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(71) Applicant: **APPLE INC.** [US/US]; One Apple Park Way,
Cupertino, California 95014 (US).

(72) Inventor: **LIAO, Ching-Yu**; c/o APPLE INC., One Apple
Park Way, Cupertino, California 95014 (US).

(74) Agent: **HICKS, Ross et al.**; Sterne, Kessler, Goldstein &
Fox P.L.L.C, 1100 New York Avenue, NW, Washington,
District of Columbia 20005 (US).

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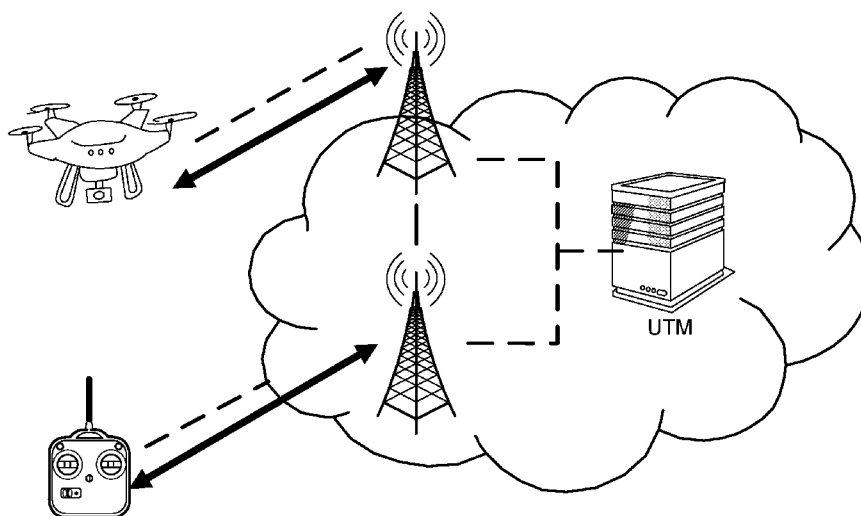


FIG. 1

(57) Abstract: Some embodiments of this disclosure include systems, apparatuses, methods, and computer-readable media for use in a wireless network for facilitating Unmanned Aerial System (UAS) services over evolved packet systems. Some embodiments are directed to a method, the method including receiving a registration request from each of an unmanned aerial vehicle (UAV) and a UAV controller to establish an Unmanned Aerial System (UAS). Additionally, the method includes initiating a UAS Operation Service Request Procedure via a network exposure function (NEF) and associating the UAV and the UAV controller to operate as the UAS in response to obtaining the results of the UAS operation service authorization from each of the UAV and the UAV controller. Moreover, the method also includes transmitting a UAS operation status update procedure to the UAV and the UAV controller, the update procedure including UAS association information, a UAS policy update, and initiation of a UAS operation.



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ENABLING UAS SERVICE FOR IDENTIFICATION AND OPERATION IN 3GPP SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

- [0001]** This application claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Application No. 62/802,602, filed February 7, 2019, which is hereby incorporated by reference in its entirety.

FIELD

- [0002]** Various embodiments generally may relate to the field of wireless communications.

SUMMARY

- [0003]** Some embodiments of this disclosure include systems, apparatuses, methods, and computer-readable media for use in a wireless network for configuring the operation of a use equipment (UE).
- [0004]** Some embodiments are directed to a method, the method including receiving a registration request from each of an unmanned aerial vehicle (UAV) and a UAV controller to establish an Unmanned Aerial System (UAS), each registration request including an application layer registration through an Unmanned Aircraft Traffic Management (UM) application function (AF), in which an IP address of the server is provided. Additionally, the method includes initiating a UAS Operation Service Request Procedure via a network exposure function (NEF) to obtain results of a UAS operation service authorization from each of the UAV and the UAV controller. Furthermore, the method also includes associating the UAV and the UAV controller to operate as the UAS in response to obtaining the results of the UAS operation service authorization from each of the UAV and the UAV controller. Moreover, the method also includes transmitting a UAS operation status update procedure to the UAV and the UAV controller, the update procedure including UAS association information, a UAS policy update, and initiation of a UAS operation.

[0005] Some embodiments are directed to an unmanned aircraft traffic management server facilitating Unmanned Aerial System (UAS) services over evolved packet systems. In some aspects, the server may include network circuitry and processor circuitry coupled to the network circuitry and configured to receive a registration request from each of an unmanned aerial vehicle (UAV) and a UAV controller to establish an Unmanned Aerial System (UAS), each registration request including an application layer registration through an Unmanned Aircraft Traffic Management (UM) application function (AF), in which an IP address of the server is provided. Additionally, the processor circuitry may further be configured to initiate a UAS Operation Service Request Procedure via a network exposure function (NEF) to obtain results of a UAS operation service authorization from each of the UAV and the UAV controller. Furthermore, the processor circuitry may further be configured to associate the UAV and the UAV controller to operate as the UAS in response to obtaining the results of the UAS operation service authorization from each of the UAV and the UAV controller. Moreover, the processor circuitry may further be configured to transmit a UAS operation status update procedure to the UAV and the UAV controller, the update procedure including UAS association information, a UAS policy update, and initiation of a UAS operation.

BRIEF DESCRIPTION OF THE DRAWINGS/FIGURES

- [0006]** Fig. 1 illustrates an unmanned aerial system (UAS) operation via a network based command and control (C2) communication between an unmanned aerial vehicle (UAV) and UAV controller, according to some embodiments;
- [0007]** Fig. 2 illustrates a UAS operation via network navigated C2, according to some embodiments;
- [0008]** Fig. 3 illustrates a service based architecture in fifth generation system (5GS), according to some embodiments;
- [0009]** Fig. 4 illustrates a high level procedure for UAS operation, according to some embodiments;
- [0010]** Fig. 5 illustrates a user equipment (UE) configuration update procedure, according to some embodiments;

- [0011] Fig. 6 illustrates a procedure for UAS operation service request by an unmanned aircraft traffic management system (UTM) via network exposure function (NEF), according to some embodiments;
- [0012] Fig. 7 illustrates a procedure for UAS operation service request by the UTM-SCS via service capability exposure function (SCEF), according to some embodiments;
- [0013] Fig. 8 illustrates a procedure for notifying a UAS operation status in 5GS, according to some embodiments;
- [0014] Fig. 9 illustrates a procedure for notifying UAS operation status in evolved packet systems (EPS), according to some embodiments;
- [0015] Fig. 10 illustrates a depiction of a setup of an application server (AS) session with a required quality of service (QoS) in 5GS, according to some embodiments;
- [0016] Fig. 11 illustrates a depiction of a setup of an AS session with a required QoS in EPS, according to some embodiments;
- [0017] Fig. 12 illustrates an NEF parameter provision update request/response operation, according to some embodiments;
- [0018] Fig. 13 illustrates a proximity request procedure, according to some embodiments;
- [0019] Fig. 14 illustrates a proximity alert procedure, according to some embodiments;
- [0020] Fig. 15 illustrates a one-to-many ProSe Direct Communication transmission, according to some embodiments;
- [0021] Fig. 16 depicts an architecture of a system of a network, in accordance with some embodiments;
- [0022] Fig. 17 depicts an architecture of a system including a first core network, in accordance with some embodiments;
- [0023] Fig. 18 depicts an architecture of a system including a second core network in accordance with some embodiments;
- [0024] Fig. 19 depicts an example of infrastructure equipment, in accordance with various embodiments;
- [0025] Fig. 20 depicts example components of a computer platform, in accordance with various embodiments;
- [0026] Fig. 21 depicts example components of baseband circuitry and radio frequency circuitry, in accordance with various embodiments;

- [0027] Fig. 22 is an illustration of various protocol functions that may be used for various protocol stacks, in accordance with various embodiments;
- [0028] Fig. 23 illustrates components of a core network, in accordance with various embodiments;
- [0029] Fig. 24 is a block diagram illustrating components, according to some example embodiments, of a system to support NFV, according to some embodiments;
- [0030] Fig. 25 depicts 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;
- [0031] Fig. 26 illustrates a flow diagram of a UAS service, according to some embodiments; and
- [0032] Fig. 27 illustrates a flow diagram of a UAS service, according to some embodiments.

DETAILED DESCRIPTION

- [0033] 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).
- [0034] Based on SA1 service requirements in TS 22.125, 3GPP has started the architecture study on 5GS enhanced support of UAS (Unmanned Aerial System) as indicated in SA2 SID: SP-181114.
- [0035] According to UAS Traffic Management Concept of Operations by NASA (National Aeronautics and Space Administration) and FAA (Federal Aviation

Administration), the Unmanned Aircraft Traffic Management (UTM) architecture can refer to UTM concept of operation available from NASA.

- [0036] Embodiments disclosed herein may be directed to providing UAS service over the 3GPP Evolved Packet System to address the following issues:
- [0037] Issue 1: Architectural Aspects: A role of 3GPP system to support UAS operation with National Aeronautics and Space Administration – Federal Aviation Administration (NASA-FAA) defined UTM concept of to enable UTM to associate the UAV and UAV controller, and to identify the combination as a UAS.
- [0038] Issue 2: How the 3GPP system may support UAS association and identification.
- [0039] Issue 3: How the 3GPP system may provide UAV and UAV controller the 3GPP connectivity for communication between them and with an Unmanned Aerial System Traffic Management (UTM), including communication requirements for UAS cover both the Command and Control (C2) between UAV and UAV controller, but also uplink and downlink data to/from the UAS components towards both the serving 3GPP network and network servers.
- [0040] Issue 4: When the application function (AF) session is with multiple traffic types, it requires a mechanism to provide differentiated QoS for different traffics in C2 communication.

Table 1 shows the KPIs for the considered use cases for C2 communication:

Traffic Type for C2	Bandwidth	Latency
Commands	0.005 Mbps	e.g. 1-5 msec
Telemetry	0.012 Mbps	e.g. 1sec
Real-Time	0.06 Mbps w/o video	e.g. 100msec
Video Streaming	4 Mbps for 720p video 9 Mbps for 1080p video 30 Mbps for 4K Video	e.g. 100msec
Situation Aware report	1Mbps	10msec-100msec

- [0041] Issue 5: According to TS22.125, in decentralized traffic management, the local broadcasting mechanism is used for collision avoidance. However, the legacy message may not be sufficient to identify the nearby UAV and keep distance from collision.

- [0042] In embodiments described herein, the 3GPP system may enable a UAV to broadcast the following identity data in a short-range area for collision avoidance: UAV type, current location and time, route data, operating status.
- [0043] Furthermore, embodiments may enhance 5GS/Evolved Packet System (EPS) system architecture in support of UAS operation, and to enable UAS operation service by proposed new procedures and the enhancement to the existing procedures.
- [0044] The legacy functionalities in 5GS/EPS may not sufficiently support a UAS operation.
- [0045] Accordingly, embodiments disclosed herein may be directed to at least the following implementations for provision UAS services in 5GS/EPS
- Implementation 0: High level Procedure for UAS Association, Identification, and Operation
 - Implementation 1: UAS subscriptions
 - Implementation 2, 3: New UAS association and identification procedure
 - Implementation 4: C2 communication Set up for an AS session with required QoS
 - Implementation 5: Flight Plan based UAS operation
 - Implementation 6: UAS association and identification procedure using EPC-Level ProSe Discovery
- [0046] As a result of one or more of the embodiments disclosed herein, the UAS services may be authorized and identified by the 3GPP system. Further, the UAS operation may be provisioned with required QoS and would result in increased safety for UAS operation.
- [0047] Embodiments described within this disclosure may include the following:
- [0048] The UAV and UAV controller are both with 3GPP UE capabilities including required capabilities for UAS operation.
- [0049] The UAS operation with both UAV and UAV controller is based on Fig. 1, in which the UAV and UAV controller communicate to each other via respective unicast connection to 3GPP network via same or different RAN node in the same or different PLMNs. The UAV controller and UAV establish respective unicast C2 (control and command) communication links to the 3GPP network and communicate with each other via 3GPP network.

- [0050] The UAS operation without UAV controller bases on network navigated C2 communication and flight plan is as shown in Fig. 2. The corresponding implementation is in implementation 5.
- [0051] Embodiments described herein may include the following:
- [0052] A new network function, Cellular based UAS traffic management (C-UTM), in the control plane is introduced
- [0053] According to some embodiments, C-UTM function may be supported in EPC architecture (TS 23.401) and 5GS architecture (TS23.501).
- [0054] According to some embodiments, the C-UTM function may store the authorization information for the UAV and UAV controller for the UAS operation.
- [0055] According to some embodiments, for EPS, C-UTM function may interface with SCEF (new interface), and SCEF can expose network capabilities requested by SCS/AS with UTM-Application server (TS23.682) over T8.
- [0056] For 5GS, the UTM-AF interfaces with C-UTM over N33.
- [0057] The UTM-Application server via SCS/AS or AF can request services from 3GPP network via PCRF (over Rx interface) or PCF or via SCEF in EPS or NEF in 5GS (TS23.203, TS23.682, TS23.501, TS23.502).
- [0058] According to some embodiments, Fig. 3 shows service based system architecture in 5GS based on TS 23.501, as an example, in which C-UTM may be a new network function. Alternatively, the C-UTM functionalities can be supported in PCF using existing interfaces to communicate other Network functions, e.g. SMF, NEF, and AF. Embodiments disclosed herein may be directed to enhanced 5GS architecture and procedure 5GS (TS 23.501, 23.502, 23.503). All embodiments are applicable to 3GPP system in EPS (TS 23.401, 23.402, 23.303), with the corresponding additions to the network entities/functions, e.g. HSS is corresponding to UDM, PCRF is corresponding to PCF, SCEF is corresponding to NEF, etc.
- [0059] Fig. 4 shows the High-Level Procedure for UAS Association, Identification and Operation, whereby the actions indicate the corresponding implementations. For simplicity, the Figure shows only one 3GPP network. Embodiments described herein may be applicable to the case that the UAV and UAV controller (UAV-C) register to 3GPP network via same or different RAN/CN node in the same or different PLMNs according to the following actions:

- [0060] Action 0: the UE in the UAV and UAV controller is pre-configured with the UAS operation authorization parameters.
- [0061] Action 1: the UE in UAV/UAV controller both register to the 5GC with indications to enable UAS operation service if the UE has corresponding UAS subscriptions.
- [0062] Action 2: the UE in UAV/UAV controller requests to establish PDU session for a specific UAS-DNN. The SMF can initiate secondary authentication procedure with UAS-DN-AAA if the UE sends the request with NAI (network access identifier).
- [0063] Action 3A: the UE in UAV performs application layer registration to the UTM-Application server associated to UTM-AF, in which IP address of the UTM-Application server is pre-configured in the UE or provided in a PDU session accept message.
- [0064] Action 3B: the AF initiates UAS Operation Service Request Procedure towards C-UTM/PCF function via NEF to obtain the results of the UAS Operation Service Authorization per Application identified by Application Identifier.
- [0065] Action 4A, 4B: same as Action 3A, 3B for the UAV controller.
- [0066] Action 5: when the UTM-AF obtains results of UAS operation service authorization per application from both UAV and UAV controller, it determines if the UAV and UAV controller can be associated to operate as a UAS.
- [0067] Action 6: If the UAS association is done successfully, the UTM-AF sends UAS Operation Status Update procedure to notify the UAS operation status including UAS association information, UAS policies updates, and initiation of the UAS operation. When the AF receives response message to the status update, the UAS operation can be started.
- [0068] Action 7: The UTM-AF initiates AF Session Setup Procedure with required QoS to steer the IP flows for the UTM session between the UAV and the UTM-AF and C2 (command and control) session between UAV and the UAV controller.
- [0069] It should be appreciated that the actions described above may be performed in any order, or that one of the more actions may be omitted.

Implementation 1: UAS Subscription

- [0070] A user's profile in the HSS in EPS or UDM in 5GS may contain the subscription information to give the user permission to use UAS service. At any time, the operator can remove the UAS UE subscription rights from user's profile in the HSS/UDM, and revoke

the user's permission to use UAS service. The following subscription information may be defined for UAS:

- Subscription for UE operating UAV in a UAS.
- Subscription for UE operating UAV Controller in a UAS.
- Subscription for UAS Operation using Indirect C2 Communication (as shown in Fig. 1).
- Subscription for UAS Operation using network navigated C2 with flight plan (as shown in Fig. 2)
- Subscription for UAS Operation using Direct C2 Communication (i.e. UAS direct communication between UEs).
- Subscription for EPC-Level UAS Discovery and Association.

[0071] Additional parameters related to the ProSe Direct service may be stored in the user's profile, such as:

- the list of the PLMNs where the UE is authorised for UAS Operation using Indirect C2 Communication:
- the list of the PLMNs where the UE is authorised for UAS Operation using Direct C2 Communication.
- the list of the PLMNs whether the UE is authorized for UAS Operation using network navigated C2 with flight plan.
- the list of the PLMNs where the UE is authorised for UAS Operation using EPC-Level UAS Association Discovery.

[0072] According to some embodiments, for each subscription, the UE can be pre-configured or provisioned by the PCF function with the following service authorization parameters:

[0073] Authorization for UAS Operation using Indirect C2 Communication:

- the list of the PLMNs where the UE is authorized
- the list of the allowed Application Identifiers per PLMN
- the list of the allowed traffic types per Application Identifier
- UAS-DNN

[0074] Authorization for UAS Operation using Direct C2 Communication:

- the list of the PLMNs where the UE is authorized
- the list of the allowed Application Identifiers per PLMN

- [0075] Authorization for UAS Operation using network navigated C2 with flight plan
- the list of the PLMNs where the UE is authorized
 - the list of the allowed Application Identifiers per PLMN
 - the list of the UTM Application Servers per Application Identifier
 - the list of the allowed traffic types per Application Identifier
 - UAS-DNN
- [0076] The list of the allowed traffic types can be associated to different port numbers. This is used to resolve issue 4 in implementation 4.2.
- [0077] Authorization for UAS Operation using EPC-Level UAS Association Discovery
- the list of the PLMNs where the UE is authorized
 - the list of the allowed Application Identifiers per PLMN
- [0078] The provisioning of the UAS operation authorization parameters can use UE configuration update procedure as clause 4.2.4 in TS23.502, and as illustrated in Fig. 5 (associated with Fig. 4.2.4.3-1 of TS23.502).

Implementation 2: UAS association and identification procedure

- [0079] For supporting the UAS association between the UAV and UAV controller, the UTM-Application server initiates C-UTM service request procedure for UAV and UAV controller respectively as follows, as shown in Fig. 6:
- [0080] According to some embodiments, the association procedure may follow the following steps:
- [0081] 1. The AF requests for UAS operation service authorization by sending a Nnef_UAS_Operation_Service Request (AF Identifier, Generic Public Subscription Identifier (GPSI)/External Group Identifier of the UAV/UAV controller, external Application Identifiers, UAS operation authorization for each Application Identifier) message to the NEF. In some embodiments, UAS operation authorization indicates that the UAS operation policy is to be created in the operator's network if successfully authorized, e.g. UAS operation mode, including via Network based C2 (as shown in Fig. 1) or via Network navigated C2 (as shown in Fig. 2), operation location, requested operation start time, flight duration, flight routes, etc., for the UAV/UAV controller.
- [0082] 2. The NEF authorizes the AF to request UAS operation service authorization together with the AF Identifier.

- If the authorisation is not granted, Action 2 is skipped and the NEF replies to the AF with a Result value indicating that the authorisation failed.
- If the authorization is granted, the NEF allocates a Transaction Reference ID to identify the follow up messages regarding to the request.
- Based on operator configuration, the NEF may skip this action. In this case the authorization is performed by the C-UTM/PCF in action 3.

[0083] 3. The NEF sends a Ncutm_UAS Operation_Authorization Request message (Application Identifier(s), one or more sets of UAS operation information for each Application Identifier, SUPI) to the C-UTMF/PCF.

- The NEF may query for the translation of GPSI/External Group Identifier of the UAV/UAV controller to Subscription Permanent Identifier (SUPI) of the UE.

[0084] 4. The C-UTM/PCF function determines whether the request is allowed.

- If UAS operation authorization is done successfully, it continues to create the list of UAS operation policies into the C-UTM function based on the operator's configured policies for each requested UAS operation per application ID and respond to NEF.

[0085] 5. the C-UTM function sends Ncutm_UAS Operation_Authorization Request message (Application Identifier(s), Results) message to the NEF and indicates the Results. If any of the services authorization fails, a cause is provided per Application ID, e.g. service suspend, service expiration, service unavailable, etc.

[0086] 6. The NEF sends a Unef_UAS Operation_Service Response (Transaction Reference ID, Results) message to the UTM-AF to provide the feedback of the result for Unef_UAS_Operation_Service Request.

- The Transaction Reference ID generated in Action is used by the AF to provide the follow up information regarding to the request for the UAS operation of the UAV/UAV controller.

[0087] As another example for EPS, the similar procedure can be applied in the following procedure, as illustrated in Fig. 7 (Procedure for UAS Operation Service request by the UTM-SCS/AS via SCEF):

[0088] 1. The 3rd party SCS/AS sends a C-UTM Service Request (SCS/AS Identifier, TTRI, External Identifiers/External Group Identifier of the UAV/UAV controller,

external Application Identifiers, UAS operation authorization for each Application Identifier) message to the SCEF.

- The external Application Identifier(s) may be provided by an 3rd party SCS/AS that is known at the SCEF, so that the 3rd party SCS/AS and the MNO has an SLA in place.
- The definition of the external identifier or external group identifier of the UAV/UAV controller can be referred to TS23.682 clause 4.6.2.
- UAS operation authorization indicates that the UAS operation policy is to be created in the operator's network if successfully authorized, e.g. UAS operation mode, including via Network based C2 (as shown in Fig. 1) or via Network navigated C2 (as shown in Fig. 2), operation location, requested operation start time, flight duration, flight routes, etc., for the UAV/UAV controller.
- T8 Transaction Reference ID (TTRI) is a parameter which refers to transactions between the SCEF and the SCS/AS when using T8 interface. The transactions consist of one request message followed by one or more response messages. It is created by the originator of the transaction, and is unique through the duration of the transaction. It is stored on both the SCEF and the SCS/AS for the duration of the transaction, in TS23.303 clause 4.9.2.

[0089] 2. Based on operator policies, if the 3rd party SCS/AS is not authorized to perform this request (e.g. if the SLA does not allow it, e.g. due to the system load situation), the SCEF performs action 6 and provides a Cause value appropriately indicating the error. Otherwise, the SCEF translates each external Application Identifier to the corresponding Application Identifier known at the C-UTM function. Also, the SCEF may interact with HSS to request for the translations of External identifiers/External Group identifiers.

[0090] 3. The SCEF sends a UAS Operation Service Authorization Request message (Application Identifier(s), one or more sets of UAS operation information for each Application Identifier, External identifiers/External Group identifiers or IMSI) to the C-UTMF.

[0091] 4. The C-UTM function checks the UAS authorization for the UAV/UAV controller based on External identifiers/External Group identifiers or IMSI.

- [0092] 5. If UAS operation authorization is done successfully, it continues to create the list of UAS operation policies for each Application Identifier into the C-UTM function as requested by the respective UAS operation. If any of the authorization fails, the C-UTM function sends UAS Operation Service Authorization Response (Application Identifier(s), Cause) message to provide the feedback of the handling result for the C-UTM Service Request, whereby the cause can indicate the failure reasons for the authorization per Application ID, e.g. service suspend, service expiration, service unavailable, etc.
- [0093] 6. The SCEF sends a UAS Operation Service Response (TTRI, Result) message to the 3rd party SCS/AS to provide the feedback of the handling result for UAS Operation Service Request.

Implementation 3: UAS Operation Status Update Notification

- [0094] According to some embodiments, following implementation 2, based on the received C-UTM Service Response from the NEF for both of the UAV and the UAV controller, the AF determines if the UAS authorization can be accepted.
- If the association is done successfully to find the match, the AF sends a notification to C-UTM function via NEF to notify the UAS operation status including UAS association information, UAS policies updates, and initiation of the UAS operation. When the AF receives response message to the status update, the UAS operation can be started.
 - The AF may reply application layer confirmation message to the UAV and the UAV controller for the start of the UAS operation.
- [0095] The procedure for notifying UAS operation status in 5GS is illustrated in Fig. 8. According to some embodiments, the UAS operation services requested may rely on the following process:
- [0096] 1. The UTM-AF notifies the successful association of a UAS by sending a Nnef_UAS_Operation_Status_Update Request (AF Identifier, Transaction Reference ID, External identifiers/External Group identifiers of the UAV/UAV controller, UAS operation Status for each Application Identifier, UAS_ID) message to the NEF.
- the UAS operation status can indicate the enabled UAS operation parameters per Application identifier and indicates the corresponding UAS_ID.

- the UAS_ID is allocated by the UTM-AF to identify the association between a UAV and a UAV controller. The related UAS operation for the UAS is associated to the same UAS-ID.
- The UAS operation parameters may include: the allowed application IDs for the UAS operation, UAS operation mode (e.g. indirect C2, direct C2, network navigated C2), IP addresses of available UTM application servers, allowed geographical areas, allowed operation time, allowed operation duration, etc.

[0097] 2. NEF checks the AF authorization of the request for UAS operation status update if the Transaction Reference ID is expired.

[0098] 3. NEF sends the Ncutm_UAS_Status_Update request (SUPI, UAS operation Status for each Application Identifier, UAS_ID) message to the C-UTM/PCF.

[0099] 4. C-UTM/PCF function updates the UAS operation status including the policies per application identifier and the associated UAS_ID.

[0100] 5. C-UTM/PCF function returns the confirmation of the status update to the NEF by sending Ncutm_UAS_Operation_Update response (UAS_ID, SUPI) message.

[0101] 6. The NEF returns the Nnef_UAS_Operation_Status_Update response (Transaction Reference ID) message to the AF.

[0102] Alternatively, the UAS_ID can be allocated by the C-UTM/PCF in action 4 to identify the associated UAS operation policies when received the status update indicating the successful association for the UAV/UAV controller. The C-UTM/PCF function starts to use the UAS-ID to identify the UAS and activate UAS operation policy for any indicated UAS services events associated to the UAV and the UAV controller. In this case, the following modification may be implemented:

- Action 1: replace UAS_ID with External identifiers/External Group identifiers of the UAV/UAV controller
- Action 3: UAS_ID is not included
- Action 5: UAS_ID is provided along with the SUPI to indicate that the SUPI is with active UAS_operation policies associated to the UAS_ID.
- Action 6: UAS_ID is provided in the Nnef_UAS_Operation_Status_Update response message.

[0103] The similar procedure can be supported in EPS as further illustrated in Fig. 9 (Procedure for Notifying UAS Operating Status in EPS).

[0104] The similar message flows can be exchanged between the SCS/AS with UTM-Application Server and the C-UTM function for the UAS operation Stop/Suspend/Resume procedure as shown in Fig. 7 with proper messages or indication in the messages to indicate the action requested, e.g. start, stop, suspend, resume, for the indicated service identified by the application ID.

Implementation 4: C2 communication Set up for an AS session with required QoS

[0105] According to some embodiments, in the AF session setup with required QoS procedure, the AF includes description of the application flows to indicate the following two sessions:

- The UTM session between AF and the UAV: this connection is to track real-time UAV trajectories, in flight meters information, etc. In the network navigated C2 (as shown in Fig. 2), this session can be used to transport commands to control/operate the UAV remotely and directly.
- The C2 session between UEs in UAV and the UAV controller: this connection is to transport the control and commands received from the UAV controller, operated by a pilot, and forwarded to UAV, and vice versa. In response, the UAV can also use this C2 session to respond some real-time UAV trajectories, in flight meters information, and even a real-time video. There are two options to anchor the C2 session between the UAV and the UAV controller
 - Option 1-The AF is the anchor point: the UAV and the UAV controller sends commands and response message to the AF and the AF forwards the message, e.g. from the UAV controller to the UAV.
 - Option 2-The AF session is identified by the policies associated with DNAI (DN access identifier over N6) for the UAV or UAV controller.

[0106] According to some aspects, if the PCF support C-UTM functionalities, the procedure of setting up an AS session with required QoS in clause 4.15.6.6 at TS23.502 can be reused with the abovementioned description of the application flows for UTM session and C2 session.

[0107] According to some aspects, if the C-UTM function is a standalone network function, the additional message exchange is required to interact with PCF directly (with new interface between PCF and the C-UTM) or via NEF (with request to NEF for

triggering message as action 3 and 4 via NEF in Fig. 10 (Setting up an AS session with required QoS in 5GS).

[0108] In EPS, similar message flows can be exchanged between the SCS/AS with UTM-Application Server as shown in Fig. 11 (Setting up an AS session with required QoS in EPS), in which the C-UTM function can be PCRF or interact with policy control rules function (PCRF) for dynamic Policy and Charging Control (PCC) and inferencing traffics in PDN connections via PCEF (PGW) and BBERF (SGW), TS23.203. The procedure of setting up an AS session with required QoS in clause 5.11 at TS23.682 can be reused with the abovementioned description of the application flows for UTM session and C2 session.

Implementation 4.1:

[0109] According to some embodiments, following implementation 3, if the UTM-AF detecting the violation of the agreed flight policy, e.g. approaching/entering a forbidden zone, the UTM-AF may enforce the following actions to take over the control of the UAV:

Option 1: (C2 session is anchored at the AF)

- the UTM application server replaces the commands sent by the UAV controller with its new command to take over the UAV controller using the C2 session.
- In this option, the UAV is not aware that UTM-AF is involving the C2 communication to fly the UAV.

Option 2: (C2 session is associated with DNAI)

- The UTM-AF may send warning message to notify the UAV controller for UAS operation via UTM session with UAV controller.
- The UTM-AF may send notification message to notify the UAV for UAS operation via UTM session with the UAV.
- the UTM-AF sends a request message to C-UTM/PCF for suspending the UAS operation via C2 session or update the UAS operation mode to network navigated C2 mode (as shown in Fig. 2).
- Further, the UTM-AF uses the UTM session to signal the commands for navigating the UAV directly.
- The UAV receives the notification indication and then ignores any information sent by the UAV controller and only follows the instructions from the UTM.

