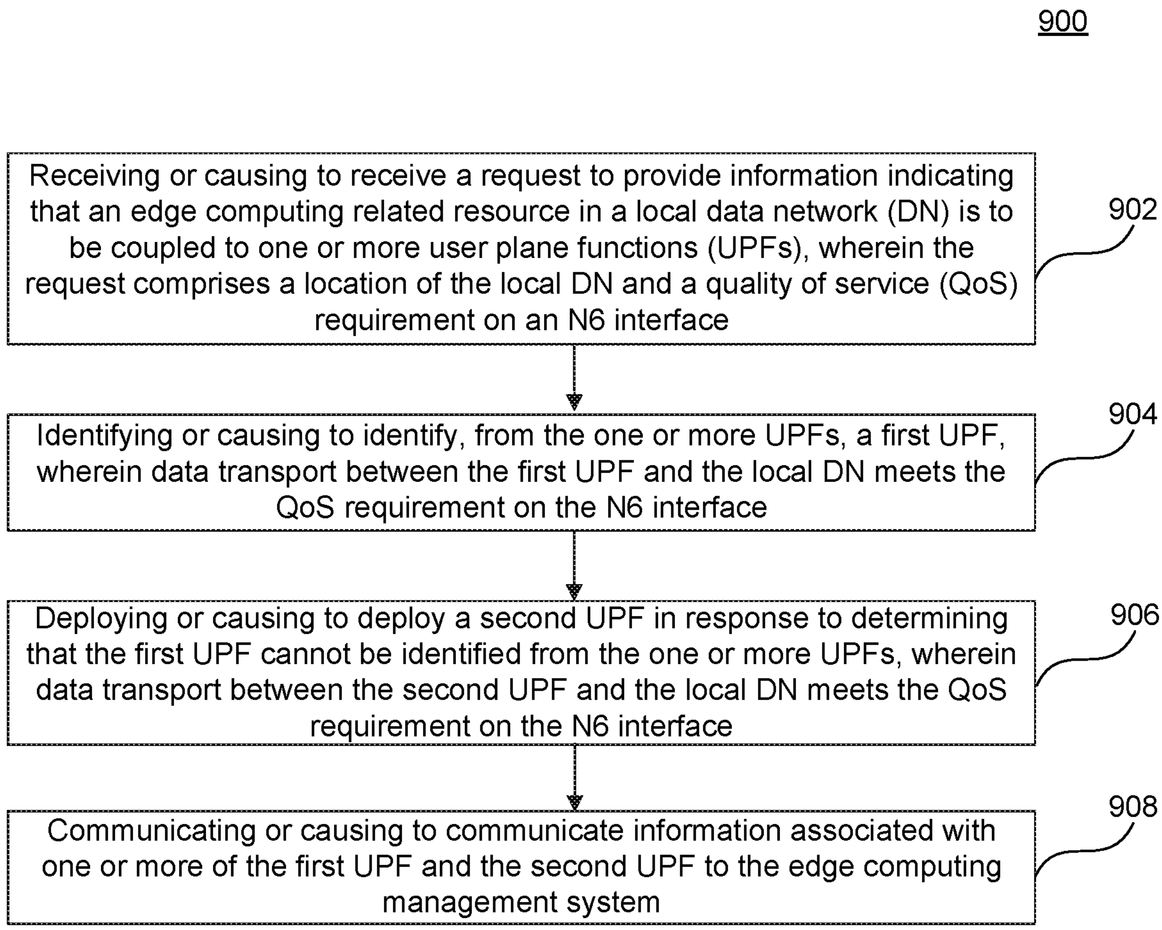

900
Receiving or causing to receive a request to provide information indicating that an edge computing related resource in a local data network (DN) is to be coupled to one or more user plane functions (UPFs), wherein the request comprises a location of the local DN and a quality of service (QoS) requirement on an N6 interface
902
Identifying or causing to identify, from the one or more UPFs, a first UPF, wherein data transport between the first UPF and the local DN meets the QoS requirement on the N6 interface
904
Deploying or causing to deploy a second UPF in response to determining that the first UPF cannot be identified from the one or more UPFs, wherein data transport between the second UPF and the local DN meets the QoS requirement on the N6 interface
906
Communicating or causing to communicate information associated with one or more of the first UPF and the second UPF to the edge computing management system
908