Implementation 4.2: For the AF session with multiple traffic types.

- [0110] According to some embodiments, following implementation 4, for the C2 session with the traffic types as indicated in Table 1, this implementation provide mechanism for the AF to request differentiated QoS for each IP flows with different traffic types.
- [0111] Referring to Fig. 10, the AF sends Nnef_AFsessionWithQoS_Create request message and include traffic type information per Description of the application flows, i.e. per application and IP flows.
- [0112] Option 1: The traffic type definition can be pre-configured in NEF/PCF based on the agreements between the MNO and third party AF. By this way, the NEF and PCF can differentiate the traffic flows based on the traffic type definition and provision with corresponding QoS, whereby the traffic types includes commands, video streaming, real-time traffic (voice), telemetry, etc.
- [0113] Option 2: the UTM provisions parameters to NEF/PCF for defining traffic types of C2 communication including commands, video streaming, real-time traffic (voice), telemetry, etc. The procedure illustrated in Fig. 12 (associated with Fig. 4.15.6.2-1 Nnef_ParameterProvision_update request/response operations in TS23.502) can be used to provision parameters of traffic types with associated application identifier to the UDM/UDR via NEF.
- [0114] Option 3: The UTM allocates different port numbers for an IP flow which is corresponding to different traffic types. The AS session setting up with required QoS procedure as indicated in Figs. 10 and 11 can be used to differentiate IP flows with port number corresponding to different traffic types. Different traffic types can thus be provisioned with required QoS.
- [0115] According to some aspects, by this way, the NEF and PCF can differentiate the traffic flows with corresponding QoS, in which the following service requirements can be fulfilled.
- The 5G system shall support a mechanism to interact with UTM for obtaining required UAS service information with traffic types, traffic flows, and requested QoS for handling C2 communication with differentiated QoS and traffic policies.
 - The 5G system shall allow UTM to provision parameters for traffic types of C2 communication including commands, video streaming, telemetry, etc.

- The 5G system shall be able to identify the traffic of a UAS for command and control (C2) communication and other traffic associated to the same or different applications.
- The 5G system shall provide a mechanism to provision required QoS to the traffic for C2 communication and other traffic associated to the same or different applications.

Implementation 5: Flight Plan based UAS operation

[0116] For the flight plan based operation as shown in Fig. 2, the UTM-AF acts as a role of UAV controller. Therefore, UAS association procedure is not needed.

- For the network navigated C2 with flight plan for UAS operation, the previous implementation 2 and 3 are needed only for UAV.
- For solution 3, only UTM session is required.
- Further, for the subscription, the UAV needs to have subscription for UAS Operation using network navigated C2. In this case, the UAV is remotely controlled by the UTM application server.

Implementation 6: EPS enhancement for UAS association and identification procedure

[0117] This solution provides the following method for the UAS association and UAS identification between the UAV and UAV controller.

[0118] In this solution, assuming that the UE in the UAS is registered to EPC, the UAS association between the UAV and UAV controller may reuse the method in TS23.303 clause 5.5 of EPC-level ProSe Discovery procedure, with the following modification as EPC-level UAS Identification and Association procedure for UAS service.

- The related identifiers can be referred to clause 4.6.1. The corresponding sets of identifiers are designed for UAS users.
- The C-UTM function acts as a ProSe Function, and the UTM-AF is as Application Server.
- The C-UTM function stores the UAS service authorization information.
- After the UAV and the UAV controller get confirmation for the successful association from the C-UTM function, they don't need to perform ProSe direct discovery procedure.

[0119] According to some aspects, a Proximity Request procedure comparable to clause 5.5.5 in TS23.303 (illustrated in Fig. 13), may be used to identify the UAV and the UAV controller to be associated and can be operated as a UAS:

- The App Server stores the association information of the UAV and the UAV controller.
- If UAV and the UAV controller have been registered to the Application server.
 - In action 3, the MAP Response message contains an indication for the confirmation of the association.
 - In action 4, the Proximity Request message indicates to the ProSe Function B for the confirmation of the association.
 - In action 8b, Proximity Request Ack message indicates to the UE-A for the confirmation of the association.
- The indication in the above message can be an UAS-ID allocated by the App Server/C-UTM Function A.
- In Action 5, the new criterion to reject the request is added such that the C-UTM Function B may determine that the network cannot provide reliable and low latency C2 communication connection between the UAV and the UAV controller via network. The C-UTM Function B can reject the proximity request with an appropriate cause value.
- If the indication is an UAS ID, in the Proximity Alert procedure in clause 5.5.7 of TS23.303 (illustrated in Fig. 14), in Action 4b and 5a Proximity Alert message may then contain the UAS ID to UE A and UE B, respectively.

[0120] Alternatively, since two UEs do not have to be in proximity to be associated (discovered). Therefore, the following optimization can be done:

- for the proximity Request procedure in clause 5.5.5e, location related procedure may be skipped in action 5a, 7a, 8a, e.g. by setting Range class as a value that can be ignored, e.g. * means any ranges, or making Range IE as optional (not included in the action 1).
- After receiving Proximity request in action 4, if the UE B has not been authorized by the C-UTM Function B, the C-UTM Function B sets a validity timer for the UE B based on the value of window. If the UE B reaches to C-

UTM function B for UAS authorization using Proximity Request to the C-UTM function B, and the C-UTM Function B authorizes the UE B before the validity timer is expired, the C-UTM function B sends Proximity Alert message to UE A via C-UTM Function A, as shown in action 4b in clause 5.5.7, Proximity Alert procedure.

[0121] According to some embodiments, for 5GS, the procedure can use the similar message flows with the following additions:

- Requires new messages to exchange information for interface between the C-UTM/PCF function A and C-UTM/PCF function B.
- Requires new message to exchange information for communication between the UAV/UAV-C and the C-UTM/PCF function. If PCF is with C-UTM functionalities, the UE initiated UE Configuration Update procedure can be applied.
- LCS related message flows can be replaced by the eLCS procedures in 5GS.

Implementation 7:

[0122] This implementation addresses issue 5.

[0123] According to some embodiments, the 3GPP system shall enable a UAV to broadcast the following information in broadcasting message in a short-range area for collision avoidance: UAV identities, UAV type, current location and time, locations at point of interest at next 6-10 seconds, current speed, detected information from nearby UAVs, operating status.

[0124] The local broadcasting mechanism can refer to TS23.303 clause 5.4.1-5.4.3: Procedures for ProSe Direct one-to-many Communication without related group configuration. Illustrated in Fig. 15 is a one-to-many ProSe Direct Communication transmission (associated with Fig. 5.4.2-1 of TS23.303).

Systems and Implementations

[0125] Fig. 16 illustrates an example architecture of a system 1600 of a network, in accordance with various embodiments. The following description is provided for an example system 1600 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.

[0126] As shown by Fig. 16, the system 1600 includes UE 1601a and UE 1601b (collectively referred to as “UEs 1601” or “UE 1601”). In this example, UEs 1601 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.

[0127] In some embodiments, any of the UEs 1601 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.

[0128] The UEs 1601 may be configured to connect, for example, communicatively couple, with an or RAN 1610. In embodiments, the RAN 1610 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 1610 that operates in an NR or 5G system 1600, and the term “E-UTRAN” or the like may refer to a RAN 1610 that

operates in an LTE or 4G system 1600. The UEs 1601 utilize connections (or channels) 1603 and 1604, respectively, each of which comprises a physical communications interface or layer (discussed in further detail below).

[0129] In this example, the connections 1603 and 1604 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 1601 may directly exchange communication data via a ProSe interface 1605. The ProSe interface 1605 may alternatively be referred to as a SL interface 1605 and may comprise one or more logical channels, including but not limited to a PSCCH, a PSSCH, a PSDCH, and a PSBCH.

[0130] The UE 1601b is shown to be configured to access an AP 1606 (also referred to as “WLAN node 1606,” “WLAN 1606,” “WLAN Termination 1606,” “WT 1606” or the like) via connection 1607. The connection 1607 can comprise a local wireless connection, such as a connection consistent with any IEEE 802.11 protocol, wherein the AP 1606 would comprise a wireless fidelity (Wi-Fi®) router. In this example, the AP 1606 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 1601b, RAN 1610, and AP 1606 may be configured to utilize LWA operation and/or LWIP operation. The LWA operation may involve the UE 1601b in RRC_CONNECTED being configured by a RAN node 1611a-b to utilize radio resources of LTE and WLAN. LWIP operation may involve the UE 1601b using WLAN radio resources (e.g., connection 1607) via IPsec protocol tunneling to authenticate and encrypt packets (e.g., IP packets) sent over the connection 1607. 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.

[0131] The RAN 1610 can include one or more AN nodes or RAN nodes 1611a and 1611b (collectively referred to as “RAN nodes 1611” or “RAN node 1611”) that enable the connections 1603 and 1604. 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 1611 that operates in an NR or 5G system 1600 (for example, a gNB), and the term “E-UTRAN node” or the like may refer to a RAN node 1611 that operates in an LTE or 4G system 1600 (e.g., an eNB). According to various embodiments, the RAN nodes 1611 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.

[0132] In some embodiments, all or parts of the RAN nodes 1611 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 1611; 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 1611; 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 1611. This virtualized framework allows the freed-up processor cores of the RAN nodes 1611 to perform other virtualized applications. In some implementations, an individual RAN node 1611 may represent individual gNB-DUs that are connected to a gNB-CU via individual F1 interfaces (not shown by Fig. 16). In these implementations, the gNB-DUs may include one or more remote radio heads or RFEMs (see, e.g., Fig. 19), and the gNB-CU may be operated by a server that is located in the RAN 1610 (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 1611 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 1601, and are connected to a 5GC (e.g., CN 1820 of Fig. 18) via an NG interface (discussed infra).

[0133] In V2X scenarios one or more of the RAN nodes 1611 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 1601 (vUEs 1601). 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.

[0134] Any of the RAN nodes 1611 can terminate the air interface protocol and can be the first point of contact for the UEs 1601. In some embodiments, any of the RAN nodes 1611 can fulfill various logical functions for the RAN 1610 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.

[0135] In embodiments, the UEs 1601 can be configured to communicate using OFDM communication signals with each other or with any of the RAN nodes 1611 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.

[0136] In some embodiments, a downlink resource grid can be used for downlink transmissions from any of the RAN nodes 1611 to the UEs 1601, 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.

[0137] According to various embodiments, the UEs 1601, 1602 and the RAN nodes 1611, 1612 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.

[0138] To operate in the unlicensed spectrum, the UEs 1601, 1602 and the RAN nodes 1611, 1612 may operate using LAA, eLAA, and/or feLAA mechanisms. In these implementations, the UEs 1601, 1602 and the RAN nodes 1611, 1612 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.

[0139] LBT is a mechanism whereby equipment (for example, UEs 1601, 1602, RAN nodes 1611, 1612, 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.

[0140] 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 1601 or 1602, AP 1606, 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 (μ s); however, the size of the CWS and a MCOT (for example, a transmission burst) may be based on governmental regulatory requirements.

[0141] 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.

[0142] 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 1601, 1602 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.

[0143] The PDSCH carries user data and higher-layer signaling to the UEs 1601. 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 1601 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 1601b within a cell) may be performed at any of the RAN nodes 1611 based on channel quality information fed back from any of the UEs 1601. The downlink resource assignment information may be sent on the PDCCH used for (e.g., assigned to) each of the UEs 1601.

[0144] 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).

[0145] 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.

[0146] The RAN nodes 1611 may be configured to communicate with one another via interface 1612. In embodiments where the system 1600 is an LTE system (e.g., when CN 1620 is an EPC 1720 as in Fig. 17), the interface 1612 may be an X2 interface 1612. The X2 interface may be defined between two or more RAN nodes 1611 (e.g., two or more eNBs and the like) that connect to EPC 1620, and/or between two eNBs connecting to EPC 1620. 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 1601 from an SeNB for user data; information of PDCP PDUs that were not delivered to a UE 1601; 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.

[0147] In embodiments where the system 1600 is a 5G or NR system (e.g., when CN 1620 is an 5GC 1820 as in Fig. 18), the interface 1612 may be an Xn interface 1612. The Xn interface is defined between two or more RAN nodes 1611 (e.g., two or more gNBs and the like) that connect to 5GC 1620, between a RAN node 1611 (e.g., a gNB) connecting to 5GC 1620 and an eNB, and/or between two eNBs connecting to 5GC 1620.

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 1601 in a connected mode (e.g., CM-CONNECTED) including functionality to manage the UE mobility for connected mode between one or more RAN nodes 1611. The mobility support may include context transfer from an old (source) serving RAN node 1611 to new (target) serving RAN node 1611; and control of user plane tunnels between old (source) serving RAN node 1611 to new (target) serving RAN node 1611. 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.

[0148] The RAN 1610 is shown to be communicatively coupled to a core network—in this embodiment, core network (CN) 1620. The CN 1620 may comprise a plurality of network elements 1622, which are configured to offer various data and telecommunications services to customers/subscribers (e.g., users of UEs 1601) who are connected to the CN 1620 via the RAN 1610. The components of the CN 1620 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 1620 may be referred to as a network slice, and a logical instantiation of a portion of the CN 1620 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.

[0149] Generally, the application server 1630 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 1630 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 1601 via the EPC 1620.

[0150] In embodiments, the CN 1620 may be a 5GC (referred to as “5GC 1620” or the like), and the RAN 1610 may be connected with the CN 1620 via an NG interface 1613. In embodiments, the NG interface 1613 may be split into two parts, an NG user plane (NG-U) interface 1614, which carries traffic data between the RAN nodes 1611 and a UPF, and the S1 control plane (NG-C) interface 1615, which is a signaling interface between the RAN nodes 1611 and AMFs. Embodiments where the CN 1620 is a 5GC 1620 are discussed in more detail with regard to Fig. 18.

[0151] In embodiments, the CN 1620 may be a 5G CN (referred to as “5GC 1620” or the like), while in other embodiments, the CN 1620 may be an EPC). Where CN 1620 is an EPC (referred to as “EPC 1620” or the like), the RAN 1610 may be connected with the CN 1620 via an S1 interface 1613. In embodiments, the S1 interface 1613 may be split into two parts, an S1 user plane (S1-U) interface 1614, which carries traffic data between the RAN nodes 1611 and the S-GW, and the S1-MME interface 1615, which is a signaling interface between the RAN nodes 1611 and MMEs. An example architecture wherein the CN 1620 is an EPC 1620 is shown by Fig. 17.

[0152] Fig. 17 illustrates an example architecture of a system 1700 including a first CN 1720, in accordance with various embodiments. In this example, system 1700 may implement the LTE standard wherein the CN 1720 is an EPC 1720 that corresponds with CN 1620 of Fig. 16. Additionally, the UE 1701 may be the same or similar as the UEs 1601 of Fig. 16, and the E-UTRAN 1710 may be a RAN that is the same or similar to the RAN 1610 of Fig. 16, and which may include RAN nodes 1611 discussed previously.

The CN 1720 may comprise MMEs 1721, an S-GW 1722, a P-GW 1723, a HSS 1724, and a SGSN 1725.

[0153] The MMEs 1721 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 1701. The MMEs 1721 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 1701, provide user identity confidentiality, and/or perform other like services to users/subscribers. Each UE 1701 and the MME 1721 may include an MM or EMM sublayer, and an MM context may be established in the UE 1701 and the MME 1721 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 1701. The MMEs 1721 may be coupled with the HSS 1724 via an S6a reference point, coupled with the SGSN 1725 via an S3 reference point, and coupled with the S-GW 1722 via an S11 reference point.

[0154] The SGSN 1725 may be a node that serves the UE 1701 by tracking the location of an individual UE 1701 and performing security functions. In addition, the SGSN 1725 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 1721; handling of UE 1701 time zone functions as specified by the MMEs 1721; and MME selection for handovers to E-UTRAN 3GPP access network. The S3 reference point between the MMEs 1721 and the SGSN 1725 may enable user and bearer information exchange for inter-3GPP access network mobility in idle and/or active states.

[0155] The HSS 1724 may comprise a database for network users, including subscription-related information to support the network entities’ handling of communication sessions. The EPC 1720 may comprise one or several HSSs 1724, depending on the number of mobile subscribers, on the capacity of the equipment, on the organization of the network, etc. For example, the HSS 1724 can provide support for routing/roaming, authentication, authorization, naming/addressing resolution, location dependencies, etc. An S6a reference point between the HSS 1724 and the MMEs 1721

may enable transfer of subscription and authentication data for authenticating/authorizing user access to the EPC 1720 between HSS 1724 and the MMEs 1721.

[0156] The S-GW 1722 may terminate the S1 interface 1613 (“S1-U” in Fig. 17) toward the RAN 1710, and routes data packets between the RAN 1710 and the EPC 1720. In addition, the S-GW 1722 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 1722 and the MMEs 1721 may provide a control plane between the MMEs 1721 and the S-GW 1722. The S-GW 1722 may be coupled with the P-GW 1723 via an S5 reference point.

[0157] The P-GW 1723 may terminate an SGi interface toward a PDN 1730. The P-GW 1723 may route data packets between the EPC 1720 and external networks such as a network including the application server 1630 (alternatively referred to as an “AF”) via an IP interface 1625 (see e.g., Fig. 16). In embodiments, the P-GW 1723 may be communicatively coupled to an application server (application server 1630 of Fig. 16 or PDN 1730 in Fig. 17) via an IP communications interface 1625 (see, e.g., Fig. 16). The S5 reference point between the P-GW 1723 and the S-GW 1722 may provide user plane tunneling and tunnel management between the P-GW 1723 and the S-GW 1722. The S5 reference point may also be used for S-GW 1722 relocation due to UE 1701 mobility and if the S-GW 1722 needs to connect to a non-located P-GW 1723 for the required PDN connectivity. The P-GW 1723 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 1723 and the packet data network (PDN) 1730 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 1723 may be coupled with a PCRF 1726 via a Gx reference point.

[0158] PCRF 1726 is the policy and charging control element of the EPC 1720. In a non-roaming scenario, there may be a single PCRF 1726 in the Home Public Land Mobile Network (HPLMN) associated with a UE 1701’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 1701’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 1726 may be communicatively coupled to the application server 1730 via the P-GW 1723. The application server 1730 may signal the PCRF 1726 to indicate a new service flow and select the appropriate QoS and charging parameters. The PCRF 1726 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 1730. The Gx reference point between the PCRF 1726 and the P-GW 1723 may allow for the transfer of QoS policy and charging rules from the PCRF 1726 to PCEF in the P-GW 1723. An Rx reference point may reside between the PDN 1730 (or “AF 1730”) and the PCRF 1726.

[0159] Fig. 18 illustrates an architecture of a system 1800 including a second CN 1820 in accordance with various embodiments. The system 1800 is shown to include a UE 1801, which may be the same or similar to the UEs 1601 and UE 1701 discussed previously; a (R)AN 1810, which may be the same or similar to the RAN 1610 and RAN 1710 discussed previously, and which may include RAN nodes 1611 discussed previously; and a DN 1803, which may be, for example, operator services, Internet access or 3rd party services; and a 5GC 1820. The 5GC 1820 may include an AUSF 1822; an AMF 1821; a SMF 1824; a NEF 1823; a PCF 1826; a NRF 1825; a UDM 1827; an AF 1828; a UPF 1802; and a NSSF 1829.

[0160] The UPF 1802 may act as an anchor point for intra-RAT and inter-RAT mobility, an external PDU session point of interconnect to DN 1803, and a branching point to support multi-homed PDU session. The UPF 1802 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 1802 may include an uplink classifier to support routing traffic flows to a data network. The DN 1803 may represent various network operator services, Internet access, or third party services. DN 1803 may include, or be similar to, application server 1630 discussed previously. The UPF 1802 may interact with the SMF 1824 via an N4 reference point between the SMF 1824 and the UPF 1802.

- [0161] The AUSF 1822 may store data for authentication of UE 1801 and handle authentication-related functionality. The AUSF 1822 may facilitate a common authentication framework for various access types. The AUSF 1822 may communicate with the AMF 1821 via an N12 reference point between the AMF 1821 and the AUSF 1822; and may communicate with the UDM 1827 via an N13 reference point between the UDM 1827 and the AUSF 1822. Additionally, the AUSF 1822 may exhibit an Nausf service-based interface.
- [0162] The AMF 1821 may be responsible for registration management (e.g., for registering UE 1801, etc.), connection management, reachability management, mobility management, and lawful interception of AMF-related events, and access authentication and authorization. The AMF 1821 may be a termination point for the an N11 reference point between the AMF 1821 and the SMF 1824. The AMF 1821 may provide transport for SM messages between the UE 1801 and the SMF 1824, and act as a transparent proxy for routing SM messages. AMF 1821 may also provide transport for SMS messages between UE 1801 and an SMSF (not shown by Fig. 18). AMF 1821 may act as SEAF, which may include interaction with the AUSF 1822 and the UE 1801, receipt of an intermediate key that was established as a result of the UE 1801 authentication process. Where USIM based authentication is used, the AMF 1821 may retrieve the security material from the AUSF 1822. AMF 1821 may also include a SCM function, which receives a key from the SEA that it uses to derive access-network specific keys. Furthermore, AMF 1821 may be a termination point of a RAN CP interface, which may include or be an N2 reference point between the (R)AN 1810 and the AMF 1821; and the AMF 1821 may be a termination point of NAS (N1) signalling, and perform NAS ciphering and integrity protection.
- [0163] AMF 1821 may also support NAS signalling with a UE 1801 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 1810 and the AMF 1821 for the control plane, and may be a termination point for the N3 reference point between the (R)AN 1810 and the UPF 1802 for the user plane. As such, the AMF 1821 may handle N2 signalling from the SMF 1824 and the AMF 1821 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 1801 and AMF 1821 via an N1 reference point between the UE 1801 and the AMF 1821, and relay uplink and downlink user-plane packets between the UE 1801 and UPF 1802. The N3IWF also provides mechanisms for IPsec tunnel establishment with the UE 1801. The AMF 1821 may exhibit an Namf service-based interface, and may be a termination point for an N14 reference point between two AMFs 1821 and an N17 reference point between the AMF 1821 and a 5G-EIR (not shown by Fig. 18).

[0164] The UE 1801 may need to register with the AMF 1821 in order to receive network services. RM is used to register or deregister the UE 1801 with the network (e.g., AMF 1821), and establish a UE context in the network (e.g., AMF 1821). The UE 1801 may operate in an RM-REGISTERED state or an RM-DEREGISTERED state. In the RM-DEREGISTERED state, the UE 1801 is not registered with the network, and the UE context in AMF 1821 holds no valid location or routing information for the UE 1801 so the UE 1801 is not reachable by the AMF 1821. In the RM-REGISTERED state, the UE 1801 is registered with the network, and the UE context in AMF 1821 may hold a valid location or routing information for the UE 1801 so the UE 1801 is reachable by the AMF 1821. In the RM-REGISTERED state, the UE 1801 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 1801 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.

[0165] The AMF 1821 may store one or more RM contexts for the UE 1801, 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 1821 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 1821 may store a CE mode B Restriction parameter of the UE 1801 in an associated MM context or RM context. The AMF 1821 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).

[0166] CM may be used to establish and release a signaling connection between the UE 1801 and the AMF 1821 over the N1 interface. The signaling connection is used to enable NAS signaling exchange between the UE 1801 and the CN 1820, 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 1801 between the AN (e.g., RAN 1810) and the AMF 1821. The UE 1801 may operate in one of two CM states, CM-IDLE mode or CM-CONNECTED mode. When the UE 1801 is operating in the CM-IDLE state/mode, the UE 1801 may have no NAS signaling connection established with the AMF 1821 over the N1 interface, and there may be (R)AN 1810 signaling connection (e.g., N2 and/or N3 connections) for the UE 1801. When the UE 1801 is operating in the CM-CONNECTED state/mode, the UE 1801 may have an established NAS signaling connection with the AMF 1821 over the N1 interface, and there may be a (R)AN 1810 signaling connection (e.g., N2 and/or N3 connections) for the UE 1801. Establishment of an N2 connection between the (R)AN 1810 and the AMF 1821 may cause the UE 1801 to transition from CM-IDLE mode to CM-CONNECTED mode, and the UE 1801 may transition from the CM-CONNECTED mode to the CM-IDLE mode when N2 signaling between the (R)AN 1810 and the AMF 1821 is released.

[0167] The SMF 1824 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 1801 and a data network (DN) 1803 identified by a Data Network Name (DNN). PDU sessions may be established upon UE 1801 request, modified upon UE 1801 and 5GC 1820 request, and released upon UE 1801 and 5GC 1820 request using NAS SM signaling exchanged over the N1 reference point between the UE 1801 and the SMF 1824. Upon request from an application server, the 5GC 1820 may trigger a specific

application in the UE 1801. In response to receipt of the trigger message, the UE 1801 may pass the trigger message (or relevant parts/information of the trigger message) to one or more identified applications in the UE 1801. The identified application(s) in the UE 1801 may establish a PDU session to a specific DNN. The SMF 1824 may check whether the UE 1801 requests are compliant with user subscription information associated with the UE 1801. In this regard, the SMF 1824 may retrieve and/or request to receive update notifications on SMF 1824 level subscription data from the UDM 1827.

[0168] The SMF 1824 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 1824 may be included in the system 1800, which may be between another SMF 1824 in a visited network and the SMF 1824 in the home network in roaming scenarios. Additionally, the SMF 1824 may exhibit the Nsmf service-based interface.

[0169] The NEF 1823 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 1828), edge computing or fog computing systems, etc. In such embodiments, the NEF 1823 may authenticate, authorize, and/or throttle the AFs. NEF 1823 may also translate information exchanged with the AF 1828 and information exchanged with internal network functions. For example, the NEF 1823 may translate between an AF-Service-Identifier and an internal 5GC information. NEF 1823 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 1823 as structured data, or at a data storage NF using standardized interfaces. The stored information can then be re-exposed by the NEF 1823 to other NFs and AFs, and/or used for other purposes such as analytics. Additionally, the NEF 1823 may exhibit an Nnef service-based interface.

[0170] The NRF 1825 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 1825 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 1825 may exhibit the Nnrf service-based interface.

[0171] The PCF 1826 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 1826 may also implement an FE to access subscription information relevant for policy decisions in a UDR of the UDM 1827. The PCF 1826 may communicate with the AMF 1821 via an N15 reference point between the PCF 1826 and the AMF 1821, which may include a PCF 1826 in a visited network and the AMF 1821 in case of roaming scenarios. The PCF 1826 may communicate with the AF 1828 via an N5 reference point between the PCF 1826 and the AF 1828; and with the SMF 1824 via an N7 reference point between the PCF 1826 and the SMF 1824. The system 1800 and/or CN 1820 may also include an N24 reference point between the PCF 1826 (in the home network) and a PCF 1826 in a visited network. Additionally, the PCF 1826 may exhibit an Npcf service-based interface.

[0172] The UDM 1827 may handle subscription-related information to support the network entities' handling of communication sessions, and may store subscription data of UE 1801. For example, subscription data may be communicated between the UDM 1827 and the AMF 1821 via an N8 reference point between the UDM 1827 and the AMF. The UDM 1827 may include two parts, an application FE and a UDR (the FE and UDR are not shown by Fig. 18). The UDR may store subscription data and policy data for the UDM 1827 and the PCF 1826, and/or structured data for exposure and application data (including PFDs for application detection, application request information for multiple UEs 1801) for the NEF 1823. The Nudr service-based interface may be exhibited by the UDR 221 to allow the UDM 1827, PCF 1826, and NEF 1823 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 1824 via an N10 reference point between the UDM 1827 and the SMF 1824. UDM 1827 may also support SMS management, wherein an SMS-FE implements the similar application logic as discussed previously. Additionally, the UDM 1827 may exhibit the Nudm service-based interface.

[0173] The AF 1828 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 1820 and AF 1828 to provide information to each other via NEF 1823, 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 1801 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 1802 close to the UE 1801 and execute traffic steering from the UPF 1802 to DN 1803 via the N6 interface. This may be based on the UE subscription data, UE location, and information provided by the AF 1828. In this way, the AF 1828 may influence UPF (re)selection and traffic routing. Based on operator deployment, when AF 1828 is considered to be a trusted entity, the network operator may permit AF 1828 to interact directly with relevant NFs. Additionally, the AF 1828 may exhibit an Naf service-based interface.

[0174] The NSSF 1829 may select a set of network slice instances serving the UE 1801. The NSSF 1829 may also determine allowed NSSAI and the mapping to the subscribed S-NSSAIs, if needed. The NSSF 1829 may also determine the AMF set to be used to serve the UE 1801, or a list of candidate AMF(s) 1821 based on a suitable configuration and possibly by querying the NRF 1825. The selection of a set of network slice instances for the UE 1801 may be triggered by the AMF 1821 with which the UE 1801 is registered by interacting with the NSSF 1829, which may lead to a change of AMF 1821. The NSSF 1829 may interact with the AMF 1821 via an N22 reference point between AMF 1821 and NSSF 1829; and may communicate with another NSSF 1829 in a visited network via an N31 reference point (not shown by Fig. 18). Additionally, the NSSF 1829 may exhibit an Nnssf service-based interface.

[0175] As discussed previously, the CN 1820 may include an SMSF, which may be responsible for SMS subscription checking and verification, and relaying SM messages to/from the UE 1801 to/from other entities, such as an SMS-GMSC/IW MSC/SMS-router.

The SMS may also interact with AMF 1821 and UDM 1827 for a notification procedure that the UE 1801 is available for SMS transfer (e.g., set a UE not reachable flag, and notifying UDM 1827 when UE 1801 is available for SMS).

[0176] The CN 1820 may also include other elements that are not shown by Fig. 18, 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 Fig. 18). 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 Fig. 18). 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.

[0177] 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 Fig. 18 for clarity. In one example, the CN 1820 may include an Nx interface, which is an inter-CN interface between the MME (e.g., MME 1721) and the AMF 1821 in order to enable interworking between CN 1820 and CN 1720. 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.

[0178] Fig. 19 illustrates an example of infrastructure equipment 1900 in accordance with various embodiments. The infrastructure equipment 1900 (or “system 1900”) may be implemented as a base station, radio head, RAN node such as the RAN nodes 1611 and/or AP 1606 shown and described previously, application server(s) 1630, and/or any other element/device discussed herein. In other examples, the system 1900 could be implemented in or by a UE.

[0179] The system 1900 includes application circuitry 1905, baseband circuitry 1910, one or more radio front end modules (RFEMs) 1915, memory circuitry 1920, power management integrated circuitry (PMIC) 1925, power tee circuitry 1930, network

controller circuitry 1935, network interface connector 1940, satellite positioning circuitry 1945, and user interface 1950. In some embodiments, the device 1900 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.

[0180] Application circuitry 1905 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, I²C 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 1905 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 1900. 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.

[0181] The processor(s) of application circuitry 1905 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 1905 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 1905 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 1900 may not utilize application circuitry 1905, and instead may include a special-purpose processor/controller to process IP data received from an EPC or 5GC, for example.

[0182] In some implementations, the application circuitry 1905 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 1905 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 1905 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.

[0183] The baseband circuitry 1910 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 1910 are discussed infra with regard to Fig. 21.

[0184] User interface circuitry 1950 may include one or more user interfaces designed to enable user interaction with the system 1900 or peripheral component interfaces designed to enable peripheral component interaction with the system 1900. 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.

[0185] The radio front end modules (RFEMs) 1915 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 2111 of Fig. 21 *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 1915, which incorporates both mmWave antennas and sub-mmWave.

[0186] The memory circuitry 1920 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 1920 may be implemented as one or more of solder down packaged integrated circuits, socketed memory modules and plug-in memory cards.

[0187] The PMIC 1925 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 1930 may provide for electrical power drawn from a network cable to provide both power supply and data connectivity to the infrastructure equipment 1900 using a single cable.

[0188] The network controller circuitry 1935 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 1900 via network interface connector 1940 using a physical connection, which may be electrical (commonly referred to as a “copper interconnect”), optical, or wireless. The network controller circuitry 1935 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 1935 may include multiple controllers to provide connectivity to other networks using the same or different protocols.

[0189] The positioning circuitry 1945 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 1945 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 1945 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 1945 may also be part of, or interact with, the baseband circuitry 1910 and/or RFEMs 1915 to communicate with the nodes and components of the positioning network. The positioning circuitry 1945 may also provide position data and/or time data to the application circuitry 1905, which may use the data to synchronize operations with various infrastructure (e.g., RAN nodes 1611, etc.), or the like.

[0190] The components shown by Fig. 19 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 I²C interface, an SPI interface, point to point interfaces, and a power bus, among others.

[0191] Fig. 20 illustrates an example of a platform 2000 (or “device 2000”) in accordance with various embodiments. In embodiments, the computer platform 2000 may be suitable for use as UEs 1601, 1602, 1701, application servers 1630, and/or any other element/device discussed herein. The platform 2000 may include any combinations of the components shown in the example. The components of platform 2000 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 2000, or as components otherwise incorporated within a chassis of a larger system. The block diagram of Fig. 20 is intended to show a high level view of components of the computer platform 2000. 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.

[0192] Application circuitry 2005 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, I²C 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 2005 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 2000. 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.

[0193] The processor(s) of application circuitry 1905 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 1905 may comprise, or may be, a special-purpose processor/controller to operate according to the various embodiments herein.

[0194] As examples, the processor(s) of application circuitry 2005 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 2005 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 2005 may be a part of a system on a chip (SoC) in which the application circuitry 2005 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.

[0195] Additionally or alternatively, application circuitry 2005 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 2005 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 2005 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.

[0196] The baseband circuitry 2010 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 2010 are discussed infra with regard to Fig. 21.

[0197] The RFEMs 2015 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 2111 of Fig. 21 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 2015, which incorporates both mmWave antennas and sub-mmWave.

[0198] The memory circuitry 2020 may include any number and type of memory devices used to provide for a given amount of system memory. As examples, the memory circuitry 2020 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 2020 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 2020 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 2020 may be on-die memory or registers associated with the application circuitry 2005. To provide for persistent storage of information such as data, applications, operating systems and so forth, memory circuitry 2020 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 2000 may incorporate the three-dimensional (3D) cross-point (XPOINT) memories from Intel® and Micron®.

[0199] Removable memory circuitry 2023 may include devices, circuitry, enclosures/housings, ports or receptacles, etc. used to couple portable data storage devices with the platform 2000. 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.

[0200] The platform 2000 may also include interface circuitry (not shown) that is used to connect external devices with the platform 2000. The external devices connected to the platform 2000 via the interface circuitry include sensor circuitry 2021 and electro-mechanical components (EMCs) 2022, as well as removable memory devices coupled to removable memory circuitry 2023.

[0201] The sensor circuitry 2021 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.

[0202] EMCs 2022 include devices, modules, or subsystems whose purpose is to enable platform 2000 to change its state, position, and/or orientation, or move or control a mechanism or (sub)system. Additionally, EMCs 2022 may be configured to generate and send messages/signalling to other components of the platform 2000 to indicate a current

state of the EMCs 2022. Examples of the EMCs 2022 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 2000 is configured to operate one or more EMCs 2022 based on one or more captured events and/or instructions or control signals received from a service provider and/or various clients.

[0203] In some implementations, the interface circuitry may connect the platform 2000 with positioning circuitry 2045. The positioning circuitry 2045 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 2045 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 2045 may include a Micro-PNT IC that uses a master timing clock to perform position tracking/estimation without GNSS assistance. The positioning circuitry 2045 may also be part of, or interact with, the baseband circuitry 1910 and/or RFEMs 2015 to communicate with the nodes and components of the positioning network. The positioning circuitry 2045 may also provide position data and/or time data to the application circuitry 2005, 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

[0204] In some implementations, the interface circuitry may connect the platform 2000 with Near-Field Communication (NFC) circuitry 2040. NFC circuitry 2040 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 2040 and NFC-enabled devices external to the platform 2000 (e.g., an "NFC touchpoint"). NFC circuitry 2040 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 2040 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 2040, or initiate data transfer between the NFC circuitry 2040 and another active NFC device (e.g., a smartphone or an NFC-enabled POS terminal) that is proximate to the platform 2000.

[0205] The driver circuitry 2046 may include software and hardware elements that operate to control particular devices that are embedded in the platform 2000, attached to the platform 2000, or otherwise communicatively coupled with the platform 2000. The driver circuitry 2046 may include individual drivers allowing other components of the platform 2000 to interact with or control various input/output (I/O) devices that may be present within, or connected to, the platform 2000. For example, driver circuitry 2046 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 2000, sensor drivers to obtain sensor readings of sensor circuitry 2021 and control and allow access to sensor circuitry 2021, EMC drivers to obtain actuator positions of the EMCs 2022 and/or control and allow access to the EMCs 2022, 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.

[0206] The power management integrated circuitry (PMIC) 2025 (also referred to as “power management circuitry 2025”) may manage power provided to various components of the platform 2000. In particular, with respect to the baseband circuitry 2010, the PMIC 2025 may control power-source selection, voltage scaling, battery charging, or DC-to-DC conversion. The PMIC 2025 may often be included when the platform 2000 is capable of being powered by a battery 2030, for example, when the device is included in a UE 1601, 1602, 1701.

[0207] In some embodiments, the PMIC 2025 may control, or otherwise be part of, various power saving mechanisms of the platform 2000. For example, if the platform

2000 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 2000 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 2000 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 2000 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 2000 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.

[0208] A battery 2030 may power the platform 2000, although in some examples the platform 2000 may be mounted deployed in a fixed location, and may have a power supply coupled to an electrical grid. The battery 2030 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 2030 may be a typical lead-acid automotive battery.

[0209] In some implementations, the battery 2030 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 2000 to track the state of charge (SoCh) of the battery 2030. The BMS may be used to monitor other parameters of the battery 2030 to provide failure predictions, such as the state of health (SoH) and the state of function (SoF) of the battery 2030. The BMS may communicate the information of the battery 2030 to the application circuitry 2005 or other components of the platform 2000. The BMS may also include an analog-to-digital (ADC) convertor that allows the application circuitry 2005 to directly monitor the voltage of the battery 2030 or the current flow from the battery 2030. The battery parameters may be used to determine

actions that the platform 2000 may perform, such as transmission frequency, network operation, sensing frequency, and the like.

[0210] A power block, or other power supply coupled to an electrical grid may be coupled with the BMS to charge the battery 2030. In some examples, the power block XS30 may be replaced with a wireless power receiver to obtain the power wirelessly, for example, through a loop antenna in the computer platform 2000. 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 2030, 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.

[0211] User interface circuitry 2050 includes various input/output (I/O) devices present within, or connected to, the platform 2000, and includes one or more user interfaces designed to enable user interaction with the platform 2000 and/or peripheral component interfaces designed to enable peripheral component interaction with the platform 2000. The user interface circuitry 2050 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 2000. 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 2021 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.

[0212] Although not shown, the components of platform 2000 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 I²C interface, an SPI interface, point-to-point interfaces, and a power bus, among others.

[0213] Fig. 21 illustrates example components of baseband circuitry 2110 and radio front end modules (RFEM) 2115 in accordance with various embodiments. The baseband circuitry 2110 corresponds to the baseband circuitry 1910 and 2010 of Figs. 19 and 20, respectively. The RFEM 2115 corresponds to the RFEM 1915 and 2015 of Figs. 19 and 20, respectively. As shown, the RFEMs 2115 may include Radio Frequency (RF) circuitry 2106, front-end module (FEM) circuitry 2108, antenna array 2111 coupled together at least as shown.

[0214] The baseband circuitry 2110 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 2106. 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 2110 may include Fast-Fourier Transform (FFT), precoding, or constellation mapping/demapping functionality. In some embodiments, encoding/decoding circuitry of the baseband circuitry 2110 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 2110 is configured to

process baseband signals received from a receive signal path of the RF circuitry 2106 and to generate baseband signals for a transmit signal path of the RF circuitry 2106. The baseband circuitry 2110 is configured to interface with application circuitry 1905/2005 (see Figs 19 and 20) for generation and processing of the baseband signals and for controlling operations of the RF circuitry 2106. The baseband circuitry 2110 may handle various radio control functions.

[0215] The aforementioned circuitry and/or control logic of the baseband circuitry 2110 may include one or more single or multi-core processors. For example, the one or more processors may include a 3G baseband processor 2104A, a 4G/LTE baseband processor 2104B, a 5G/NR baseband processor 2104C, or some other baseband processor(s) 2104D 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 2104A-D may be included in modules stored in the memory 2104G and executed via a Central Processing Unit (CPU) 2104E. In other embodiments, some or all of the functionality of baseband processors 2104A-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 2104G may store program code of a real-time OS (RTOS), which when executed by the CPU 2104E (or other baseband processor), is to cause the CPU 2104E (or other baseband processor) to manage resources of the baseband circuitry 2110, 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 2110 includes one or more audio digital signal processor(s) (DSP) 2104F. The audio DSP(s) 2104F include elements for compression/decompression and echo cancellation and may include other suitable processing elements in other embodiments.

[0216] In some embodiments, each of the processors 2104A-2104E include respective memory interfaces to send/receive data to/from the memory 2104G. The baseband circuitry 2110 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 2110; an application circuitry interface to send/receive data to/from the application circuitry 1905/2005 of FIGS. 19-21); an RF circuitry interface to send/receive data to/from RF circuitry 2106 of Fig. 21; 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 2025.

[0217] In alternate embodiments (which may be combined with the above described embodiments), baseband circuitry 2110 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 2110 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 2115).

[0218] Although not shown by Fig. 21, in some embodiments, the baseband circuitry 2110 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 2110 and/or RF circuitry 2106 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 2110 and/or RF circuitry 2106 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., 2104G) 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 2110 may also support radio communications for more than one wireless protocol.

[0219] The various hardware elements of the baseband circuitry 2110 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 2110 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 2110 and RF circuitry 2106 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 2110 may be implemented as a separate SoC that is communicatively coupled with and RF circuitry 2106 (or multiple instances of RF circuitry 2106). In yet another example, some or all of the constituent components of the baseband circuitry 2110 and the application circuitry 1905/2005 may be implemented together as individual SoCs mounted to a same circuit board (e.g., a “multi-chip package”).

[0220] In some embodiments, the baseband circuitry 2110 may provide for communication compatible with one or more radio technologies. For example, in some embodiments, the baseband circuitry 2110 may support communication with an E-UTRAN or other WMAN, a WLAN, a WPAN. Embodiments in which the baseband

circuitry 2110 is configured to support radio communications of more than one wireless protocol may be referred to as multi-mode baseband circuitry.

[0221] RF circuitry 2106 may enable communication with wireless networks using modulated electromagnetic radiation through a non-solid medium. In various embodiments, the RF circuitry 2106 may include switches, filters, amplifiers, etc. to facilitate the communication with the wireless network. RF circuitry 2106 may include a receive signal path, which may include circuitry to down-convert RF signals received from the FEM circuitry 2108 and provide baseband signals to the baseband circuitry 2110. RF circuitry 2106 may also include a transmit signal path, which may include circuitry to up-convert baseband signals provided by the baseband circuitry 2110 and provide RF output signals to the FEM circuitry 2108 for transmission.

[0222] In some embodiments, the receive signal path of the RF circuitry 2106 may include mixer circuitry 2106a, amplifier circuitry 2106b and filter circuitry 2106c. In some embodiments, the transmit signal path of the RF circuitry 2106 may include filter circuitry 2106c and mixer circuitry 2106a. RF circuitry 2106 may also include synthesizer circuitry 2106d for synthesizing a frequency for use by the mixer circuitry 2106a of the receive signal path and the transmit signal path. In some embodiments, the mixer circuitry 2106a of the receive signal path may be configured to down-convert RF signals received from the FEM circuitry 2108 based on the synthesized frequency provided by synthesizer circuitry 2106d. The amplifier circuitry 2106b may be configured to amplify the down-converted signals and the filter circuitry 2106c 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 2110 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 2106a of the receive signal path may comprise passive mixers, although the scope of the embodiments is not limited in this respect.

[0223] In some embodiments, the mixer circuitry 2106a of the transmit signal path may be configured to up-convert input baseband signals based on the synthesized frequency provided by the synthesizer circuitry 2106d to generate RF output signals for the FEM

circuitry 2108. The baseband signals may be provided by the baseband circuitry 2110 and may be filtered by filter circuitry 2106c.

[0224] In some embodiments, the mixer circuitry 2106a of the receive signal path and the mixer circuitry 2106a 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 2106a of the receive signal path and the mixer circuitry 2106a 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 2106a of the receive signal path and the mixer circuitry 2106a of the transmit signal path may be arranged for direct downconversion and direct upconversion, respectively. In some embodiments, the mixer circuitry 2106a of the receive signal path and the mixer circuitry 2106a of the transmit signal path may be configured for super-heterodyne operation.

[0225] 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 2106 may include analog-to-digital converter (ADC) and digital-to-analog converter (DAC) circuitry and the baseband circuitry 2110 may include a digital baseband interface to communicate with the RF circuitry 2106.

[0226] 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.

[0227] In some embodiments, the synthesizer circuitry 2106d 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 2106d may be a delta-sigma synthesizer, a frequency multiplier, or a synthesizer comprising a phase-locked loop with a frequency divider.

[0228] The synthesizer circuitry 2106d may be configured to synthesize an output frequency for use by the mixer circuitry 2106a of the RF circuitry 2106 based on a frequency input and a divider control input. In some embodiments, the synthesizer circuitry 2106d may be a fractional N/N+1 synthesizer.

[0229] 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 2110 or the application circuitry 1905/2005 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 1905/2005.

[0230] Synthesizer circuitry 2106d of the RF circuitry 2106 may include a divider, a delay-locked loop (DLL), a multiplexer and a phase accumulator. In some embodiments, the divider may be a dual modulus divider (DMD) and the phase accumulator may be a digital phase accumulator (DPA). In some embodiments, the DMD may be configured to divide the input signal by either N or N+1 (e.g., based on a carry out) to provide a fractional division ratio. In some example embodiments, the DLL may include a set of cascaded, tunable, delay elements, a phase detector, a charge pump and a D-type flip-flop. In these embodiments, the delay elements may be configured to break a VCO period up into N_d equal packets of phase, where N_d is the number of delay elements in the delay line. In this way, the DLL provides negative feedback to help ensure that the total delay through the delay line is one VCO cycle.

[0231] In some embodiments, synthesizer circuitry 2106d 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 2106 may include an IQ/polar converter.

[0232] FEM circuitry 2108 may include a receive signal path, which may include circuitry configured to operate on RF signals received from antenna array 2111, amplify the received signals and provide the amplified versions of the received signals to the RF circuitry 2106 for further processing. FEM circuitry 2108 may also include a transmit signal path, which may include circuitry configured to amplify signals for transmission provided by the RF circuitry 2106 for transmission by one or more of antenna elements of antenna array 2111. In various embodiments, the amplification through the transmit or

receive signal paths may be done solely in the RF circuitry 2106, solely in the FEM circuitry 2108, or in both the RF circuitry 2106 and the FEM circuitry 2108.

[0233] In some embodiments, the FEM circuitry 2108 may include a TX/RX switch to switch between transmit mode and receive mode operation. The FEM circuitry 2108 may include a receive signal path and a transmit signal path. The receive signal path of the FEM circuitry 2108 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 2106). The transmit signal path of the FEM circuitry 2108 may include a power amplifier (PA) to amplify input RF signals (e.g., provided by RF circuitry 2106), and one or more filters to generate RF signals for subsequent transmission by one or more antenna elements of the antenna array 2111.

[0234] The antenna array 2111 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 2110 is converted into analog RF signals (e.g., modulated waveform) that will be amplified and transmitted via the antenna elements of the antenna array 2111 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 arrangements as are known and/or discussed herein. The antenna array 2111 may comprise microstrip antennas or printed antennas that are fabricated on the surface of one or more printed circuit boards. The antenna array 2111 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 2106 and/or FEM circuitry 2108 using metal transmission lines or the like.

[0235] Processors of the application circuitry 1905/2005 and processors of the baseband circuitry 2110 may be used to execute elements of one or more instances of a protocol stack. For example, processors of the baseband circuitry 2110, alone or in combination, may be used execute Layer 3, Layer 2, or Layer 1 functionality, while processors of the application circuitry 1905/2005 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.

[0236] Fig. 22 illustrates various protocol functions that may be implemented in a wireless communication device according to various embodiments. In particular, Fig. 22 includes an arrangement 2200 showing interconnections between various protocol layers/entities. The following description of Fig. 22 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 Fig. 22 may be applicable to other wireless communication network systems as well.

[0237] The protocol layers of arrangement 2200 may include one or more of PHY 2210, MAC 2220, RLC 2230, PDCP 2240, SDAP 2247, RRC 2255, and NAS layer 2257, in addition to other higher layer functions not illustrated. The protocol layers may include one or more service access points (e.g., items 2259, 2256, 2250, 2249, 2245, 2235, 2225, and 2215 in Fig. 22) that may provide communication between two or more protocol layers.

[0238] The PHY 2210 may transmit and receive physical layer signals 2205 that may be received from or transmitted to one or more other communication devices. The physical layer signals 2205 may comprise one or more physical channels, such as those discussed herein. The PHY 2210 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 2255. The PHY 2210 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 2210 may process requests from and provide indications to an instance of MAC 2220 via one or more PHY-SAP 2215. According to some embodiments, requests and indications communicated via PHY-SAP 2215 may comprise one or more transport channels.

[0239] Instance(s) of MAC 2220 may process requests from, and provide indications to, an instance of RLC 2230 via one or more MAC-SAPs 2225. These requests and indications communicated via the MAC-SAP 2225 may comprise one or more logical channels. The MAC 2220 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 2210 via the transport channels, de-multiplexing MAC SDUs to one or more logical channels from TBs delivered from the PHY 2210 via transport channels, multiplexing MAC SDUs onto TBs, scheduling information reporting, error correction through HARQ, and logical channel prioritization.

[0240] Instance(s) of RLC 2230 may process requests from and provide indications to an instance of PDCP 2240 via one or more radio link control service access points (RLC-SAP) 2235. These requests and indications communicated via RLC-SAP 2235 may comprise one or more RLC channels. The RLC 2230 may operate in a plurality of modes of operation, including: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM). The RLC 2230 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 2230 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.

[0241] Instance(s) of PDCP 2240 may process requests from and provide indications to instance(s) of RRC 2255 and/or instance(s) of SDAP 2247 via one or more packet data convergence protocol service access points (PDCP-SAP) 2245. These requests and indications communicated via PDCP-SAP 2245 may comprise one or more radio bearers. The PDCP 2240 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.).

[0242] Instance(s) of SDAP 2247 may process requests from and provide indications to one or more higher layer protocol entities via one or more SDAP-SAP 2249. These requests and indications communicated via SDAP-SAP 2249 may comprise one or more QoS flows. The SDAP 2247 may map QoS flows to DRBs, and vice versa, and may also

mark QFIs in DL and UL packets. A single SDAP entity 2247 may be configured for an individual PDU session. In the UL direction, the NG-RAN 1610 may control the mapping of QoS Flows to DRB(s) in two different ways, reflective mapping or explicit mapping. For reflective mapping, the SDAP 2247 of a UE 1601 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 2247 of the UE 1601 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 1810 may mark DL packets over the Uu interface with a QoS flow ID. The explicit mapping may involve the RRC 2255 configuring the SDAP 2247 with an explicit QoS flow to DRB mapping rule, which may be stored and followed by the SDAP 2247. In embodiments, the SDAP 2247 may only be used in NR implementations and may not be used in LTE implementations.

[0243] The RRC 2255 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 2210, MAC 2220, RLC 2230, PDCP 2240 and SDAP 2247. In embodiments, an instance of RRC 2255 may process requests from and provide indications to one or more NAS entities 2257 via one or more RRC-SAPs 2256. The main services and functions of the RRC 2255 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 1601 and RAN 1610 (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.

[0244] The NAS 2257 may form the highest stratum of the control plane between the UE 1601 and the AMF 1821. The NAS 2257 may support the mobility of the UEs 1601 and the session management procedures to establish and maintain IP connectivity between the UE 1601 and a P-GW in LTE systems.

- [0245] According to various embodiments, one or more protocol entities of arrangement 2200 may be implemented in UEs 1601, RAN nodes 1611, AMF 1821 in NR implementations or MME 1721 in LTE implementations, UPF 1802 in NR implementations or S-GW 1722 and P-GW 1723 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 1601, gNB 1611, AMF 1821, 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 1611 may host the RRC 2255, SDAP 2247, and PDCP 2240 of the gNB that controls the operation of one or more gNB-DUs, and the gNB-DUs of the gNB 1611 may each host the RLC 2230, MAC 2220, and PHY 2210 of the gNB 1611.
- [0246] In a first example, a control plane protocol stack may comprise, in order from highest layer to lowest layer, NAS 2257, RRC 2255, PDCP 2240, RLC 2230, MAC 2220, and PHY 2210. In this example, upper layers 2260 may be built on top of the NAS 2257, which includes an IP layer 2261, an SCTP 2262, and an application layer signaling protocol (AP) 2263.
- [0247] In NR implementations, the AP 2263 may be an NG application protocol layer (NGAP or NG-AP) 2263 for the NG interface 1613 defined between the NG-RAN node 1611 and the AMF 1821, or the AP 2263 may be an Xn application protocol layer (XnAP or Xn-AP) 2263 for the Xn interface 1612 that is defined between two or more RAN nodes 1611.
- [0248] The NG-AP 2263 may support the functions of the NG interface 1613 and may comprise Elementary Procedures (EPs). An NG-AP EP may be a unit of interaction between the NG-RAN node 1611 and the AMF 1821. The NG-AP 2263 services may comprise two groups: UE-associated services (e.g., services related to a UE 1601, 1602) and non-UE-associated services (e.g., services related to the whole NG interface instance between the NG-RAN node 1611 and AMF 1821). These services may include functions including, but not limited to: a paging function for the sending of paging requests to NG-RAN nodes 1611 involved in a particular paging area; a UE context management function for allowing the AMF 1821 to establish, modify, and/or release a UE context in the AMF

1821 and the NG-RAN node 1611; a mobility function for UEs 1601 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 1601 and AMF 1821; a NAS node selection function for determining an association between the AMF 1821 and the UE 1601; 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 1611 via CN 1620; and/or other like functions.

[0249] The XnAP 2263 may support the functions of the Xn interface 1612 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 1611 (or E-UTRAN 1710), 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 1601, such as Xn interface setup and reset procedures, NG-RAN update procedures, cell activation procedures, and the like.

[0250] In LTE implementations, the AP 2263 may be an S1 Application Protocol layer (S1-AP) 2263 for the S1 interface 1613 defined between an E-UTRAN node 1611 and an MME, or the AP 2263 may be an X2 application protocol layer (X2AP or X2-AP) 2263 for the X2 interface 1612 that is defined between two or more E-UTRAN nodes 1611.

[0251] The S1 Application Protocol layer (S1-AP) 2263 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 1611 and an MME 1721 within an LTE CN 1620. The S1-AP 2263 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.

[0252] The X2AP 2263 may support the functions of the X2 interface 1612 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 1620, 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 1601, such as X2 interface setup and reset procedures, load indication procedures, error indication procedures, cell activation procedures, and the like.

[0253] The SCTP layer (alternatively referred to as the SCTP/IP layer) 2262 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 2262 may ensure reliable delivery of signaling messages between the RAN node 1611 and the AMF 1821/MME 1721 based, in part, on the IP protocol, supported by the IP 2261. The Internet Protocol layer (IP) 2261 may be used to perform packet addressing and routing functionality. In some implementations the IP layer 2261 may use point-to-point transmission to deliver and convey PDUs. In this regard, the RAN node 1611 may comprise L2 and L1 layer communication links (e.g., wired or wireless) with the MME/AMF to exchange information.

[0254] In a second example, a user plane protocol stack may comprise, in order from highest layer to lowest layer, SDAP 2247, PDCP 2240, RLC 2230, MAC 2220, and PHY 2210. The user plane protocol stack may be used for communication between the UE 1601, the RAN node 1611, and UPF 1802 in NR implementations or an S-GW 1722 and P-GW 1723 in LTE implementations. In this example, upper layers 2251 may be built on top of the SDAP 2247, and may include a user datagram protocol (UDP) and IP security layer (UDP/IP) 2252, a General Packet Radio Service (GPRS) Tunneling Protocol for the user plane layer (GTP-U) 2253, and a User Plane PDU layer (UP PDU) 2263.

[0255] The transport network layer 2254 (also referred to as a “transport layer”) may be built on IP transport, and the GTP-U 2253 may be used on top of the UDP/IP layer 2252 (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.

[0256] The GTP-U 2253 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 2252 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 1611 and the S-GW 1722 may utilize an S1-U interface to exchange user plane data via a protocol stack comprising an L1 layer (e.g., PHY 2210), an L2 layer (e.g., MAC 2220, RLC 2230, PDCP 2240, and/or SDAP 2247), the UDP/IP layer 2252, and the GTP-U 2253. The S-GW 1722 and the P-GW 1723 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 2252, and the GTP-U 2253. As discussed previously, NAS protocols may support the mobility of the UE 1601 and the session management procedures to establish and maintain IP connectivity between the UE 1601 and the P-GW 1723.

[0257] Moreover, although not shown by Fig. 22, an application layer may be present above the AP 2263 and/or the transport network layer 2254. The application layer may be a layer in which a user of the UE 1601, RAN node 1611, or other network element interacts with software applications being executed, for example, by application circuitry 1905 or application circuitry 2005, respectively. The application layer may also provide one or more interfaces for software applications to interact with communications systems of the UE 1601 or RAN node 1611, such as the baseband circuitry 2110. 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).

[0258] Fig. 23 illustrates components of a core network in accordance with various embodiments. The components of the CN 1720 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 1820 may be implemented in a same or similar manner as discussed herein with regard to the components of CN 1720. 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 1720 may be referred to as a network slice 2301, and individual logical instantiations of the CN 1720 may provide specific network capabilities and network characteristics. A logical instantiation of a portion of the CN 1720 may be referred to as a network sub-slice 2302 (e.g., the network sub-slice 2302 is shown to include the P-GW 1723 and the PCRF 1726).

[0259] 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.

[0260] With respect to 5G systems (see, e.g., Fig. 18), 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 1801 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.

[0261] A network slice may include the CN 1820 control plane and user plane NFs, NG-RANs 1810 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 1801 (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 1821 instance serving an individual UE 1801 may belong to each of the network slice instances serving that UE.

[0262] Network Slicing in the NG-RAN 1810 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 1810 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 1810 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 1810 selects the RAN part of the network slice using assistance information provided by the UE 1801 or the 5GC 1820, which unambiguously identifies one or more of the pre-configured network slices in the PLMN. The NG-RAN 1810 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 1810 may also apply an appropriate RRM policy for the SLA in place to each supported slice. The NG-RAN 1810 may also support QoS differentiation within a slice.

[0263] The NG-RAN 1810 may also use the UE assistance information for the selection of an AMF 1821 during an initial attach, if available. The NG-RAN 1810 uses the assistance information for routing the initial NAS to an AMF 1821. If the NG-RAN 1810 is unable to select an AMF 1821 using the assistance information, or the UE 1801 does not provide any such information, the NG-RAN 1810 sends the NAS signaling to a default AMF 1821, which may be among a pool of AMFs 1821. For subsequent accesses, the UE 1801 provides a temp ID, which is assigned to the UE 1801 by the 5GC 1820, to enable the NG-RAN 1810 to route the NAS message to the appropriate AMF 1821 as long as the temp ID is valid. The NG-RAN 1810 is aware of, and can reach, the AMF 1821 that is associated with the temp ID. Otherwise, the method for initial attach applies.