FIG. 9

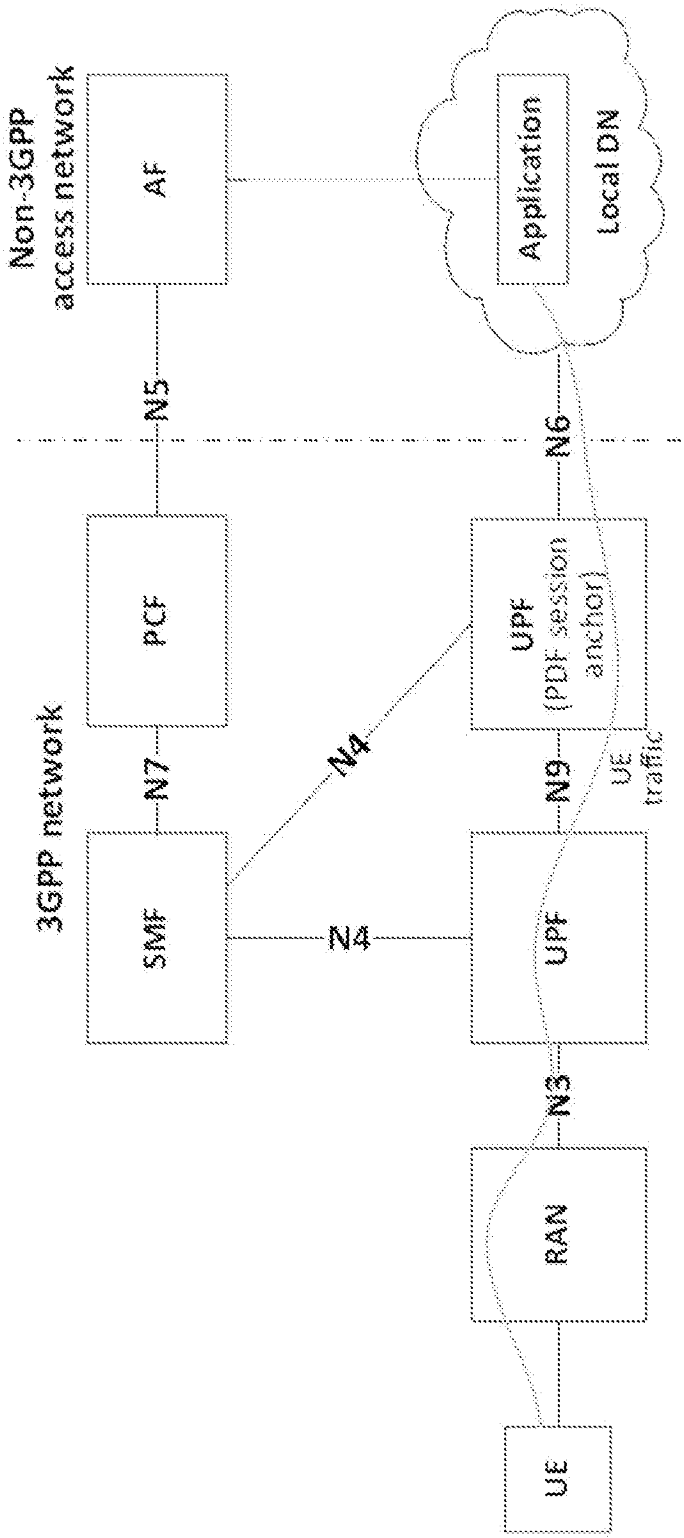

Non-3GPP access network
AF
Application
Local DN
N5
N6
3GPP network
PCF
N7
SMF
N4
N4
UPF (PDF session anchor)
N9
UE traffic
UPF
N3
RAN
UE

FIG. 10