- [0264] The NG-RAN 1810 supports resource isolation between slices. NG-RAN 1810 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 1810 resources to a certain slice. How NG-RAN 1810 supports resource isolation is implementation dependent.
- [0265] Some slices may be available only in part of the network. Awareness in the NG-RAN 1810 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 1810 and the 5GC 1820 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 1810.
- [0266] The UE 1801 may be associated with multiple network slices simultaneously. In case the UE 1801 is associated with multiple slices simultaneously, only one signaling connection is maintained, and for intra-frequency cell reselection, the UE 1801 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 1801 camps. The 5GC 1820 is to validate that the UE 1801 has the rights to access a network slice. Prior to receiving an Initial Context Setup Request message, the NG-RAN 1810 may be allowed to apply some provisional/local policies, based on awareness of a particular slice that the UE 1801 is requesting to access. During the initial context setup, the NG-RAN 1810 is informed of the slice for which resources are being requested.
- [0267] 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.
- [0268] Fig. 24 is a block diagram illustrating components, according to some example embodiments, of a system 2400 to support NFV. The system 2400 is illustrated as including a VIM 2402, an NFVI 2404, an VNFM 2406, VNFs 2408, an EM 2410, an NFVO 2412, and a NM 2414.

- [0269] The VIM 2402 manages the resources of the NFVI 2404. The NFVI 2404 can include physical or virtual resources and applications (including hypervisors) used to execute the system 2400. The VIM 2402 may manage the life cycle of virtual resources with the NFVI 2404 (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.
- [0270] The VNFM 2406 may manage the VNFs 2408. The VNFs 2408 may be used to execute EPC components/functions. The VNFM 2406 may manage the life cycle of the VNFs 2408 and track performance, fault and security of the virtual aspects of VNFs 2408. The EM 2410 may track the performance, fault and security of the functional aspects of VNFs 2408. The tracking data from the VNFM 2406 and the EM 2410 may comprise, for example, PM data used by the VIM 2402 or the NFVI 2404. Both the VNFM 2406 and the EM 2410 can scale up/down the quantity of VNFs of the system 2400.
- [0271] The NFVO 2412 may coordinate, authorize, release and engage resources of the NFVI 2404 in order to provide the requested service (e.g., to execute an EPC function, component, or slice). The NM 2414 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 2410).
- [0272] Fig. 25 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, Fig. 25 shows a diagrammatic representation of hardware resources 2500 including one or more processors (or processor cores) 2510, one or more memory/storage devices 2520, and one or more communication resources 2530, each of which may be communicatively coupled via a bus 2540. For embodiments where node virtualization (e.g., NFV) is utilized, a hypervisor 2502 may be executed to provide an execution environment for one or more network slices/sub-slices to utilize the hardware resources 2500.
- [0273] The processors 2510 may include, for example, a processor 2512 and a processor 2514. The processor(s) 2510 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.

[0274] The memory/storage devices 2520 may include main memory, disk storage, or any suitable combination thereof. The memory/storage devices 2520 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.

[0275] The communication resources 2530 may include interconnection or network interface components or other suitable devices to communicate with one or more peripheral devices 2504 or one or more databases 2506 via a network 2508. For example, the communication resources 2530 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..

[0276] Instructions 2550 may comprise software, a program, an application, an applet, an app, or other executable code for causing at least any of the processors 2510 to perform any one or more of the methodologies discussed herein. The instructions 2550 may reside, completely or partially, within at least one of the processors 2510 (e.g., within the processor's cache memory), the memory/storage devices 2520, or any suitable combination thereof. Furthermore, any portion of the instructions 2550 may be transferred to the hardware resources 2500 from any combination of the peripheral devices 2504 or the databases 2506. Accordingly, the memory of processors 2510, the memory/storage devices 2520, the peripheral devices 2504, and the databases 2506 are examples of computer-readable and machine-readable media.

[0277] Fig. 26 illustrates a flow diagram of a UAS service, according to some embodiments. For example, Fig. 26 includes a UAS services method 2600 including identifying or causing to identify a received signal from another UE, according to step 2602. Method 2600 also includes processing or causing to process the signal, according to step 2604. Moreover, method 2600 also includes determining or causing to determine

another signal, according to step 2606. Additionally, method 2600 may further include transmitting or causing to transmit the determined other signal to the other UE, wherein the received signal and transmitted signal uses a 3GPP network and wherein the UE and the other UE are part of the UAS system, according to step 2608.

[0278] Fig. 27 illustrates an unmanned aircraft traffic management method 2700 for facilitating Unmanned Aerial System (UAS) services over evolved packet systems. According to some embodiments, method 2700 may include receiving a registration request from each of an unmanned aerial vehicle (UAV) and a UAV controller to establish an Unmanned Aerial System (UAS), each registration request including an application layer registration through a Unmanned Aircraft Traffic Management (UTM) application function (AF), in which an IP address of the server is provided, as illustrated in step 2702. Method 2700 may further include initiating a UAS Operation Service Request Procedure via a network exposure function (NEF) to obtain results of a UAS operation service authorization from each of the UAV and the UAV controller, as illustrated in step 2704. According to some embodiments, method 2700 may further include associating the UAV and the UAV controller to operate as the UAS in response to obtaining the results of the UAS operation service authorization from each of the UAV and the UAV controller, as illustrated in step 2706. Additionally, method 2700 may further include transmitting a UAS operation status update procedure to the UAV and the UAV controller, the update procedure including UAS association information, a UAS policy update, and initiation of a UAS operation, as illustrated in step 2708.

[0279] According to other embodiments not illustrated in Fig. 27, method 2700 may further include initiating an AF session setup procedure including a required quality of service (QoS) to manage IP data flows for a UTM session between the UAV and the server, and command and control (C2) session between the UAV and the UAV controller. Additionally, method 2700 may also include assigning subscription rights to user equipments (UEs) associated with each of the UAV and the UAV controller. According to some aspects, the subscription rights may include a subscription for a UE operating the UAV in the UAS, a subscription of a UE operating the UAV controller in the UAS, a subscription for UAS operation using indirect communication, or a subscription for UAS operation using network navigated C2.

- [0280] According to some embodiments, method 2700 may further include providing, to the UE associated with the UAV controller, authorization for the UAS operation enabling controller C2 communication, including a list of public land mobile networks (PLMNs) for which the UAV is authorized, a list of application identifiers per PLMN, a list of allowed traffic types per application identifier, and a UAS-data network name (DNN).
- [0281] According to some embodiments, method 2700 may further include providing, to the UE associated with the UAV, authorization for the UAS operation enabling network C2 communication with flight plan, including a list of PLMNs for which the UAV is authorized, a list of application identifiers per PLMN, a list of allowed traffic types per application identifier, and the UAS-DNN.
- [0282] According to some embodiments, method 2700 may further include transmitting, to the NEF, a UAS operation service request message including a server identifier, generic public subscription identifier, an external group identifier of the UAV and UAV controller, external application identifiers, and a UAS operation authorization for each application identifier. According to some aspects, the UAS operation authorization may indicate that the UAS operation policy is to be created in a network of an operator when successfully authorized. According to some other aspects, the NEF may request the UAS operation authorization from a policy control function (PCF).
- [0283] According to some embodiments, method 2700 may further include receiving, from the NEF, the UAS operation authorization status for each application identifier, and a cause for authorization or denial of authorization for each application identifier.
- [0284] For one or more embodiments, at least one of the components set forth in one or more of the preceding Figs. 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 Figs. 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 Figs. may be configured to operate in accordance with one or more of the examples set forth below in the example section.

Example Procedures

[0285] In some embodiments, the electronic device(s), network(s), system(s), chip(s) or component(s), or portions or implementations thereof, of Figs. 16-25, or some other Fig. 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 Fig. 26 as described herein. For example, the process may include identifying or causing to identify a received signal from another UE. The process may further include processing or causing to process the signal. The process may further include determining or causing to determine another signal. The process may further include transmitting or causing to transmit the determined other signal to the other UE, wherein the received signal and transmitted signal uses a 3GPP network and wherein the UE and the other UE are part of a UAS system.

EXAMPLES:

[0286] Example 1 may include a UE apparatus comprising: means for identifying or causing to identify a received signal from another UE; means for processing or causing to process the signal; means for determining or causing to determine another signal; means for transmitting or causing to transmit the determined other signal to the other UE; wherein the received signal and transmitted signal uses a 3GPP network; and wherein the UE and the other UE are part of a UAS system.

[0287] Example 2 may include the subject matter of example 1, or of any other example herein, wherein the UE and the other UE communicate via respective unicast connections to the 3GPP network via same or different RAN node in the same or different PLMN.

[0288] Example 3 may include the subject matter of example 2, or of any other example herein, wherein the UE and the other UE establish respective unicast C2 communication links to the 3GPP network and communicate via the 3GPP network.

[0289] Example 4 may include the subject matter of example 1, or of any other example herein, wherein the transmission or reception is facilitated by a cellular based UAS traffic management (C-UTM) function.

[0290] Example 5 may include the subject matter of example 4, or of any other example herein, wherein the C-UTM function exists in the control plane.

- [0291] Example 6 may include the subject matter of example 4, or of any other example herein, wherein the C-UTM function is supported in EPC architecture or the 5GS architecture.
- [0292] Example 7 may include the subject matter of example 6, or of any other example herein, wherein the C-UTM function interfaces with SCEF.
- [0293] Example 8 may include the subject matter of example 7, or of any other example herein, wherein the SCEF exposes network capabilities requested by SCS/AS with UTM-Application server over T8.
- [0294] Example 9 may include the subject matter of example 6, or of any other example herein, wherein a UTM-AF interfaces with C-UTM over N33.
- [0295] Example 10 may include the subject matter of example 4, or of any other example herein, wherein the C-UTM function includes authorization information for the UE and for the other UE for UAS operation.
- [0296] Example 11 may include the subject matter of example 1, or of any other example herein, wherein the UE is pre-configured with UAS operation authorization parameters.
- [0297] Example 12 may include the subject matter of example 1, or of any other example herein, further including means for registering or causing to register the UE to the 5GC with indications to enable UAS operation service if the UE has corresponding UAS subscriptions.
- [0298] Example 13 may include the subject matter of example 1, or of any other example herein, further comprising means for establishing or causing to establish a PDU session for a specific UAS-DNN.
- [0299] Example 14 may include the subject matter of example 1, or of any other example herein, wherein all or part of the UE is a UAV and all or part of the other UE is a UAV controller.
- [0300] Example 15 include the subject matter of example 1, or of any other example herein, wherein all or part of the other UE is a UAV and all or part of the UE is a UAV controller.
- [0301] Example 16 may be a method of UAS operation service authorization for a UE of the UAV or UAV controller in 5GS.
- [0302] Example 17 may include the method of example 16, or of any other example herein, whereby the UAS operation service authorization is initiated by the AF by sending

a Nnef_UAS_Operation_Service Request (AF Identifier, Generic Public Subscription Identifier (GPSI)/External Group Identifier of the UAV/UAV controller, external Application Identifiers, UAS operation authorization for each Application Identifier) message to the NEF.

- [0303]** Example 18 may include the method of example 17, or of any other example herein, whereby the UAS operation authorization indicates that the UAS operation policy is to be created in the operator's network if successfully authorized, e.g. UAS operation mode, including via Network based C2 (as shown in Fig. 1) or via Network navigated C2 (as shown in Fig.2), operation location, requested operation start time, flight duration, flight routes, etc., for the UAV/UAV controller.
- [0304]** Example 19 may include the method of example 18, or of any other example herein, whereby the AF is authorized by the NEF to request UAS operation service authorization.
- [0305]** Example 20 may include the method of example 19, or of, any other example herein, whereby if the authorization is not granted, the NEF replies to the AF with a Result value indicating that the authorization failed.
- [0306]** Example 21 include the method of example 19, or of any other example herein, whereby if the authorization is granted, the NEF allocates a Transaction Reference ID to identify the follow up messages regarding to the request.
- [0307]** Example 22 may include the method of examples 20 or 21, or of any other example herein, whereby the NEF sends a Ncutm_UAS Operation_Authorization Request message (Application Identifier(s), one or more sets of UAS operation information for each Application Identifier, SUPI) to the C-UTMF/PCF.
- [0308]** Example 23 may include the method of example 22, or of any other example herein, whereby the NEF may query for the translation of GPSI/External Group Identifier of the UAV/UAV controller to Subscription Permanent Identifier (SUPI) of the UE.
- [0309]** Example 24 may include the method of example 23, or of any other example herein, whereby the C-UTM/PCF function determines whether the request is allowed.
- [0310]** Example 25 may include the method of example 24, or of any other example herein, whereby if UAS operation authorization is done successfully, the C-UTM/PCF continues to create the list of UAS operation policies into the C-UTM function based on

the operator's configured policies for each requested UAS operation per application ID and respond to NEF.

- [0311] Example 26 may include the method of example 25, or of any other example herein, whereby the C-UTM function sends Ncutm_UAS Operation_Authorization Request message (Application Identifier(s), Results) message to the NEF and indicates the Results.
- [0312] Example 27 may include the method of example 26, or of any other example herein, whereby if any of the services authorization fails, cause is provided per Application ID, e.g. service suspend, service expiration, service unavailable.
- [0313] Example 28 may include the method of example 27, or of any other example herein, whereby the NEF sends a Unef_UAS Operation_Service Response (Transaction Reference ID, Results) message to the UTM-AF to provide the feedback of the result for Unef_UAS_Operation_Service Request.
- [0314] Example 29 may include the method of example 28, or of any other example herein, whereby the Transaction Reference ID is used by the AF to provide the follow up information regarding to the request for the UAS operation of the UAV/UAV controller. Example 30 may be a method of UAS operation status update for a UE of the UAV or UAV controller in 5GS.
- [0315] Example 31 include the method of example 30, or of any other example herein, whereby the UAS operation status update request is sent by UTM-AF to notify the successful association of a UAS by sending a Nnef_UAS_Operation_Status_Update Request (AF Identifier, Transaction Reference ID, External identifiers/External Group identifiers of the UAV/UAV controller, UAS operation Status for each Application Identifier, UAS_ID) message to the NEF.
- [0316] Example 32 may include the method of example 31, or of any other example herein, whereby the UAS operation status can indicate the enabled UAS operation parameters per Application identifier and indicates the corresponding UAS_ID.
- [0317] Example 33 may include the method of example 32, or of any other example herein, whereby the UAS_ID is allocated by the UTM-AF to identify the association between a UAV and a UAV controller in which the related UAS operation for the UAS is associated to the same UAS-ID.

- [0318] Example 34 may include the method of example 33, or of any other example herein, whereby the UAS operation parameters may include: the allowed application IDs for the UAS operation, UAS operation mode (e.g. indirect C2, direct C2, network navigated C2), IP addresses of available UTM application servers, allowed geographical areas, allowed operation time, allowed operation duration, etc.
- [0319] Example 35 may include the method of example 34, or of any other example herein, whereby NEF checks the AF authorization of the request for UAS operation status update if the Transaction Reference ID is expired.
- [0320] Example 36 may include the method of example 35, or of any other example herein, whereby NEF sends the Ncutm_UAS_Status_Update request (SUPI, UAS operation Status for each Application Identifier, UAS_ID) message to the C-UTM/PCF.
- [0321] Example 37 may include the method of example 36, or of any other example herein, whereby C-UTM/PCF function updates the UAS operation status including the policies per application identifier and the associated UAS_ID.
- [0322] Example 38 may include the method of example 37, or of any other example herein, whereby the C-UTM/PCF function returns the confirmation of the status update to the NEF by sending Ncutm_UAS_Operation_Update response (UAS_ID, SUPI) message.
- [0323] Example 39 may include the method of example 38, or of any other example herein, whereby the NEF returns the Nnef_UAS_Operation_Status_Update response (Transaction Reference ID) message to the AF.
- [0324] Example 40 may include a UE apparatus to: identify or cause to identify a received signal from another UE; process or cause to process the signal; determine or cause to determine another signal; transmit or cause to transmit the determined other signal to the other UE; wherein the received signal and transmitted signal uses a 3GPP network; and wherein the UE and the other UE are part of a UAS system.
- [0325] Example 41 may include the subject matter of example 40, or of any other example herein, wherein the UE and the other UE communicate via respective unicast connections to the 3GPP network via same or different RAN node in the same or different PLMN.
- [0326] Example 42 may include the subject matter of example 41, or of any other example herein, wherein the UE and the other UE establish respective unicast C2 communication links to the 3GPP network and communicate via the 3GPP network.

- [0327] Example 43 may include the subject matter of example 40, or of any other example herein, wherein the transmission or reception is facilitated by a cellular based UAS traffic management (C-UTM) function.
- [0328] Example 44 may include the subject matter of example 43, or of any other example herein, wherein the C-UTM function exists in the control plane.
- [0329] Example 45 may include the subject matter of example 43, or of any other example herein, wherein the C-UTM function is supported in EPC architecture or the 5GS architecture.
- [0330] Example 46 may include the subject matter of example 45, or of any other example herein, wherein the C-UTM function interfaces with SCEF.
- [0331] Example 47 may include the subject matter of example 46, or of any other example herein, wherein the SCEF exposes network capabilities requested by SCS/AS with UTM-Application server over T8.
- [0332] Example 48 may include the subject matter of example 45, or of any other example herein, wherein a UTM-AF interfaces with C-UTM over N33.
- [0333] Example 49 may include the subject matter of example 43, or of any other example herein, wherein the C-UTM function includes authorization information for the UE and for the other UE for UAS operation.
- [0334] Example 50 may include the subject matter of example 40, or of any other example herein, wherein the UE is pre-configured with UAS operation authorization parameters.
- [0335] Example 51 may include the subject matter of example 40, or of any other example herein, further including register or cause to register the UE to the 5GC with indications to enable UAS operation service if the UE has corresponding UAS subscriptions.
- [0336] Example 52 may include the subject matter of example 40, or of any other example herein, further comprising establish or cause to establish a PDU session for a specific UAS-DNN.
- [0337] Example 53 may include the subject matter of example 40, or of any other example herein, wherein all or part of the UE is a UAV and all or part of the other UE is a UAV controller.

- [0338] Example 54 include the subject matter of example 40, or of any other example herein, wherein all or part of the other UE is a UAV and all or part of the UE is a UAV controller.
- [0339] Example 55 may include a method for implementing a UE comprising: identifying or causing to identify a received signal from another UE; processing or causing to process the signal; determining or causing to determine another signal; transmitting or causing to transmit the determined other signal to the other UE; wherein the received signal and transmitted signal uses a 3GPP network; and wherein the UE and the other UE are part of a UAS system.
- [0340] Example 56 may include the subject matter of example 55, or of any other example herein, wherein the UE and the other UE communicate via respective unicast connections to the 3GPP network via same or different RAN node in the same or different PLMN.
- [0341] Example 57 may include the subject matter of example 56, or of any other example herein, wherein the UE and the other UE establish respective unicast C2 communication links to the 3GPP network and communicate via the 3GPP network.
- [0342] Example 58 may include the subject matter of example 55, or of any other example herein, wherein the transmission or reception is facilitated by a cellular based UAS traffic management (C-UTM) function.
- [0343] Example 59 may include the subject matter of example 58, or of any other example herein, wherein the C-UTM function exists in the control plane.
- [0344] Example 60 may include the subject matter of example 58, or of any other example herein, wherein the C-UTM function is supported in EPC architecture or the 5GS architecture.
- [0345] Example 61 may include the subject matter of example 60, or of any other example herein, wherein the C-UTM function interfaces with SCEF.
- [0346] Example 62 may include the subject matter of example 61, or of any other example herein, wherein the SCEF exposes network capabilities requested by SCS/AS with UTM-Application server over T8.
- [0347] Example 63 may include the subject matter of example 60, or of any other example herein, wherein a UTM-AF interfaces with C-UTM over N33.

- [0348] Example 64 may include the subject matter of example 58, or of any other example herein, wherein the C-UTM function includes authorization information for the UE and for the other UE for UAS operation.
- [0349] Example 65 may include the subject matter of example 55, or of any other example herein, wherein the UE is pre-configured with UAS operation authorization parameters.
- [0350] Example 66 may include the subject matter of example 55, or of any other example herein, further including registering or causing to register the UE to the 5GC with indications to enable UAS operation service if the UE has corresponding UAS subscriptions.
- [0351] Example 67 may include the subject matter of example 55, or of any other example herein, further comprising establishing or causing to establish a PDU session for a specific UAS-DNN.
- [0352] Example 68 may include the subject matter of example 55, or of any other example herein, wherein all or part of the UE is a UAV and all or part of the other UE is a UAV controller.
- [0353] Example 69 include the subject matter of example 55, or of any other example herein, wherein all or part of the other UE is a UAV and all or part of the UE is a UAV controller.
- [0354] Example 70 may include an apparatus comprising means to perform one or more elements of a method described in or related to any of examples 1-69, or any other method or process described herein.
- [0355] Example 71 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 1-69, or any other method or process described herein.
- [0356] Example 72 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 1-69, or any other method or process described herein.
- [0357] Example 73 may include a method, technique, or process as described in or related to any of examples 1-69, or portions or parts thereof.

- [0358] Example 74 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 1-69, or portions thereof.
- [0359] Example 75 may include a signal as described in or related to any of examples 1-69, or portions or parts thereof.
- [0360] Example 76 may include a signal in a wireless network as shown and described herein.
- [0361] Example 77 may include a method of communicating in a wireless network as shown and described herein.
- [0362] Example 78 may include a system for providing wireless communication as shown and described herein.
- [0363] Example 79 may include a device for providing wireless communication as shown and described herein.
- [0364] 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

- [0365] For the purposes of the present document, the following abbreviations may apply to the examples and embodiments discussed herein.
- | | | |
|--------|------|--------------------------------------|
| [0366] | 3GPP | Third Generation Partnership Project |
| [0367] | 4G | Fourth Generation |
| [0368] | 5G | Fifth Generation |
| [0369] | 5GC | 5G Core network |
| [0370] | ACK | Acknowledgement |
| [0371] | AF | Application Function |
| [0372] | AM | Acknowledged Mode |
| [0373] | AMBR | Aggregate Maximum Bit Rate |

[0374]	AMF	Access and Mobility Management Function
[0375]	AN	Access Network
[0376]	ANR	Automatic Neighbour Relation
[0377]	AP	Application Protocol, Antenna Port, Access Point
[0378]	API	Application Programming Interface
[0379]	APN	Access Point Name
[0380]	ARP	Allocation and Retention Priority
[0381]	ARQ	Automatic Repeat Request
[0382]	AS	Access Stratum
[0383]	ASN.1	Abstract Syntax Notation One
[0384]	AUSF	Authentication Server Function
[0385]	AWGN	Additive White Gaussian Noise
[0386]	BCH	Broadcast Channel
[0387]	BER	Bit Error Ratio
[0388]	BFD	Beam Failure Detection
[0389]	BLER	Block Error Rate
[0390]	BPSK	Binary Phase Shift Keying
[0391]	BRAS	Broadband Remote Access Server
[0392]	BSS	Business Support System
[0393]	BS	Base Station
[0394]	BSR	Buffer Status Report
[0395]	BW	Bandwidth
[0396]	BWP	Bandwidth Part
[0397]	C-RNTI	Cell Radio Network Temporary Identity
[0398]	CA	Carrier Aggregation, Certification Authority
[0399]	CAPEX	CAPital EXpenditure
[0400]	CBRA	Contention Based Random Access
[0401]	CC	Component Carrier, Country Code, Cryptographic Checksum
[0402]	CCA	Clear Channel Assessment
[0403]	CCE	Control Channel Element
[0404]	CCCH	Common Control Channel
[0405]	CE	Coverage Enhancement

[0406]	CDM	Content Delivery Network
[0407]	CDMA	Code-Division Multiple Access
[0408]	CFRA	Contention Free Random Access
[0409]	CG	Cell Group
[0410]	CI	Cell Identity
[0411]	CID	Cell-ID (e.g., positioning method)
[0412]	CIM	Common Information Model
[0413]	CIR	Carrier to Interference Ratio
[0414]	CK	Cipher Key
[0415]	CM	Connection Management, Conditional Mandatory
[0416]	CMAS	Commercial Mobile Alert Service
[0417]	CMD	Command
[0418]	CMS	Cloud Management System
[0419]	CO	Conditional Optional
[0420]	CoMP	Coordinated Multi-Point
[0421]	CORESET	Control Resource Set
[0422]	COTS	Commercial Off-The-Shelf
[0423]	CP	Control Plane, Cyclic Prefix, Connection Point
[0424]	CPD	Connection Point Descriptor
[0425]	CPE	Customer Premise Equipment
[0426]	CPICH	Common Pilot Channel
[0427]	CQI	Channel Quality Indicator
[0428]	CPU	CSI processing unit, Central Processing Unit
[0429]	C/R	Command/Response field bit
[0430]	CRAN	Cloud Radio Access Network, Cloud RAN
[0431]	CRB	Common Resource Block
[0432]	CRC	Cyclic Redundancy Check
[0433]	CRI	Channel-State Information Resource Indicator, CSI-RS Resource Indicator
[0434]	C-RNTI	Cell RNTI
[0435]	CS	Circuit Switched
[0436]	CSAR	Cloud Service Archive

[0437]	CSI	Channel-State Information
[0438]	CSI-IM	CSI Interference Measurement
[0439]	CSI-RS	CSI Reference Signal
[0440]	CSI-RSRP	CSI reference signal received power
[0441]	CSI-RSRQ	CSI reference signal received quality
[0442]	CSI-SINR	CSI signal-to-noise and interference ratio
[0443]	CSMA	Carrier Sense Multiple Access
[0444]	CSMA/CA	CSMA with collision avoidance
[0445]	CSS	Common Search Space, Cell-specific Search Space
[0446]	CTS	Clear-to-Send
[0447]	CW	Codeword
[0448]	CWS	Contention Window Size
[0449]	D2D	Device-to-Device
[0450]	DC	Dual Connectivity, Direct Current
[0451]	DCI	Downlink Control Information
[0452]	DF	Deployment Flavour
[0453]	DL	Downlink
[0454]	DMTF	Distributed Management Task Force
[0455]	DPDK	Data Plane Development Kit
[0456]	DM-RS, DMRS	Demodulation Reference Signal
[0457]	DN	Data network
[0458]	DRB	Data Radio Bearer
[0459]	DRS	Discovery Reference Signal
[0460]	DRX	Discontinuous Reception
[0461]	DSL	Domain Specific Language. Digital Subscriber Line
[0462]	DSLAM	DSL Access Multiplexer
[0463]	DwPTS	Downlink Pilot Time Slot
[0464]	E-LAN	Ethernet Local Area Network
[0465]	E2E	End-to-End
[0466]	ECCA	extended clear channel assessment, extended CCA
[0467]	ECCE	Enhanced Control Channel Element, Enhanced CCE
[0468]	ED	Energy Detection

[0469]	EDGE	Enhanced Data rates for GSM Evolution (GSM Evolution)
[0470]	EGMF	Exposure Governance Management Function
[0471]	EGPRS	Enhanced GPRS
[0472]	EIR	Equipment Identity Register
[0473]	eLAA	enhanced Licensed Assisted Access, enhanced LAA
[0474]	EM	Element Manager
[0475]	eMBB	Enhanced Mobile Broadband
[0476]	EMS	Element Management System
[0477]	eNB	evolved NodeB, E-UTRAN Node B
[0478]	EN-DC	E-UTRA-NR Dual Connectivity
[0479]	EPC	Evolved Packet Core
[0480]	EPDCCH	enhanced PDCCH, enhanced Physical Downlink Control Channel
[0481]	EPRE	Energy per resource element
[0482]	EPS	Evolved Packet System
[0483]	EREG	enhanced REG, enhanced resource element groups
[0484]	ETSI	European Telecommunications Standards Institute
[0485]	ETWS	Earthquake and Tsunami Warning System
[0486]	eUICC	embedded UICC, embedded Universal Integrated Circuit Card
[0487]	E-UTRA	Evolved UTRA
[0488]	E-UTRAN	Evolved UTRAN
[0489]	EV2X	Enhanced V2X
[0490]	F1AP	F1 Application Protocol
[0491]	F1-C	F1 Control plane interface
[0492]	F1-U	F1 User plane interface
[0493]	FACCH	Fast Associated Control Channel
[0494]	FACCH/F	Fast Associated Control Channel/Full rate
[0495]	FACCH/H	Fast Associated Control Channel/Half rate
[0496]	FACH	Forward Access Channel
[0497]	FAUSCH	Fast Uplink Signalling Channel
[0498]	FB	Functional Block
[0499]	FBI	Feedback Information
[0500]	FCC	Federal Communications Commission

[0501]	FCCH	Frequency Correction CHannel
[0502]	FDD	Frequency Division Duplex
[0503]	FDM	Frequency Division Multiplex
[0504]	FDMA	Frequency Division Multiple Access
[0505]	FE	Front End
[0506]	FEC	Forward Error Correction
[0507]	FFS	For Further Study
[0508]	FFT	Fast Fourier Transformation
[0509]	feLAA	further enhanced Licensed Assisted Access, further enhanced LAA
[0510]	FN	Frame Number
[0511]	FPGA	Field-Programmable Gate Array
[0512]	FR	Frequency Range
[0513]	G-RNTI	GERAN Radio Network Temporary Identity
[0514]	GERAN	GSM EDGE RAN, GSM EDGE Radio Access Network
[0515]	GGSN	Gateway GPRS Support Node
[0516]	GLONASS	GLObal'naya NAvigatsionnaya Sputnikovaya Sistema (Engl.: Global Navigation Satellite System)
[0517]	gNB	Next Generation NodeB
[0518]	gNB-CU	gNB-centralized unit, Next Generation NodeB centralized unit
[0519]	gNB-DU	gNB-distributed unit, Next Generation NodeB distributed unit
[0520]	GNSS	Global Navigation Satellite System
[0521]	GPRS	General Packet Radio Service
[0522]	GSM	Global System for Mobile Communications, Groupe Spécial Mobile
[0523]	GTP	GPRS Tunneling Protocol
[0524]	GTP-U	GPRS Tunnelling Protocol for User Plane
[0525]	GTS	Go To Sleep Signal (related to WUS)
[0526]	GUMMEI	Globally Unique MME Identifier
[0527]	GUTI	Globally Unique Temporary UE Identity
[0528]	HARQ	Hybrid ARQ, Hybrid Automatic Repeat Request
[0529]	HANDO, HO	Handover

[0530]	HFN	HyperFrame Number
[0531]	HHO	Hard Handover
[0532]	HLR	Home Location Register
[0533]	HN	Home Network
[0534]	HO	Handover
[0535]	HPLMN	Home Public Land Mobile Network
[0536]	HSDPA	High Speed Downlink Packet Access
[0537]	HSN	Hopping Sequence Number
[0538]	HSPA	High Speed Packet Access
[0539]	HSS	Home Subscriber Server
[0540]	HSUPA	High Speed Uplink Packet Access
[0541]	HTTP	Hyper Text Transfer Protocol
[0542]	HTTPS	Hyper Text Transfer Protocol Secure (https is http/1.1 over SSL, i.e. port 443)
[0543]	I-Block	Information Block
[0544]	ICCID	Integrated Circuit Card Identification
[0545]	ICIC	Inter-Cell Interference Coordination
[0546]	ID	Identity, identifier
[0547]	IDFT	Inverse Discrete Fourier Transform
[0548]	IE	Information element
[0549]	IBE	In-Band Emission
[0550]	IEEE	Institute of Electrical and Electronics Engineers
[0551]	IEI	Information Element Identifier
[0552]	IEIDL	Information Element Identifier Data Length
[0553]	IETF	Internet Engineering Task Force
[0554]	IF	Infrastructure
[0555]	IM	Interference Measurement, Intermodulation, IP Multimedia
[0556]	IMC	IMS Credentials
[0557]	IMEI	International Mobile Equipment Identity
[0558]	IMGI	International mobile group identity
[0559]	IMPI	IP Multimedia Private Identity
[0560]	IMPU	IP Multimedia PUBlic identity

[0561]	IMS	IP Multimedia Subsystem
[0562]	IMSI	International Mobile Subscriber Identity
[0563]	IoT	Internet of Things
[0564]	IP	Internet Protocol
[0565]	Ipsec	IP Security, Internet Protocol Security
[0566]	IP-CAN	IP-Connectivity Access Network
[0567]	IP-M	IP Multicast
[0568]	IPv4	Internet Protocol Version 4
[0569]	IPv6	Internet Protocol Version 6
[0570]	IR	Infrared
[0571]	IS	In Sync
[0572]	IRP	Integration Reference Point
[0573]	ISDN	Integrated Services Digital Network
[0574]	ISIM	IM Services Identity Module
[0575]	ISO	International Organisation for Standardisation
[0576]	ISP	Internet Service Provider
[0577]	IWF	Interworking-Function
[0578]	I-WLAN	Interworking WLAN
[0579]	K	Constraint length of the convolutional code, USIM Individual key
[0580]	kB	Kilobyte (1000 bytes)
[0581]	kbps	kilo-bits per second
[0582]	Kc	Ciphering key
[0583]	Ki	Individual subscriber authentication key
[0584]	KPI	Key Performance Indicator
[0585]	KQI	Key Quality Indicator
[0586]	KSI	Key Set Identifier
[0587]	ksps	kilo-symbols per second
[0588]	KVM	Kernel Virtual Machine
[0589]	L1	Layer 1 (physical layer)
[0590]	L1-RSRP	Layer 1 reference signal received power
[0591]	L2	Layer 2 (data link layer)

[0592]	L3	Layer 3 (network layer)
[0593]	LAA	Licensed Assisted Access
[0594]	LAN	Local Area Network
[0595]	LBT	Listen Before Talk
[0596]	LCM	LifeCycle Management
[0597]	LCR	Low Chip Rate
[0598]	LCS	Location Services
[0599]	LCID	Logical Channel ID
[0600]	LI	Layer Indicator
[0601]	LLC	Logical Link Control, Low Layer Compatibility
[0602]	LPLMN	Local PLMN
[0603]	LPP	LTE Positioning Protocol
[0604]	LSB	Least Significant Bit
[0605]	LTE	Long Term Evolution
[0606]	LWA	LTE-WLAN aggregation
[0607]	LWIP	LTE/WLAN Radio Level Integration with IPsec Tunnel
[0608]	LTE	Long Term Evolution
[0609]	M2M	Machine-to-Machine
[0610]	MAC	Medium Access Control (protocol layering context)
[0611]	MAC	Message authentication code (security/encryption context)
[0612]	MAC-A	MAC used for authentication and key agreement (TSG T WG3 context)
[0613]	MAC-I	MAC used for data integrity of signalling messages (TSG T WG3 context)
[0614]	MANO	Management and Orchestration
[0615]	MBMS	Multimedia Broadcast and Multicast Service
[0616]	MBSFN	Multimedia Broadcast multicast service Single Frequency Network
[0617]	MCC	Mobile Country Code
[0618]	MCG	Master Cell Group
[0619]	MCOT	Maximum Channel Occupancy Time
[0620]	MCS	Modulation and coding scheme

[0621]	MDAF	Management Data Analytics Function
[0622]	MDAS	Management Data Analytics Service
[0623]	MDT	Minimization of Drive Tests
[0624]	ME	Mobile Equipment
[0625]	MeNB	master eNB
[0626]	MER	Message Error Ratio
[0627]	MGL	Measurement Gap Length
[0628]	MGRP	Measurement Gap Repetition Period
[0629]	MIB	Master Information Block, Management Information Base
[0630]	MIMO	Multiple Input Multiple Output
[0631]	MLC	Mobile Location Centre
[0632]	MM	Mobility Management
[0633]	MME	Mobility Management Entity
[0634]	MN	Master Node
[0635]	MO	Measurement Object, Mobile Originated
[0636]	MPBCH	MTC Physical Broadcast CHannel
[0637]	MPDCCH	MTC Physical Downlink Control CHannel
[0638]	MPDSCH	MTC Physical Downlink Shared CHannel
[0639]	MPRACH	MTC Physical Random Access CHannel
[0640]	MPUSCH	MTC Physical Uplink Shared Channel
[0641]	MPLS	MultiProtocol Label Switching
[0642]	MS	Mobile Station
[0643]	MSB	Most Significant Bit
[0644]	MSC	Mobile Switching Centre
[0645]	MSI	Minimum System Information, MCH Scheduling Information
[0646]	MSID	Mobile Station Identifier
[0647]	MSIN	Mobile Station Identification Number
[0648]	MSISDN	Mobile Subscriber ISDN Number
[0649]	MT	Mobile Terminated, Mobile Termination
[0650]	MTC	Machine-Type Communications
[0651]	mMTC	massive MTC, massive Machine-Type Communications
[0652]	MU-MIMO	Multi User MIMO

[0653]	MWUS	MTC wake-up signal, MTC WUS
[0654]	NACK	Negative Acknowledgement
[0655]	NAI	Network Access Identifier
[0656]	NAS	Non-Access Stratum, Non-Access Stratum layer
[0657]	NCT	Network Connectivity Topology
[0658]	NEC	Network Capability Exposure
[0659]	NE-DC	NR-E-UTRA Dual Connectivity
[0660]	NEF	Network Exposure Function
[0661]	NF	Network Function
[0662]	NFP	Network Forwarding Path
[0663]	NFPD	Network Forwarding Path Descriptor
[0664]	NFV	Network Functions Virtualization
[0665]	NFVI	NFV Infrastructure
[0666]	NFVO	NFV Orchestrator
[0667]	NG	Next Generation, Next Gen
[0668]	NGEN-DC	NG-RAN E-UTRA-NR Dual Connectivity
[0669]	NM	Network Manager
[0670]	NMS	Network Management System
[0671]	N-PoP	Network Point of Presence
[0672]	NMIB, N-MIB	Narrowband MIB
[0673]	NPBCH	Narrowband Physical Broadcast CHannel
[0674]	NPDCCH	Narrowband Physical Downlink Control CHannel
[0675]	NPDSCH	Narrowband Physical Downlink Shared CHannel
[0676]	NPRACH	Narrowband Physical Random Access CHannel
[0677]	NPUSCH	Narrowband Physical Uplink Shared CHannel
[0678]	NPSS	Narrowband Primary Synchronization Signal
[0679]	NSSS	Narrowband Secondary Synchronization Signal
[0680]	NR	New Radio, Neighbour Relation
[0681]	NRF	NF Repository Function
[0682]	NRS	Narrowband Reference Signal
[0683]	NS	Network Service
[0684]	NSA	Non-Standalone operation mode

[0685]	NSD	Network Service Descriptor
[0686]	NSR	Network Service Record
[0687]	NSSAI	Network Slice Selection Assistance Information
[0688]	S-NNSAI	Single-NSSAI
[0689]	NSSF	Network Slice Selection Function
[0690]	NW	Network
[0691]	NWUS	Narrowband wake-up signal, Narrowband WUS
[0692]	NZP	Non-Zero Power
[0693]	O&M	Operation and Maintenance
[0694]	ODU2	Optical channel Data Unit - type 2
[0695]	OFDM	Orthogonal Frequency Division Multiplexing
[0696]	OFDMA	Orthogonal Frequency Division Multiple Access
[0697]	OOB	Out-of-band
[0698]	OOS	Out of Sync
[0699]	OPEX	OPERating EXpense
[0700]	OSI	Other System Information
[0701]	OSS	Operations Support System
[0702]	OTA	over-the-air
[0703]	PAPR	Peak-to-Average Power Ratio
[0704]	PAR	Peak to Average Ratio
[0705]	PBCH	Physical Broadcast Channel
[0706]	PC	Power Control, Personal Computer
[0707]	PCC	Primary Component Carrier, Primary CC
[0708]	PCell	Primary Cell
[0709]	PCI	Physical Cell ID, Physical Cell Identity
[0710]	PCEF	Policy and Charging Enforcement Function
[0711]	PCF	Policy Control Function
[0712]	PCRF	Policy Control and Charging Rules Function
[0713]	PDCP	Packet Data Convergence Protocol, Packet Data Convergence Protocol layer
[0714]	PDCCCH	Physical Downlink Control Channel
[0715]	PDCP	Packet Data Convergence Protocol

[0716]	PDN	Packet Data Network, Public Data Network
[0717]	PDSCH	Physical Downlink Shared Channel
[0718]	PDU	Protocol Data Unit
[0719]	PEI	Permanent Equipment Identifiers
[0720]	PFD	Packet Flow Description
[0721]	P-GW	PDN Gateway
[0722]	PHICH	Physical hybrid-ARQ indicator channel
[0723]	PHY	Physical layer
[0724]	PLMN	Public Land Mobile Network
[0725]	PIN	Personal Identification Number
[0726]	PM	Performance Measurement
[0727]	PMI	Precoding Matrix Indicator
[0728]	PNF	Physical Network Function
[0729]	PNFD	Physical Network Function Descriptor
[0730]	PNFR	Physical Network Function Record
[0731]	POC	PTT over Cellular
[0732]	PP, PTP	Point-to-Point
[0733]	PPP	Point-to-Point Protocol
[0734]	PRACH	Physical RACH
[0735]	PRB	Physical resource block
[0736]	PRG	Physical resource block group
[0737]	ProSe	Proximity Services, Proximity-Based Service
[0738]	PRS	Positioning Reference Signal
[0739]	PRR	Packet Reception Radio
[0740]	PS	Packet Services
[0741]	PSBCH	Physical Sidelink Broadcast Channel
[0742]	PSDCH	Physical Sidelink Downlink Channel
[0743]	PSCCH	Physical Sidelink Control Channel
[0744]	PSSCH	Physical Sidelink Shared Channel
[0745]	PSCell	Primary SCell
[0746]	PSS	Primary Synchronization Signal
[0747]	PSTN	Public Switched Telephone Network

[0748]	PT-RS	Phase-tracking reference signal
[0749]	PTT	Push-to-Talk
[0750]	PUCCH	Physical Uplink Control Channel
[0751]	PUSCH	Physical Uplink Shared Channel
[0752]	QAM	Quadrature Amplitude Modulation
[0753]	QCI	QoS class of identifier
[0754]	QCL	Quasi co-location
[0755]	QFI	QoS Flow ID, QoS Flow Identifier
[0756]	QoS	Quality of Service
[0757]	QPSK	Quadrature (Quaternary) Phase Shift Keying
[0758]	QZSS	Quasi-Zenith Satellite System
[0759]	RA-RNTI	Random Access RNTI
[0760]	RAB	Radio Access Bearer, Random Access Burst
[0761]	RACH	Random Access Channel
[0762]	RADIUS	Remote Authentication Dial In User Service
[0763]	RAN	Radio Access Network
[0764]	RAND	RANDom number (used for authentication)
[0765]	RAR	Random Access Response
[0766]	RAT	Radio Access Technology
[0767]	RAU	Routing Area Update
[0768]	RB	Resource block, Radio Bearer
[0769]	RBG	Resource block group
[0770]	REG	Resource Element Group
[0771]	Rel	Release
[0772]	REQ	REQuest
[0773]	RF	Radio Frequency
[0774]	RI	Rank Indicator
[0775]	RIV	Resource indicator value
[0776]	RL	Radio Link
[0777]	RLC	Radio Link Control, Radio Link Control layer
[0778]	RLC AM	RLC Acknowledged Mode
[0779]	RLC UM	RLC Unacknowledged Mode

[0780]	RLF	Radio Link Failure
[0781]	RLM	Radio Link Monitoring
[0782]	RLM-RS	Reference Signal for RLM
[0783]	RM	Registration Management
[0784]	RMC	Reference Measurement Channel
[0785]	RMSI	Remaining MSI, Remaining Minimum System Information
[0786]	RN	Relay Node
[0787]	RNC	Radio Network Controller
[0788]	RNL	Radio Network Layer
[0789]	RNTI	Radio Network Temporary Identifier
[0790]	ROHC	RObust Header Compression
[0791]	RRC	Radio Resource Control, Radio Resource Control layer
[0792]	RRM	Radio Resource Management
[0793]	RS	Reference Signal
[0794]	RSRP	Reference Signal Received Power
[0795]	RSRQ	Reference Signal Received Quality
[0796]	RSSI	Received Signal Strength Indicator
[0797]	RSU	Road Side Unit
[0798]	RSTD	Reference Signal Time difference
[0799]	RTP	Real Time Protocol
[0800]	RTS	Ready-To-Send
[0801]	RTT	Round Trip Time
[0802]	Rx	Reception, Receiving, Receiver
[0803]	S1AP	S1 Application Protocol
[0804]	S1-MME	S1 for the control plane
[0805]	S1-U	S1 for the user plane
[0806]	S-GW	Serving Gateway
[0807]	S-RNTI	SRNC Radio Network Temporary Identity
[0808]	S-TMSI	SAE Temporary Mobile Station Identifier
[0809]	SA	Standalone operation mode
[0810]	SAE	System Architecture Evolution
[0811]	SAP	Service Access Point

[0812]	SAPD	Service Access Point Descriptor
[0813]	SAPI	Service Access Point Identifier
[0814]	SCC	Secondary Component Carrier, Secondary CC
[0815]	SCell	Secondary Cell
[0816]	SC-FDMA	Single Carrier Frequency Division Multiple Access
[0817]	SCG	Secondary Cell Group
[0818]	SCM	Security Context Management
[0819]	SCS	Subcarrier Spacing
[0820]	SCTP	Stream Control Transmission Protocol
[0821]	SDAP	Service Data Adaptation Protocol, Service Data Adaptation Protocol layer
[0822]	SDL	Supplementary Downlink
[0823]	SDNF	Structured Data Storage Network Function
[0824]	SDP	Service Discovery Protocol (Bluetooth related)
[0825]	SDSF	Structured Data Storage Function
[0826]	SDU	Service Data Unit
[0827]	SEAF	Security Anchor Function
[0828]	SeNB	secondary eNB
[0829]	SEPP	Security Edge Protection Proxy
[0830]	SFI	Slot format indication
[0831]	SFTD	Space-Frequency Time Diversity, SFN and frame timing difference
[0832]	SFN	System Frame Number
[0833]	SgNB	Secondary gNB
[0834]	SGSN	Serving GPRS Support Node
[0835]	S-GW	Serving Gateway
[0836]	SI	System Information
[0837]	SI-RNTI	System Information RNTI
[0838]	SIB	System Information Block
[0839]	SIM	Subscriber Identity Module
[0840]	SIP	Session Initiated Protocol
[0841]	SiP	System in Package

[0842]	SL	Sidelink
[0843]	SLA	Service Level Agreement
[0844]	SM	Session Management
[0845]	SMF	Session Management Function
[0846]	SMS	Short Message Service
[0847]	SMSF	SMS Function
[0848]	SMTC	SSB-based Measurement Timing Configuration
[0849]	SN	Secondary Node, Sequence Number
[0850]	SoC	System on Chip
[0851]	SON	Self-Organizing Network
[0852]	SpCell	Special Cell
[0853]	SP-CSI-RNTI	Semi-Persistent CSI RNTI
[0854]	SPS	Semi-Persistent Scheduling
[0855]	SQN	Sequence number
[0856]	SR	Scheduling Request
[0857]	SRB	Signalling Radio Bearer
[0858]	SRS	Sounding Reference Signal
[0859]	SS	Synchronization Signal
[0860]	SSB	Synchronization Signal Block, SS/PBCH Block
[0861]	SSBRI	SS/PBCH Block Resource Indicator, Synchronization Signal Block Resource Indicator
[0862]	SSC	Session and Service Continuity
[0863]	SS-RSRP	Synchronization Signal based Reference Signal Received Power
[0864]	SS-RSRQ	Synchronization Signal based Reference Signal Received Quality
[0865]	SS-SINR	Synchronization Signal based Signal to Noise and Interference Ratio
[0866]	SSS	Secondary Synchronization Signal
[0867]	SSSG	Search Space Set Group
[0868]	SSSIF	Search Space Set Indicator
[0869]	SST	Slice/Service Types
[0870]	SU-MIMO	Single User MIMO
[0871]	SUL	Supplementary Uplink

[0872]	TA	Timing Advance, Tracking Area
[0873]	TAC	Tracking Area Code
[0874]	TAG	Timing Advance Group
[0875]	TAU	Tracking Area Update
[0876]	TB	Transport Block
[0877]	TBS	Transport Block Size
[0878]	TBD	To Be Defined
[0879]	TCI	Transmission Configuration Indicator
[0880]	TCP	Transmission Communication Protocol
[0881]	TDD	Time Division Duplex
[0882]	TDM	Time Division Multiplexing
[0883]	TDMA	Time Division Multiple Access
[0884]	TE	Terminal Equipment
[0885]	TEID	Tunnel End Point Identifier
[0886]	TFT	Traffic Flow Template
[0887]	TMSI	Temporary Mobile Subscriber Identity
[0888]	TNL	Transport Network Layer
[0889]	TPC	Transmit Power Control
[0890]	TPMI	Transmitted Precoding Matrix Indicator
[0891]	TR	Technical Report
[0892]	TRP, TRxP	Transmission Reception Point
[0893]	TRS	Tracking Reference Signal
[0894]	TRx	Transceiver
[0895]	TS	Technical Specifications, Technical Standard
[0896]	TTI	Transmission Time Interval
[0897]	Tx	Transmission, Transmitting, Transmitter
[0898]	U-RNTI	UTRAN Radio Network Temporary Identity
[0899]	UART	Universal Asynchronous Receiver and Transmitter
[0900]	UCI	Uplink Control Information
[0901]	UE	User Equipment
[0902]	UDM	Unified Data Management
[0903]	UDP	User Datagram Protocol

[0904]	UDSF	Unstructured Data Storage Network Function
[0905]	UICC	Universal Integrated Circuit Card
[0906]	UL	Uplink
[0907]	UM	Unacknowledged Mode
[0908]	UML	Unified Modelling Language
[0909]	UMTS	Universal Mobile Telecommunications System
[0910]	UP	User Plane
[0911]	UPF	User Plane Function
[0912]	URI	Uniform Resource Identifier
[0913]	URL	Uniform Resource Locator
[0914]	URLLC	Ultra-Reliable and Low Latency
[0915]	USB	Universal Serial Bus
[0916]	USIM	Universal Subscriber Identity Module
[0917]	USS	UE-specific search space
[0918]	UTRA	UMTS Terrestrial Radio Access
[0919]	UTRAN	Universal Terrestrial Radio Access Network
[0920]	UwPTS	Uplink Pilot Time Slot
[0921]	V2I	Vehicle-to-Infrastructure
[0922]	V2P	Vehicle-to-Pedestrian
[0923]	V2V	Vehicle-to-Vehicle
[0924]	V2X	Vehicle-to-everything
[0925]	VIM	Virtualized Infrastructure Manager
[0926]	VL	Virtual Link,
[0927]	VLAN	Virtual LAN, Virtual Local Area Network
[0928]	VM	Virtual Machine
[0929]	VNF	Virtualized Network Function
[0930]	VNF FG	VNF Forwarding Graph
[0931]	VNF FG D	VNF Forwarding Graph Descriptor
[0932]	VNFM	VNF Manager
[0933]	VoIP	Voice-over-IP, Voice-over-Internet Protocol
[0934]	VPLMN	Visited Public Land Mobile Network
[0935]	VPN	Virtual Private Network

[0936]	VRB	Virtual Resource Block
[0937]	WiMAX	Worldwide Interoperability for Microwave Access
[0938]	WLAN	Wireless Local Area Network
[0939]	WMAN	Wireless Metropolitan Area Network
[0940]	WPAN	Wireless Personal Area Network
[0941]	X2-C	X2-Control plane
[0942]	X2-U	X2-User plane
[0943]	XML	eXtensible Markup Language
[0944]	XRES	EXpected user RESponse
[0945]	XOR	eXclusive OR
[0946]	ZC	Zadoff-Chu
[0947]	ZP	Zero Power

Terminology

[0948] For the purposes of the present document, the following terms and definitions are applicable to the examples and embodiments discussed herein.

[0949] 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.

[0950] 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.”

[0951] 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.

[0952] 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.

[0953] 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.

[0954] 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.

[0955] 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.

[0956] 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.

[0957] 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.

- [0958] 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.
- [0959] 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 link, and/or the like.
- [0960] 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.
- [0961] The term “SMTC” refers to an SSB-based measurement timing configuration configured by *SSB-MeasurementTimingConfiguration*.
- [0962] The term “SSB” refers to an SS/PBCH block.
- [0963] 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.
- [0964] 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.
- [0965] The term “Secondary Cell” refers to a cell providing additional radio resources on top of a Special Cell for a UE configured with CA.
- [0966] 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.

- [0967] 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.
- [0968] 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/.
- [0969] 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. An unmanned aircraft traffic management server facilitating Unmanned Aerial System (UAS) services over evolved packet systems, the server comprising:
 - network circuitry; and
 - processor circuitry coupled to the network circuitry and configured to:
 - receive a registration request from each of an unmanned aerial vehicle (UAV) and a UAV controller to establish an Unmanned Aerial System (UAS), each registration request including an application layer registration through a Unmanned Aircraft Traffic Management (UTM) application function (AF), in which an IP address of the server is provided,
 - initiate a UAS Operation Service Request Procedure via a network exposure function (NEF) to obtain results of a UAS operation service authorization from each of the UAV and the UAV controller,
 - associate the UAV and the UAV controller to operate as the UAS in response to obtaining the results of the UAS operation service authorization from each of the UAV and the UAV controller, and
 - transmit a UAS operation status update procedure to the UAV and the UAV controller, the update procedure including UAS association information, a UAS policy update, and initiation of a UAS operation.
2. The server of claim 1, wherein the processor circuitry is further configured to:
 - initiate an AF session setup procedure including a required quality of service (QoS) to manage IP data flows for a UTM session between the UAV and the server, and
 - command and control (C2) session between the UAV and the UAV controller.
3. The server of claim 1, wherein the processor circuitry is further configured to:
 - assign subscription rights to user equipments (UEs) associated with each of the UAV and the UAV controller.
4. The server of claim 3, wherein the subscription rights include a subscription for a UE operating the UAV in the UAS, a subscription of a UE operating the UAV controller in

the UAS, a subscription for UAS operation using indirect communication, or a subscription for UAS operation using network navigated C2.

5. The server of claim 3, wherein the processor circuitry is further configured to:
provide, to the UE associated with the UAV controller, authorization for the UAS operation enabling controller C2 communication, including a list of public land mobile networks (PLMNs) for which the UAV is authorized, a list of application identifiers per PLMN, a list of allowed traffic types per application identifier, and a UAS-data network name (DNN).
6. The server of claim 3, wherein the processor circuitry is further configured to:
provide, to the UE associated with the UAV, authorization for the UAS operation enabling network C2 communication with flight plan, including a list of PLMNs for which the UAV is authorized, a list of application identifiers per PLMN, a list of allowed traffic types per application identifier, and the UAS-DNN.
7. The server of claim 1, wherein the processor circuitry is further configured to:
transmit, to the NEF, a UAS operation service request message including a server identifier, generic public subscription identifier, an external group identifier of the UAV and UAV controller, external application identifiers, and a UAS operation authorization for each application identifier.
8. The server of claim 7, wherein the UAS operation authorization indicates that the UAS operation policy is to be created in a network of an operator when successfully authorized.
9. The server of claim 7, wherein the NEF requests the UAS operation authorization from a policy control function (PCF).
10. The server of claim 9, wherein the processor circuitry is further configured to:

receive, from the NEF, the UAS operation authorization status for each application identifier, and a cause for authorization or denial of authorization for each application identifier.

11. An unmanned aircraft traffic management method for facilitating Unmanned Aerial System (UAS) services over evolved packet systems, the method comprising:

receiving a registration request from each of an unmanned aerial vehicle (UAV) and a UAV controller to establish an Unmanned Aerial System (UAS), each registration request including an application layer registration through a Unmanned Aircraft Traffic Management (UTM) application function (AF), in which an IP address of the server is provided;

initiating a UAS Operation Service Request Procedure via a network exposure function (NEF) to obtain results of a UAS operation service authorization from each of the UAV and the UAV controller;

associating the UAV and the UAV controller to operate as the UAS in response to obtaining the results of the UAS operation service authorization from each of the UAV and the UAV controller; and

transmitting a UAS operation status update procedure to the UAV and the UAV controller, the update procedure including UAS association information, a UAS policy update, and initiation of a UAS operation.

12. The method of claim 11, further comprising:

initiating an AF session setup procedure including a required quality of service (QoS) to manage IP data flows for a UTM session between the UAV and the server, and command and control (C2) session between the UAV and the UAV controller.

13. The method of claim 11, further comprising:

assigning subscription rights to user equipments (UEs) associated with each of the UAV and the UAV controller.

14. The method of claim 13, wherein the subscription rights include a subscription for a UE operating the UAV in the UAS, a subscription of a UE operating the UAV controller in

the UAS, a subscription for UAS operation using indirect communication, or a subscription for UAS operation using network navigated C2.

15. The method of claim 13, further comprising:
 - providing, to the UE associated with the UAV controller, authorization for the UAS operation enabling controller C2 communication, including a list of public land mobile networks (PLMNs) for which the UAV is authorized, a list of application identifiers per PLMN, a list of allowed traffic types per application identifier, and a UAS-data network name (DNN).
16. The method of claim 13, further comprising:
 - providing, to the UE associated with the UAV, authorization for the UAS operation enabling network C2 communication with flight plan, including a list of PLMNs for which the UAV is authorized, a list of application identifiers per PLMN, a list of allowed traffic types per application identifier, and the UAS-DNN.
17. The method of claim 11, further comprising:
 - transmitting, to the NEF, a UAS operation service request message including a server identifier, generic public subscription identifier, an external group identifier of the UAV and UAV controller, external application identifiers, and a UAS operation authorization for each application identifier.
18. The method of claim 17, wherein the UAS operation authorization indicates that the UAS operation policy is to be created in a network of an operator when successfully authorized.
19. The method of claim 17, wherein the NEF requests the UAS operation authorization from a policy control function (PCF).
20. The method of claim 19, further comprising:

receiving, from the NEF, the UAS operation authorization status for each application identifier, and a cause for authorization or denial of authorization for each application identifier.

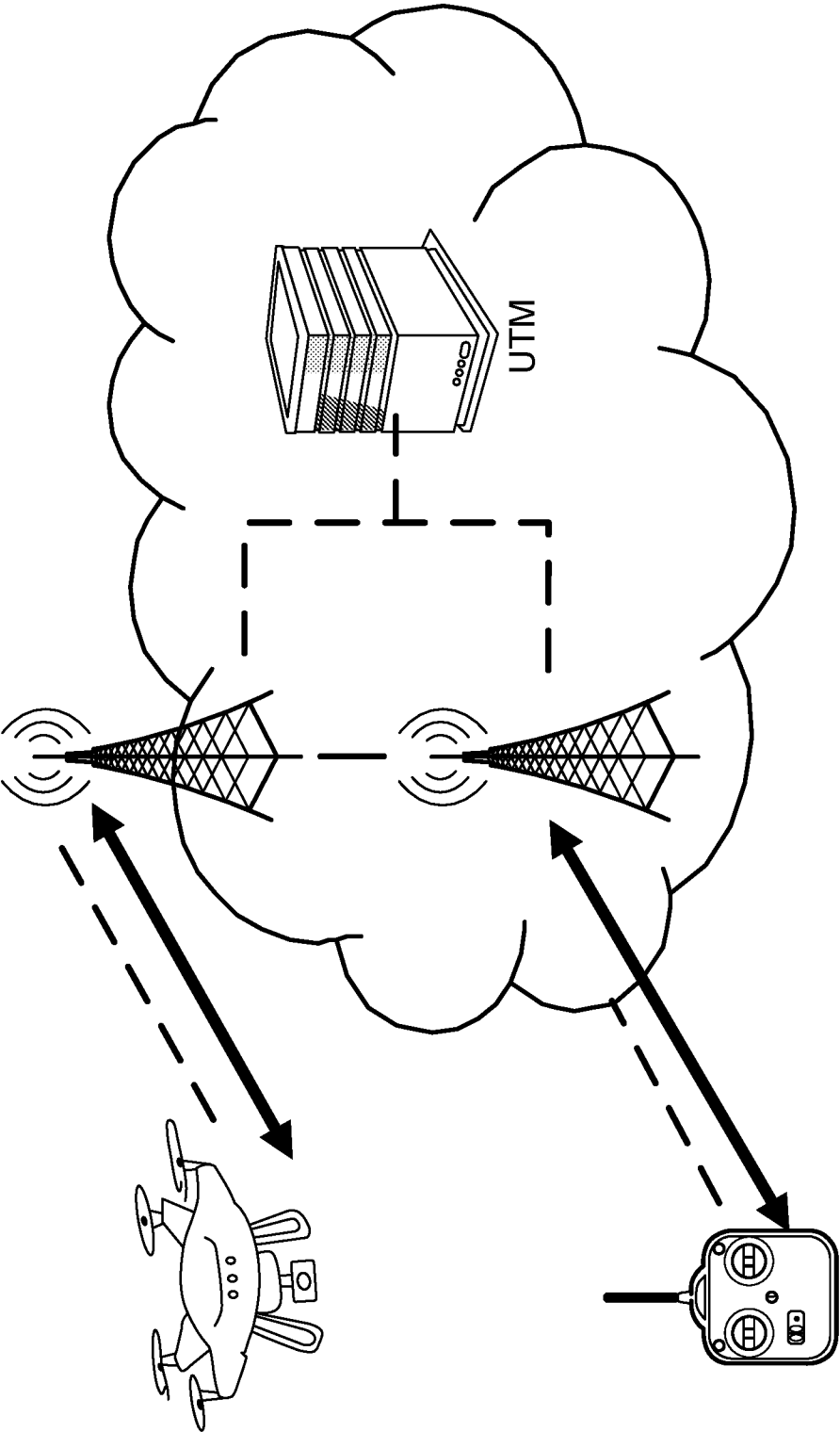


FIG. 1

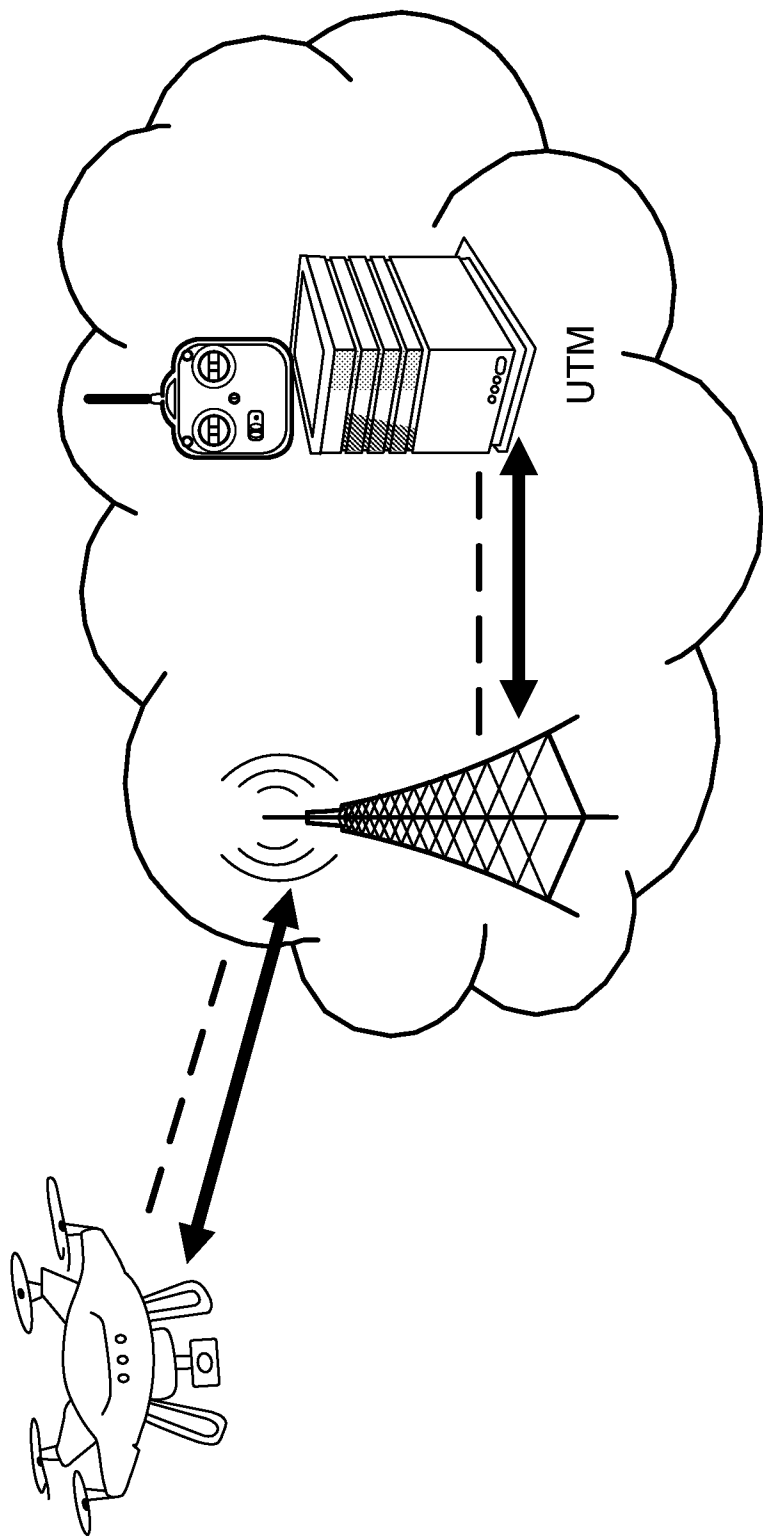


FIG. 2

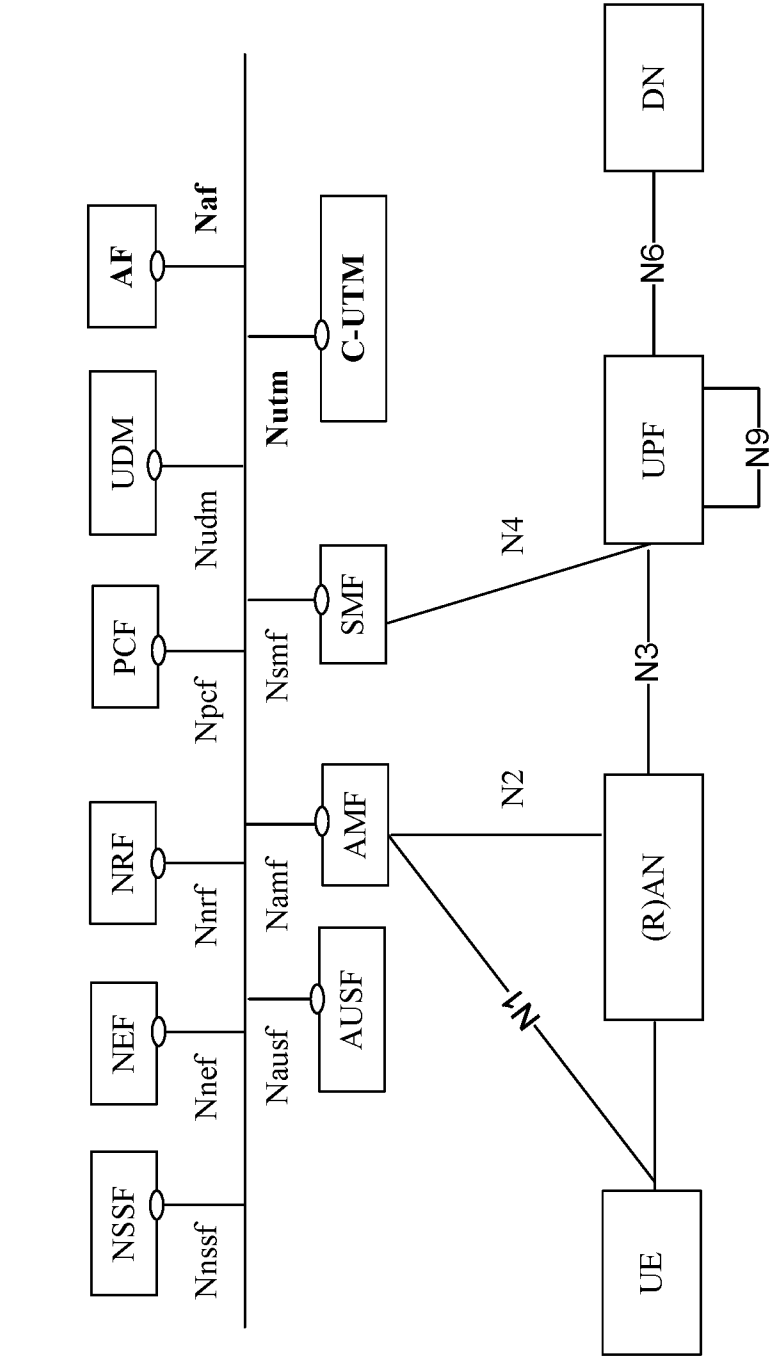


FIG. 3

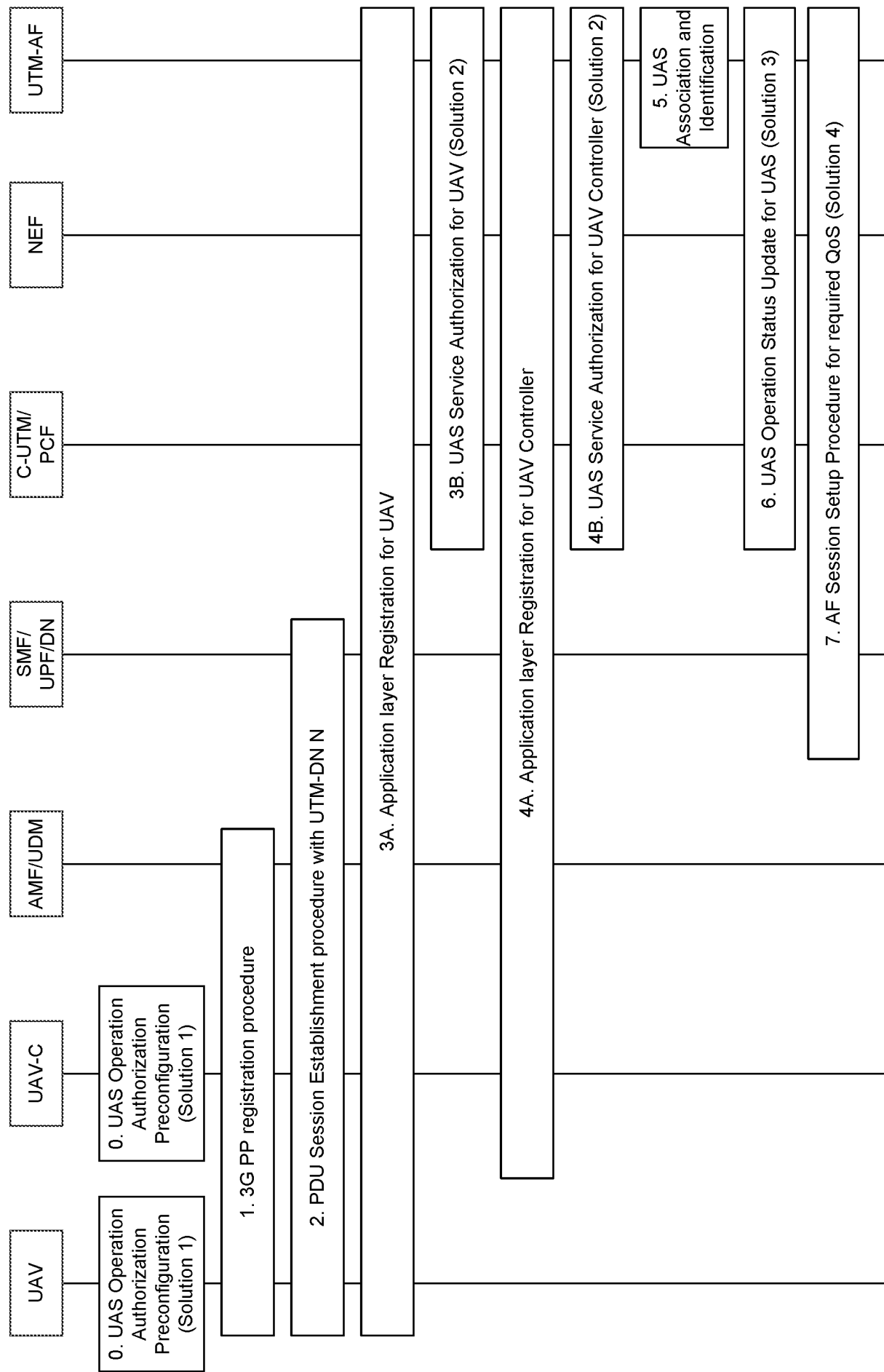


FIG. 4

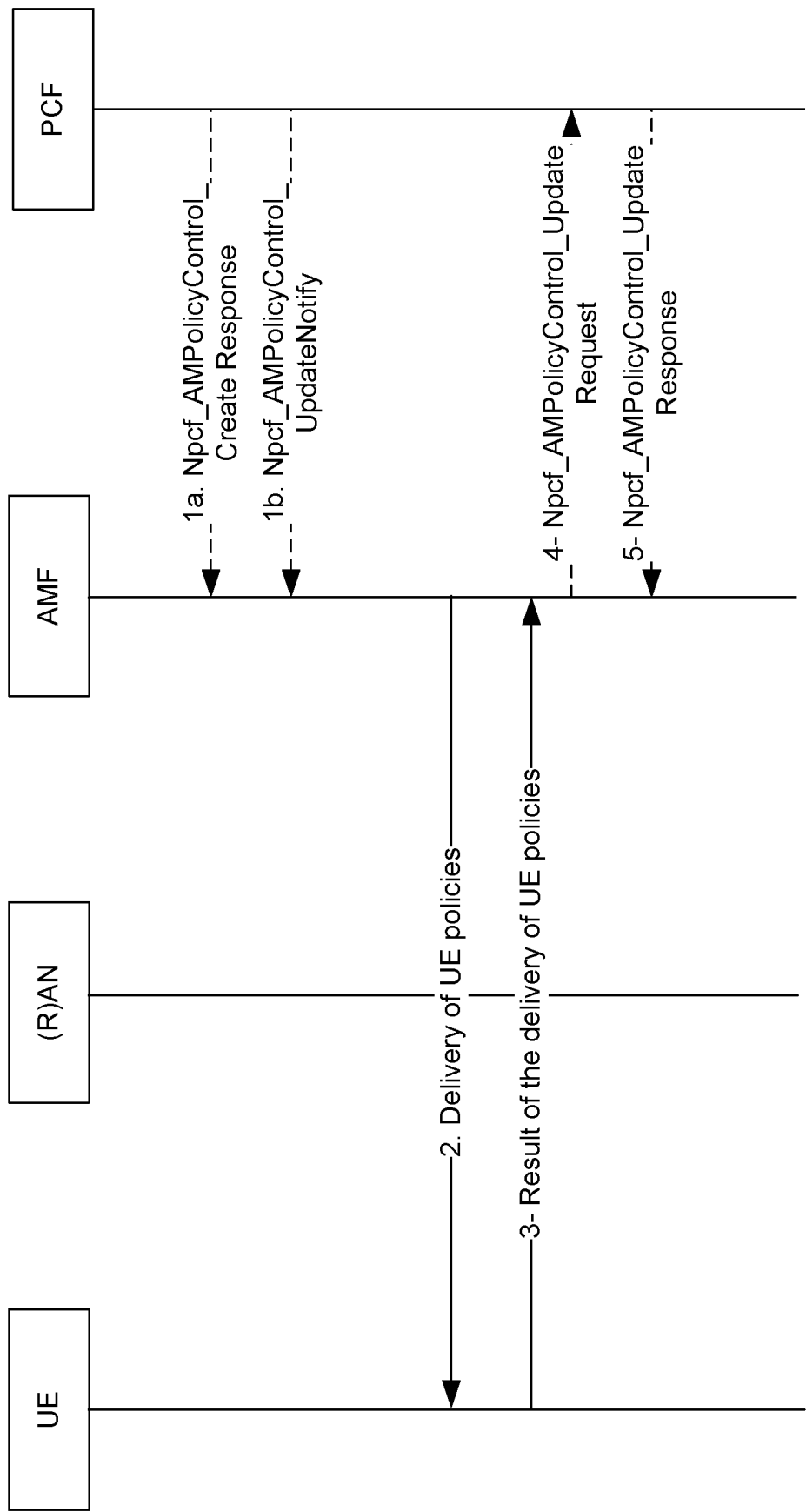


FIG. 5

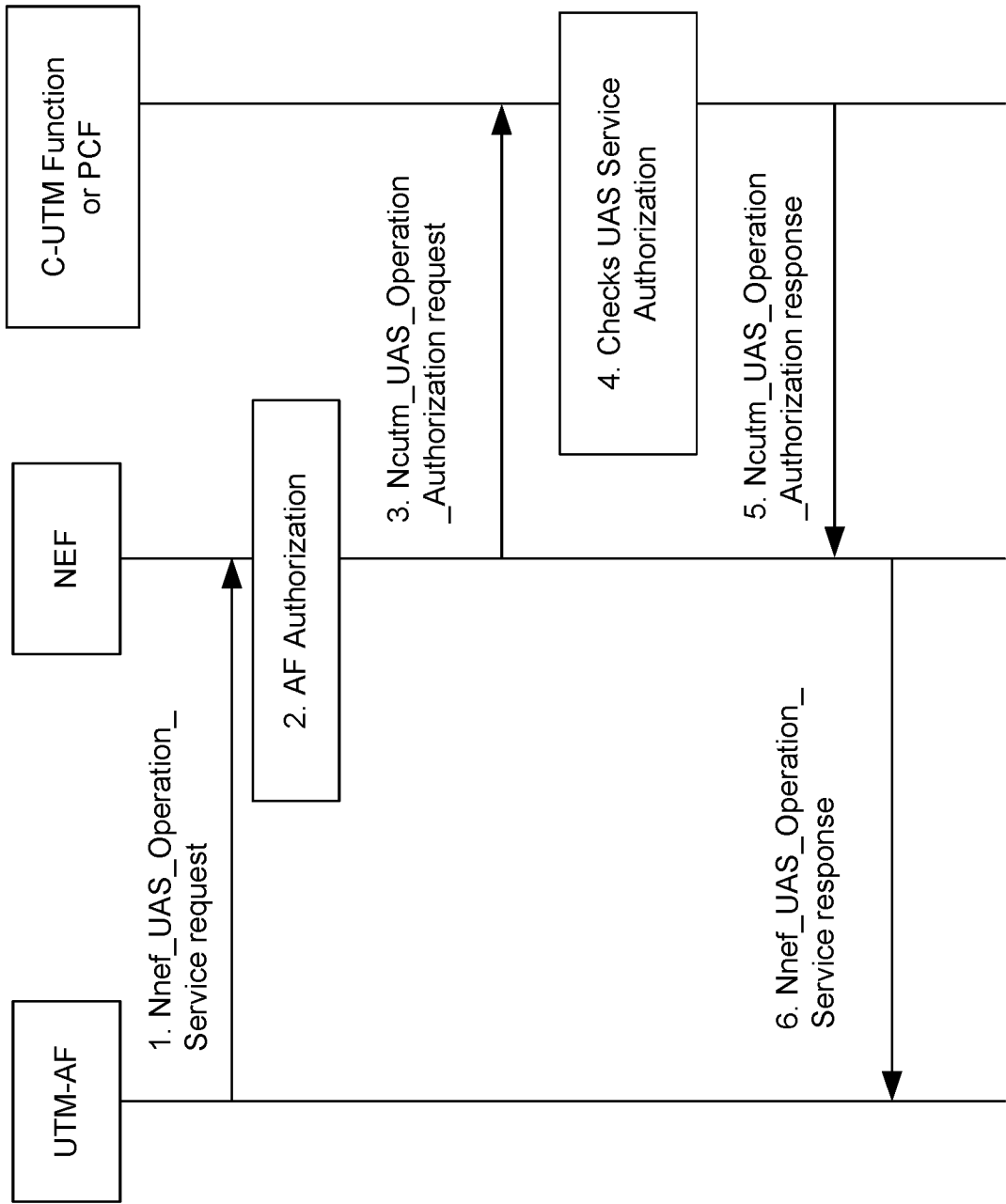


FIG. 6

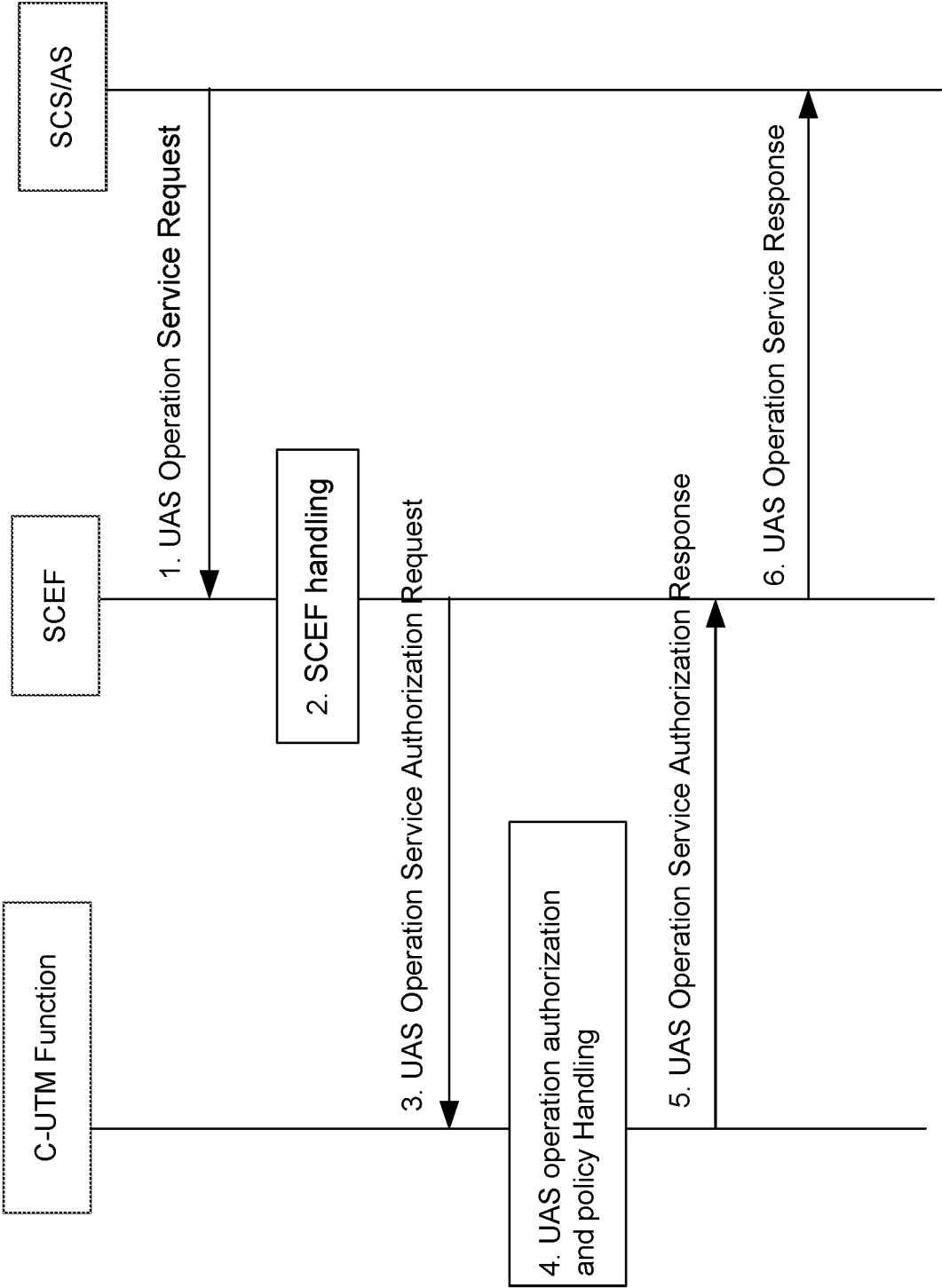


FIG. 7

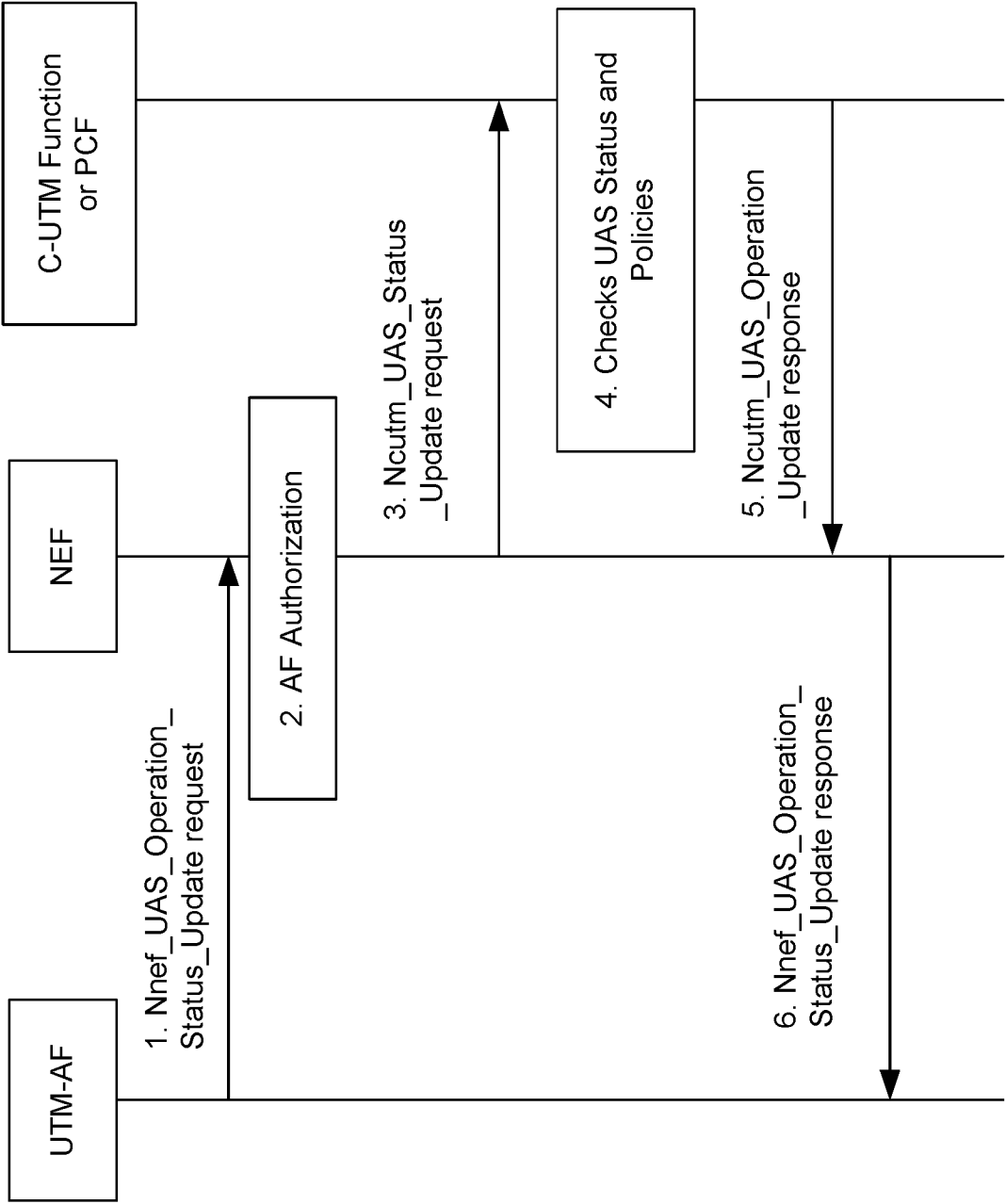


FIG. 8

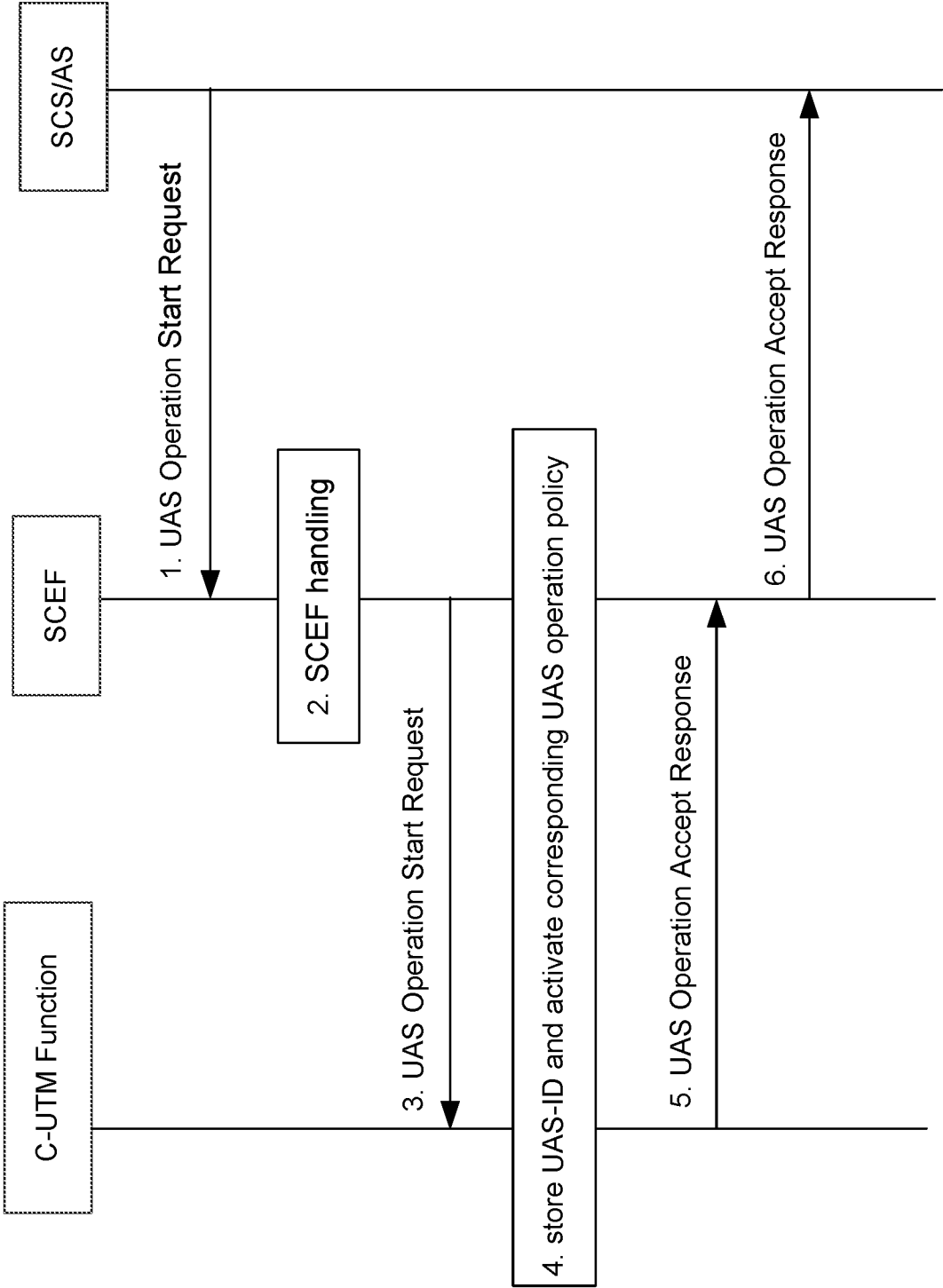


FIG. 9

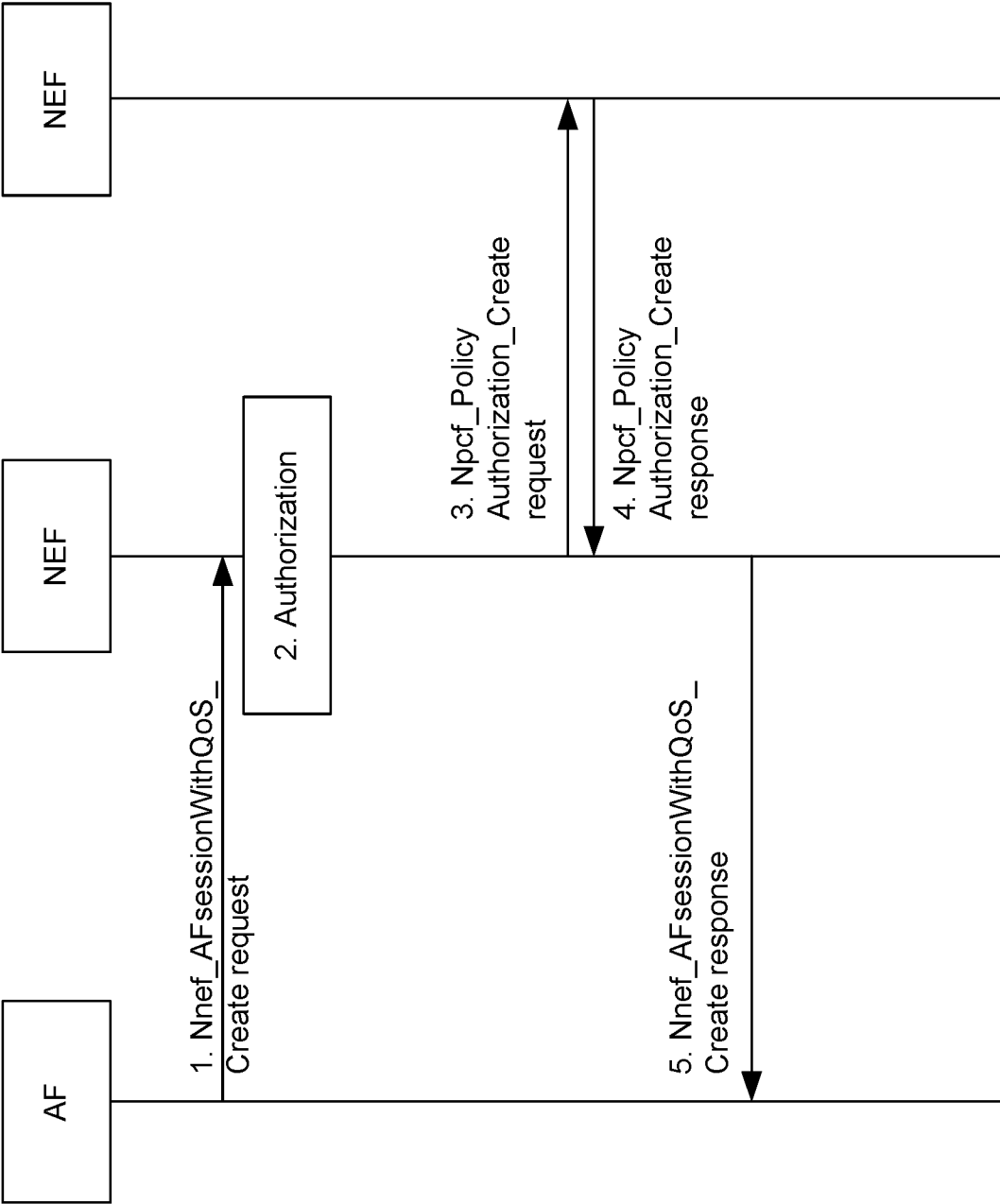


FIG. 10

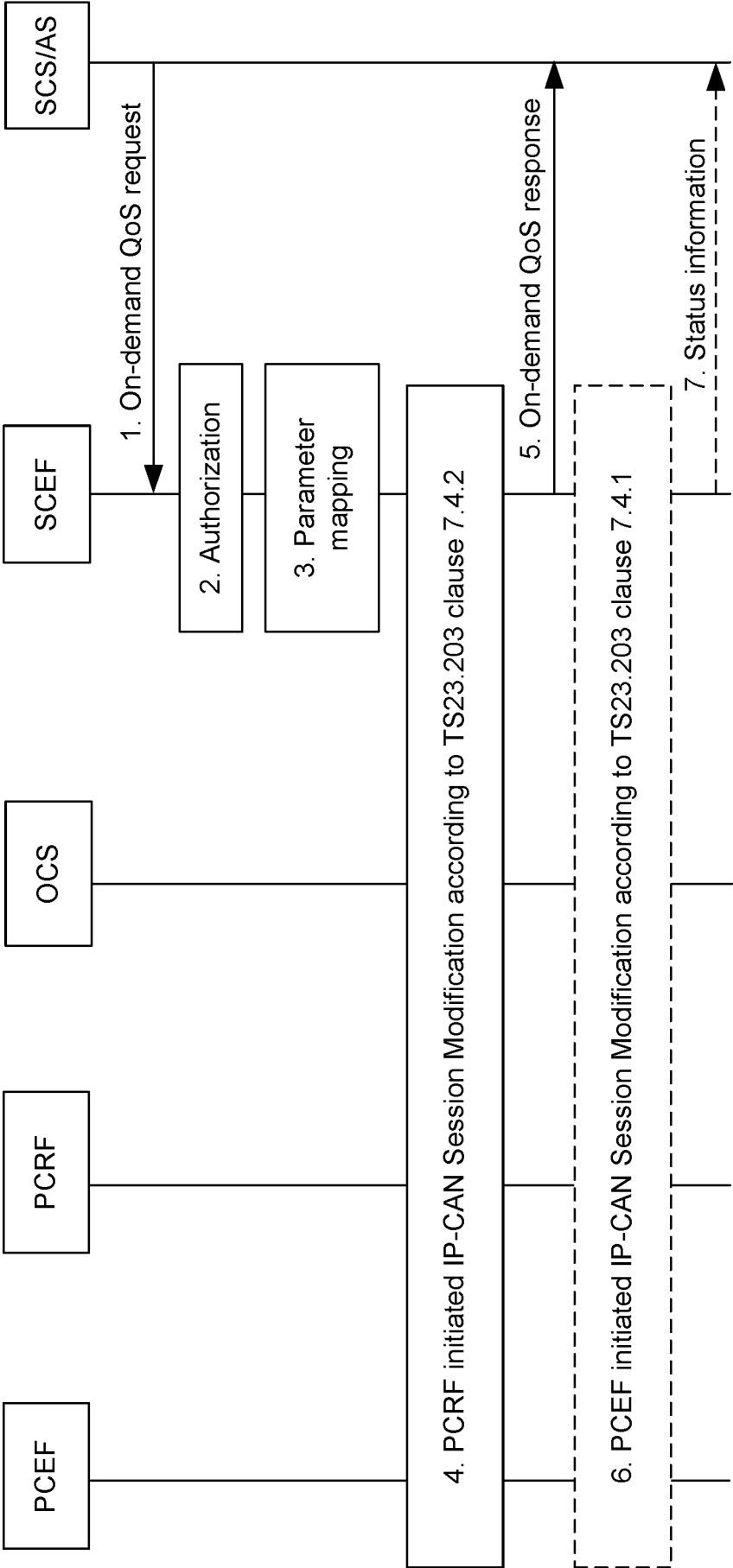


FIG. 11

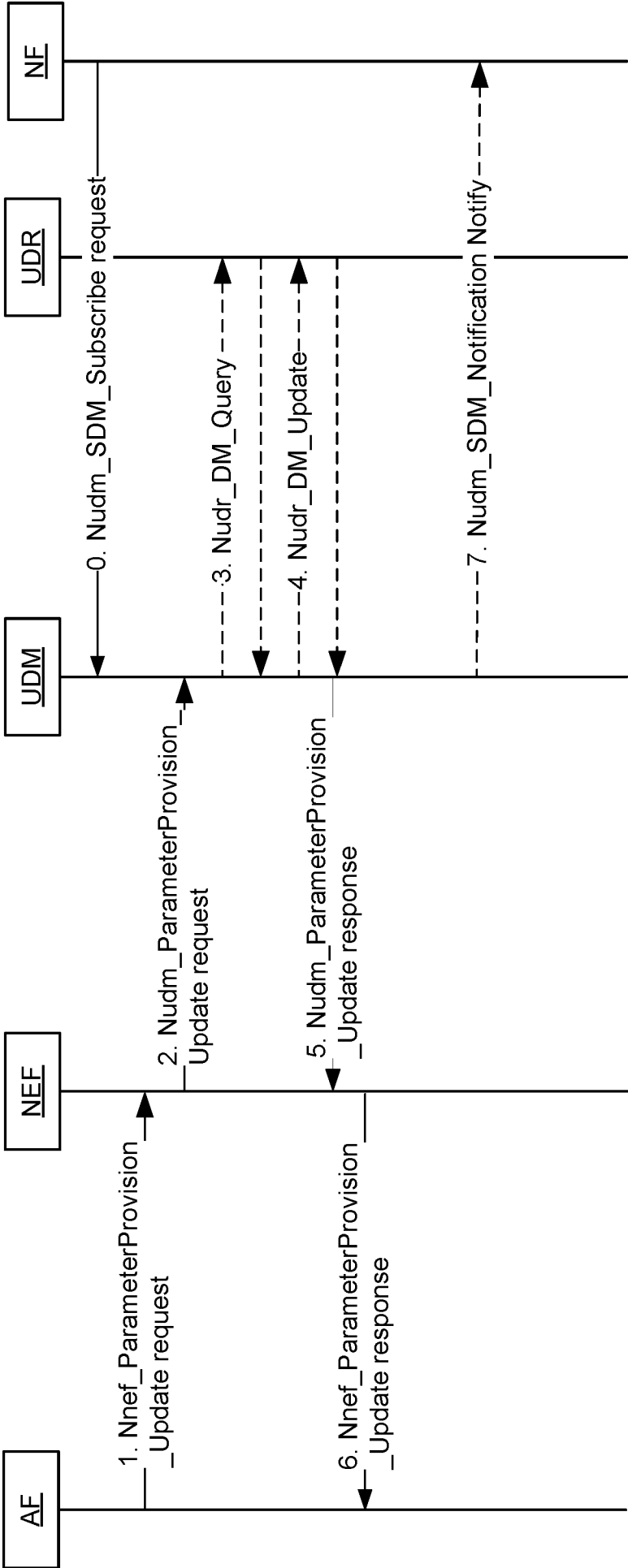


FIG. 12

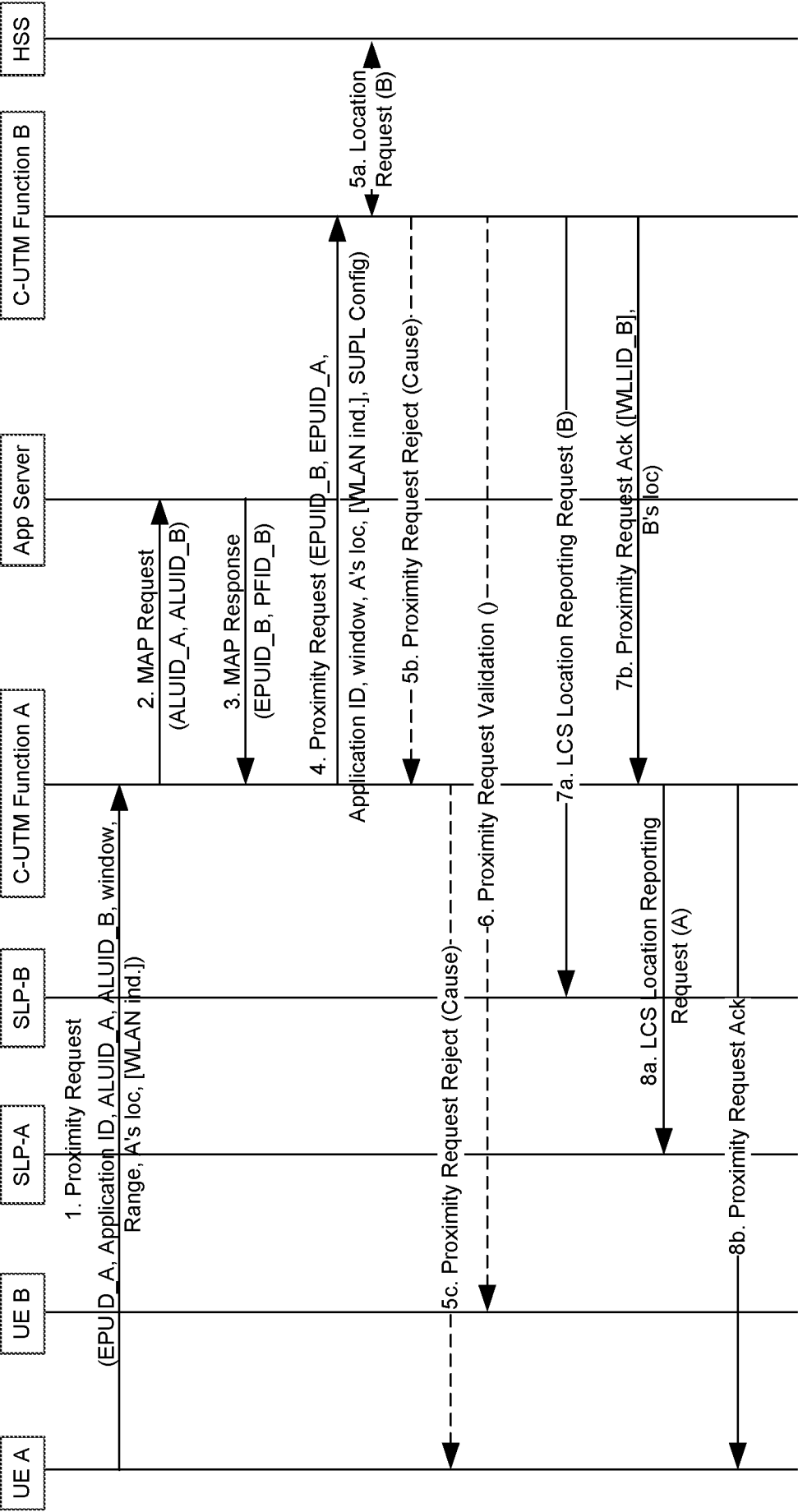


FIG. 13

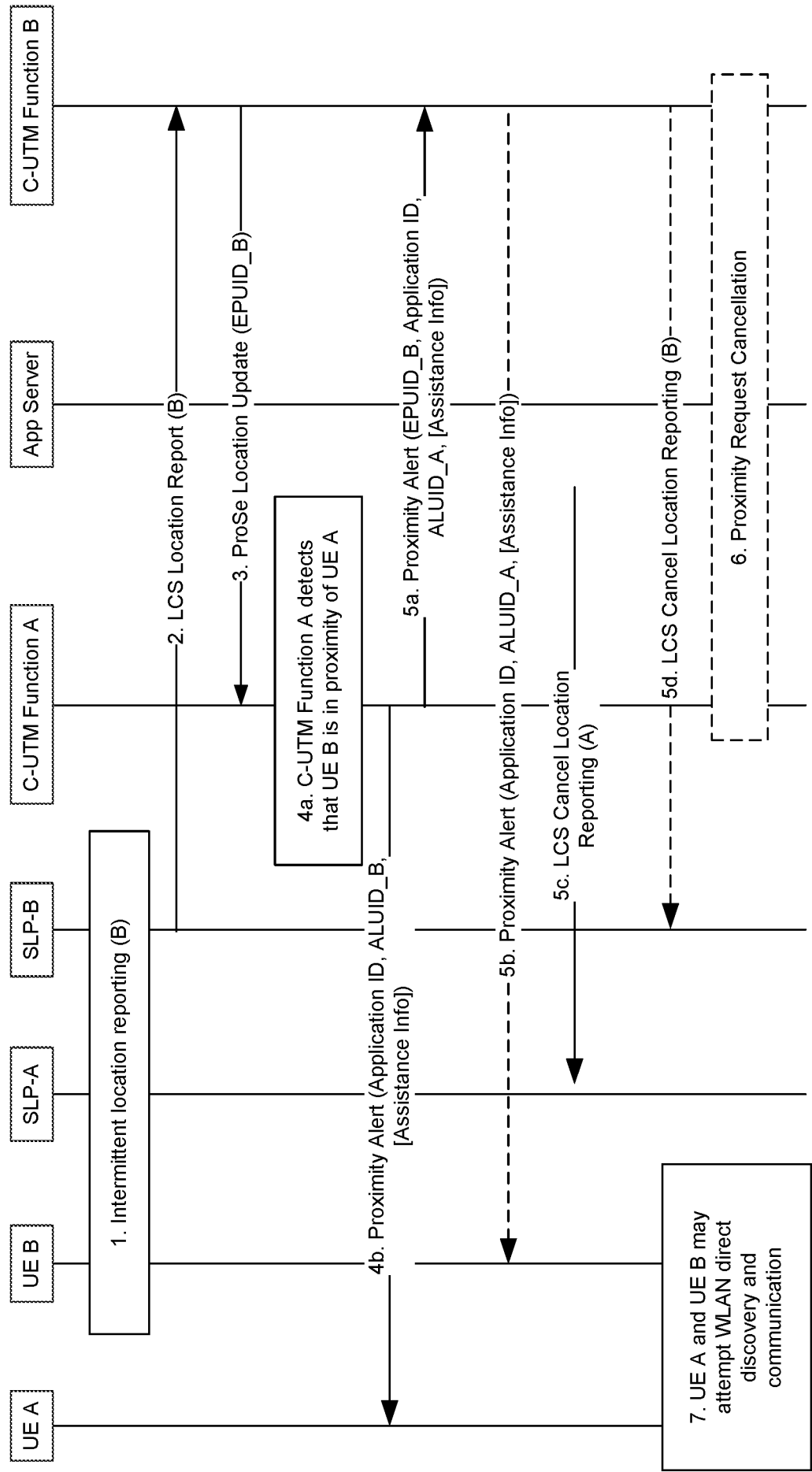


FIG. 14

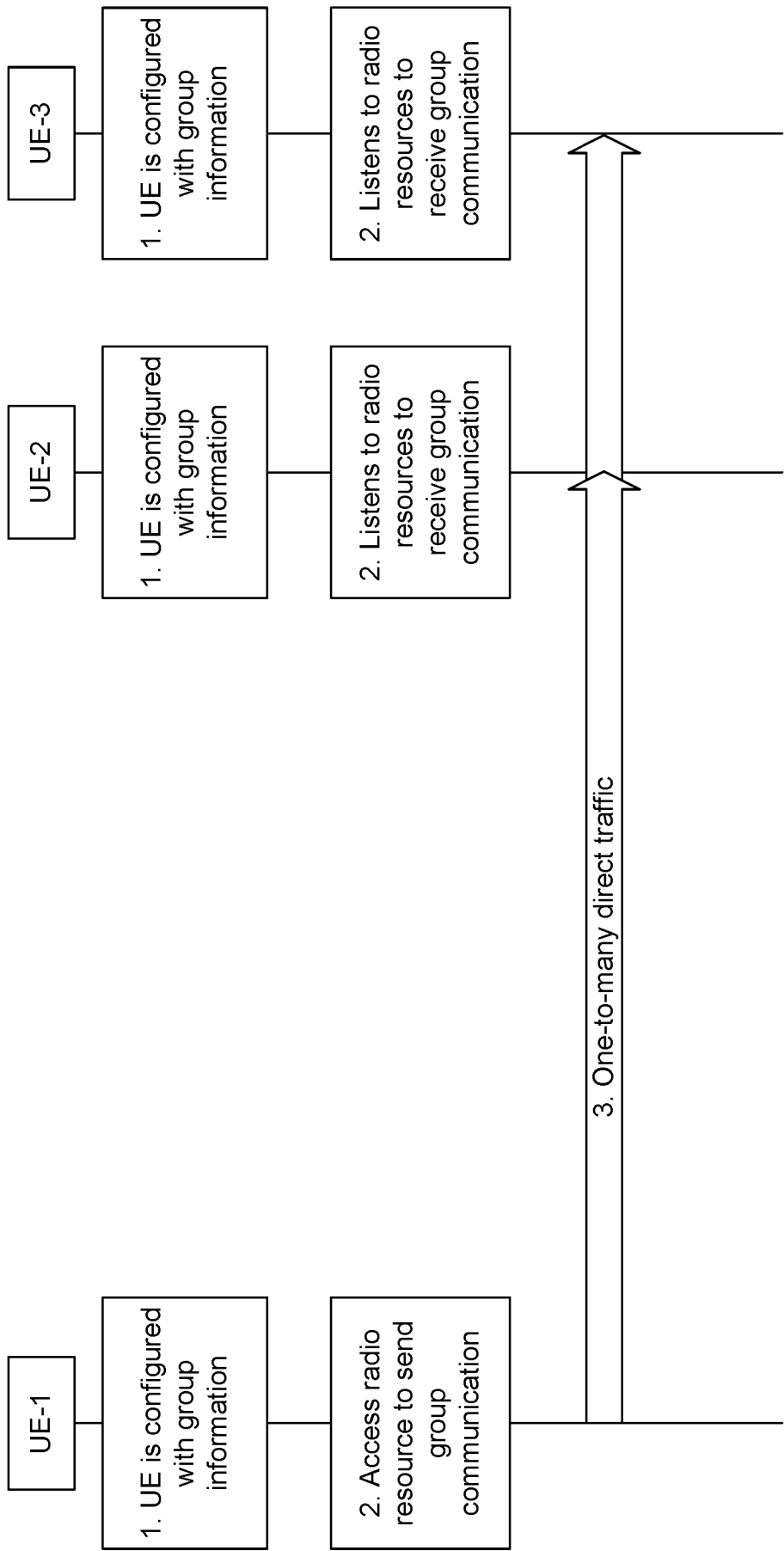


FIG. 15

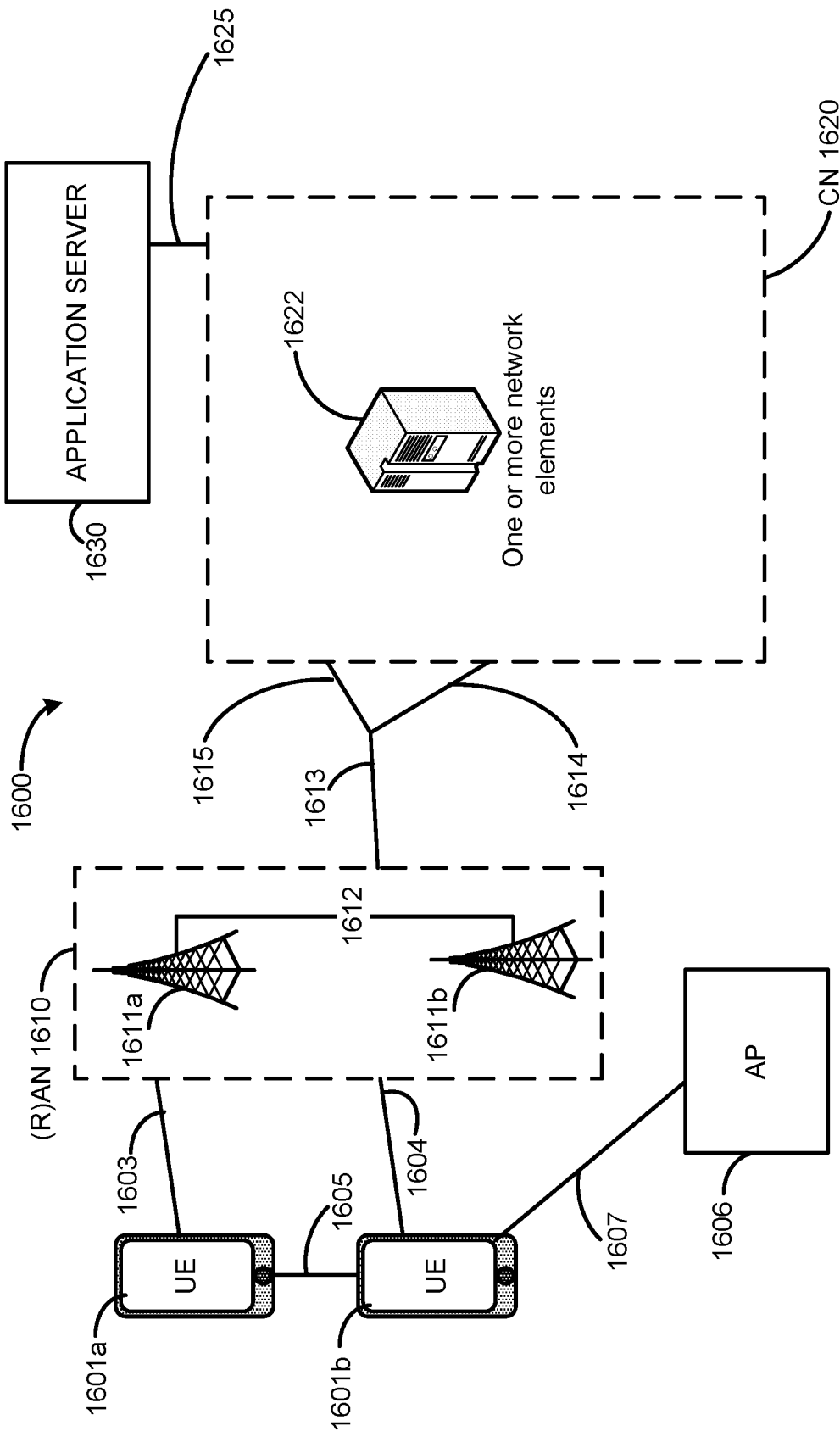


FIG. 16

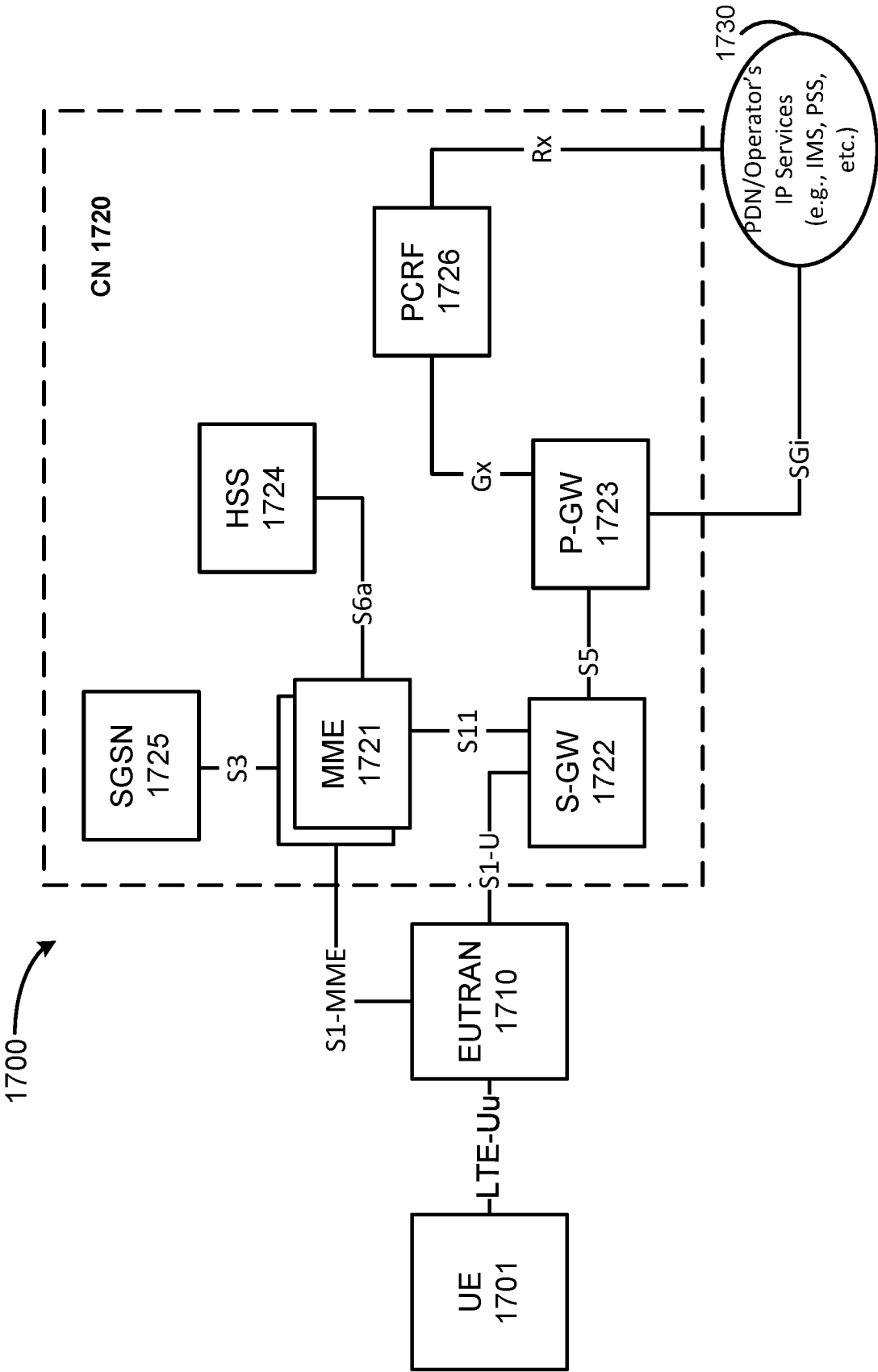


FIG. 17

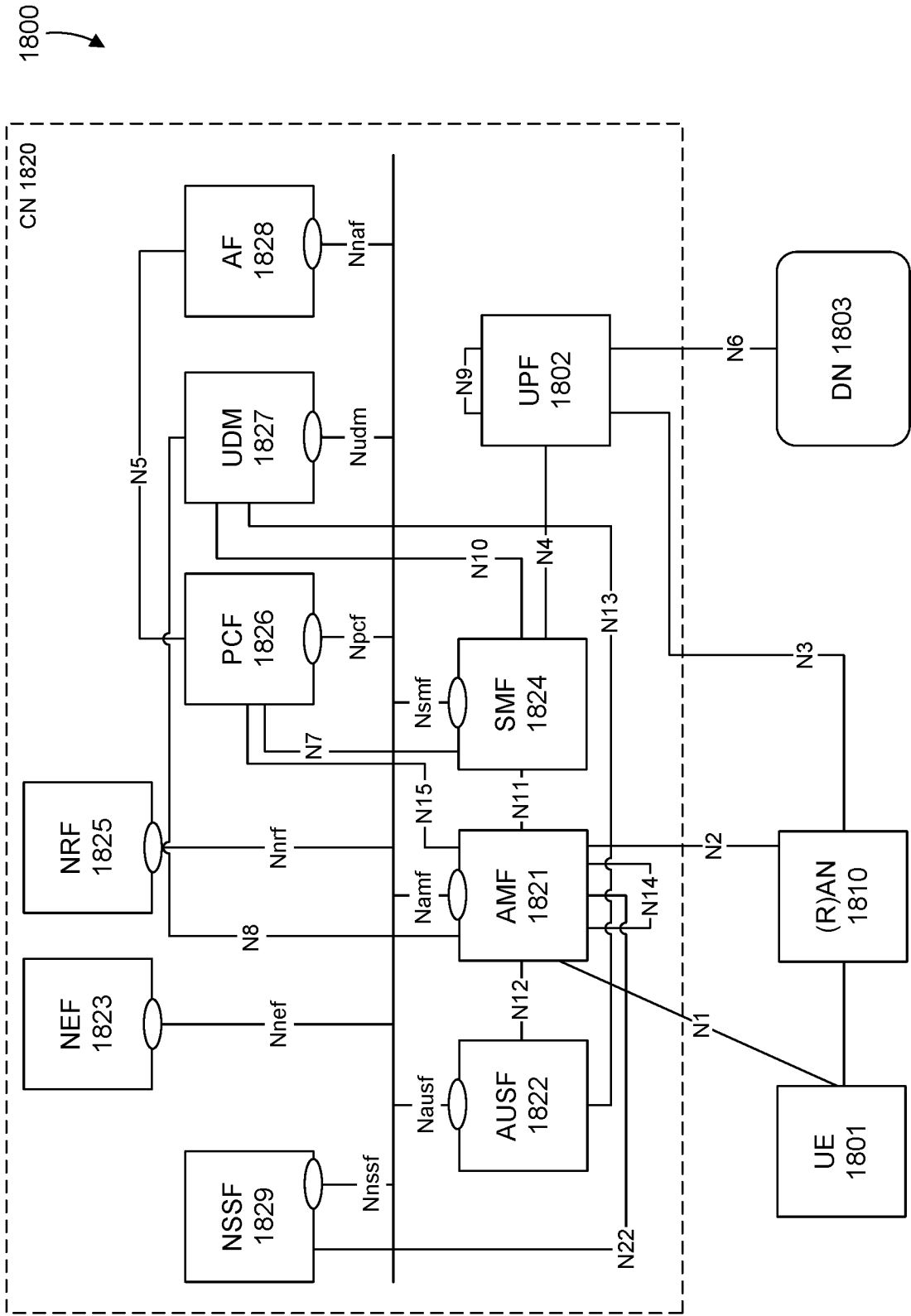


FIG. 18

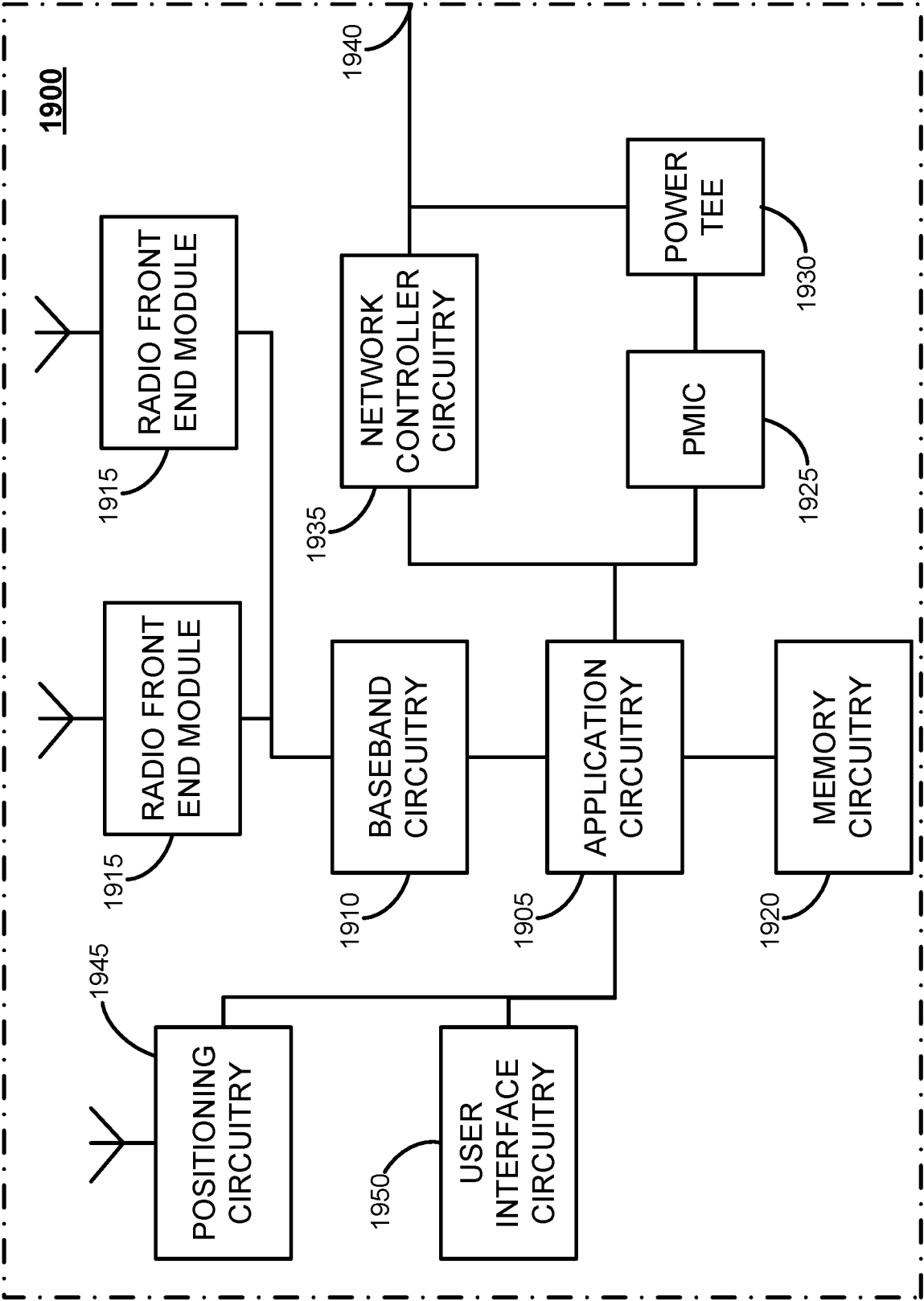


FIG. 19

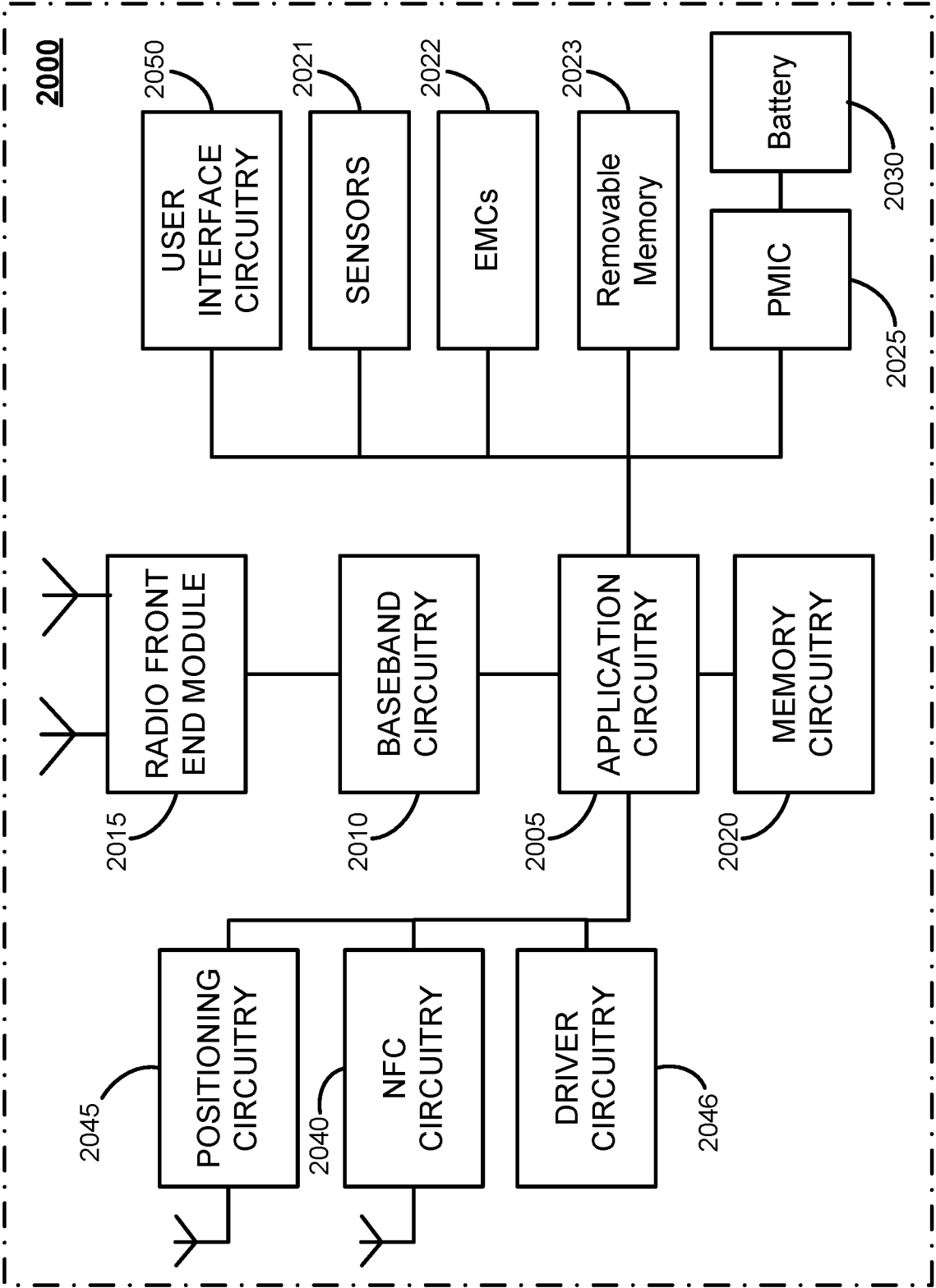


FIG. 20

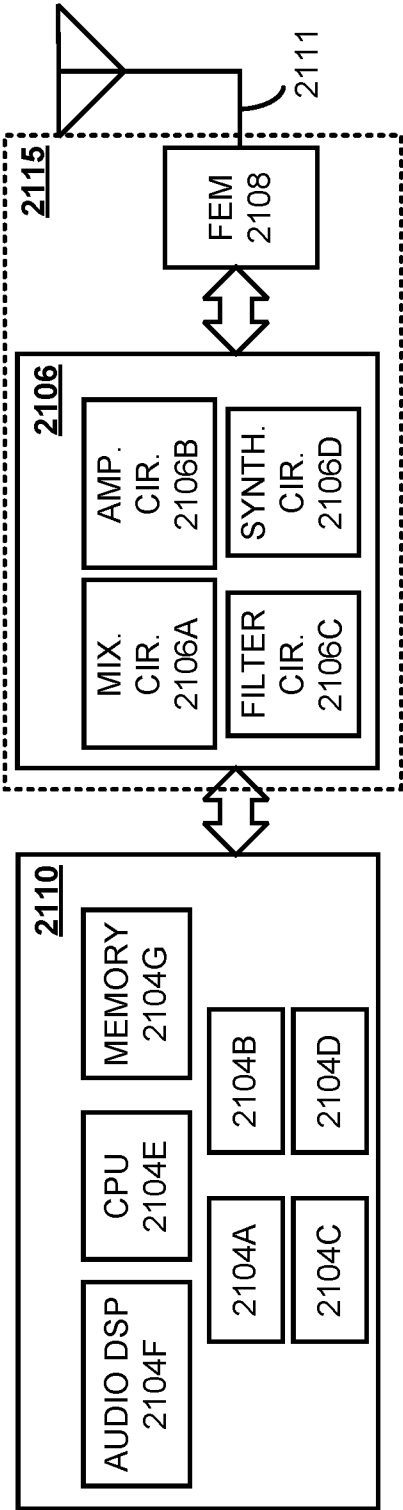


FIG. 21

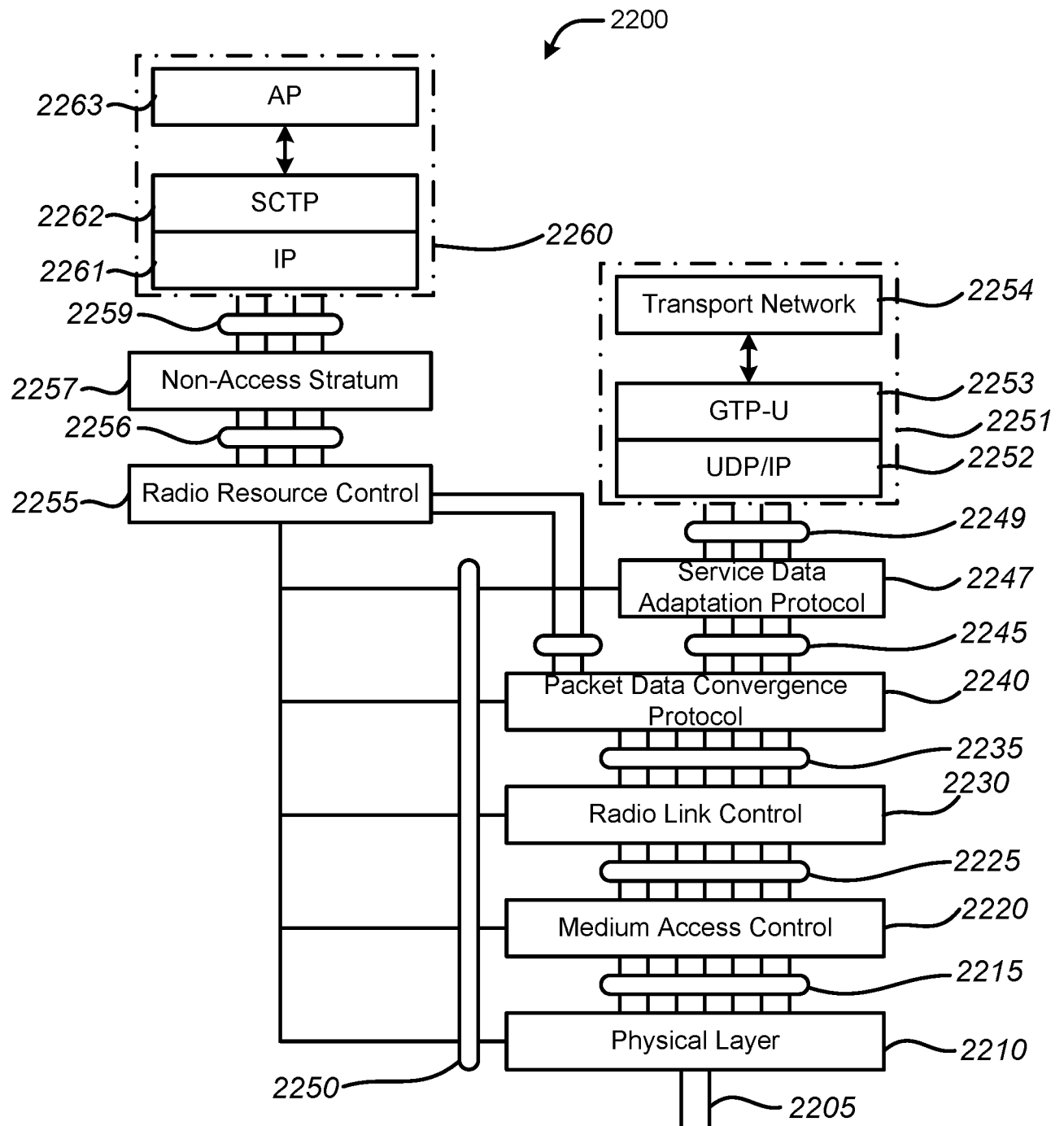


FIG. 22

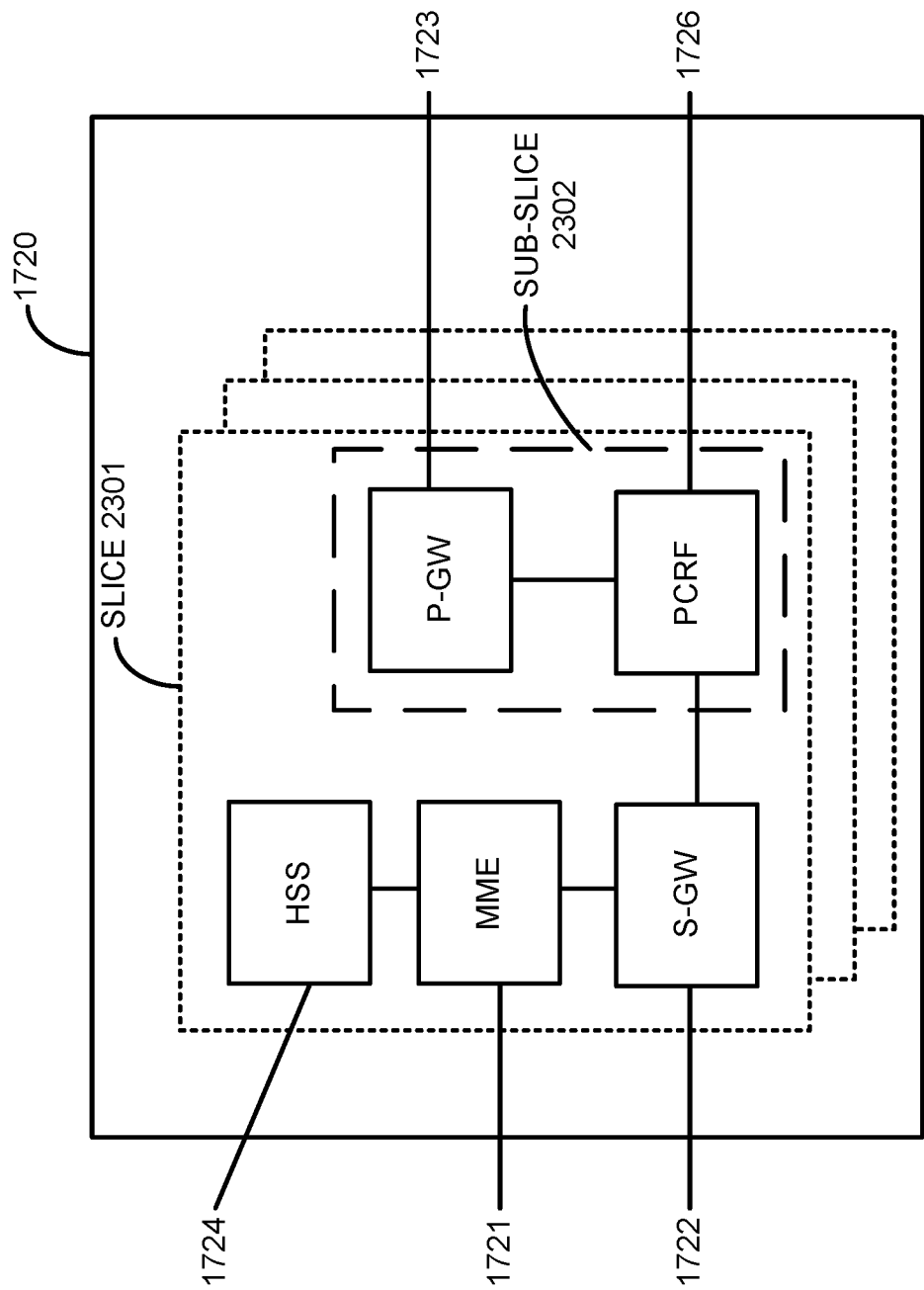


FIG. 23

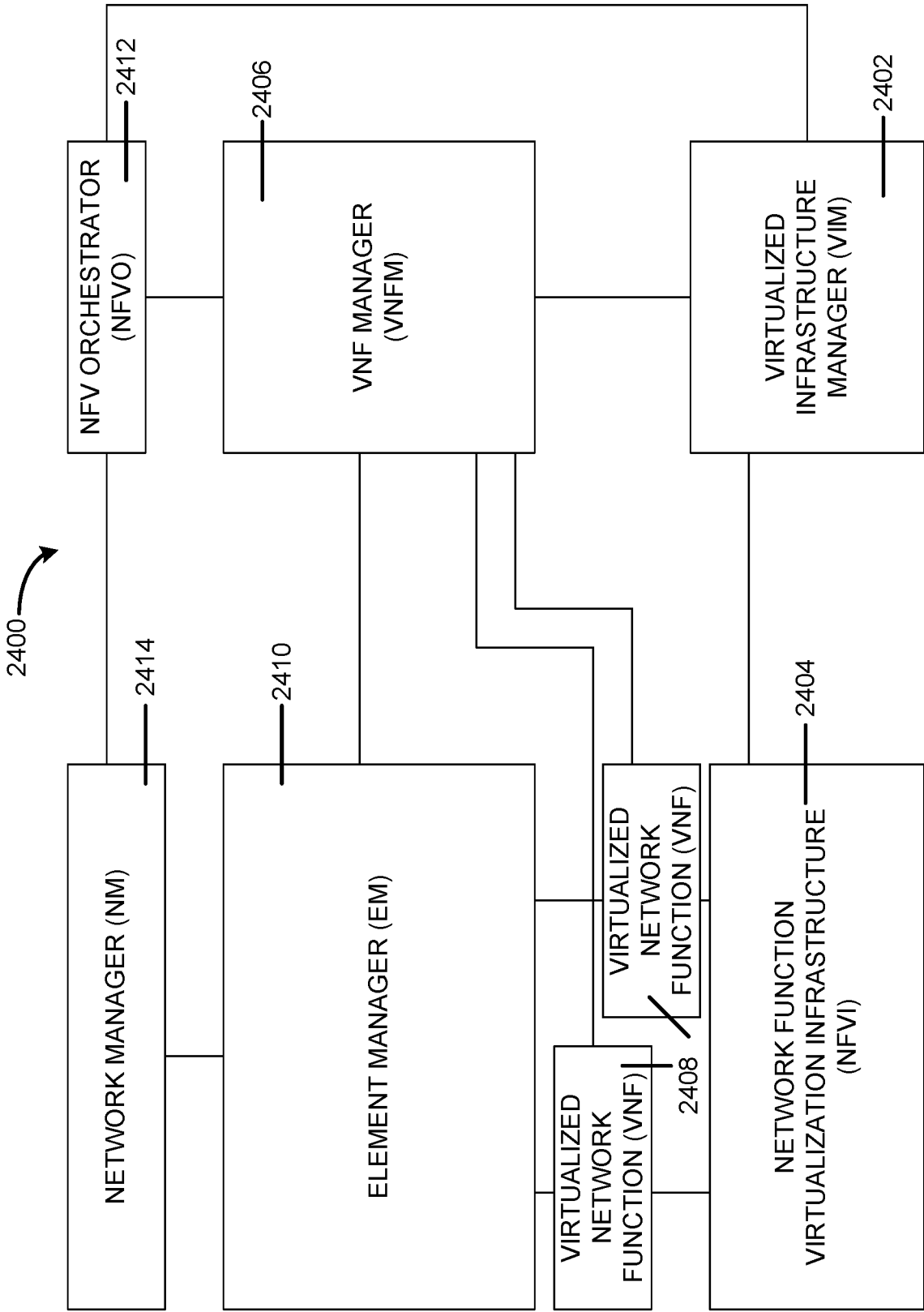


FIG. 24

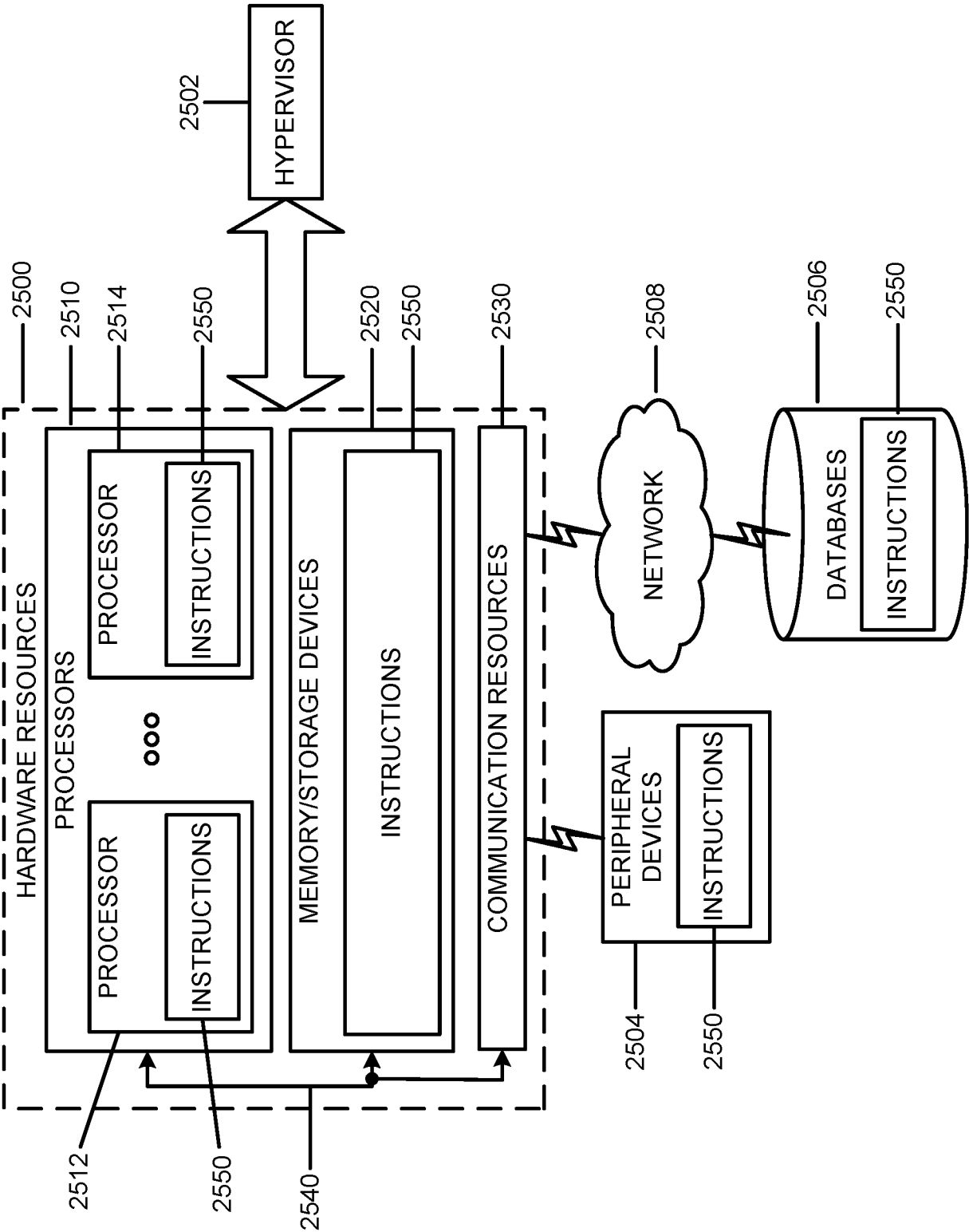


FIG. 25

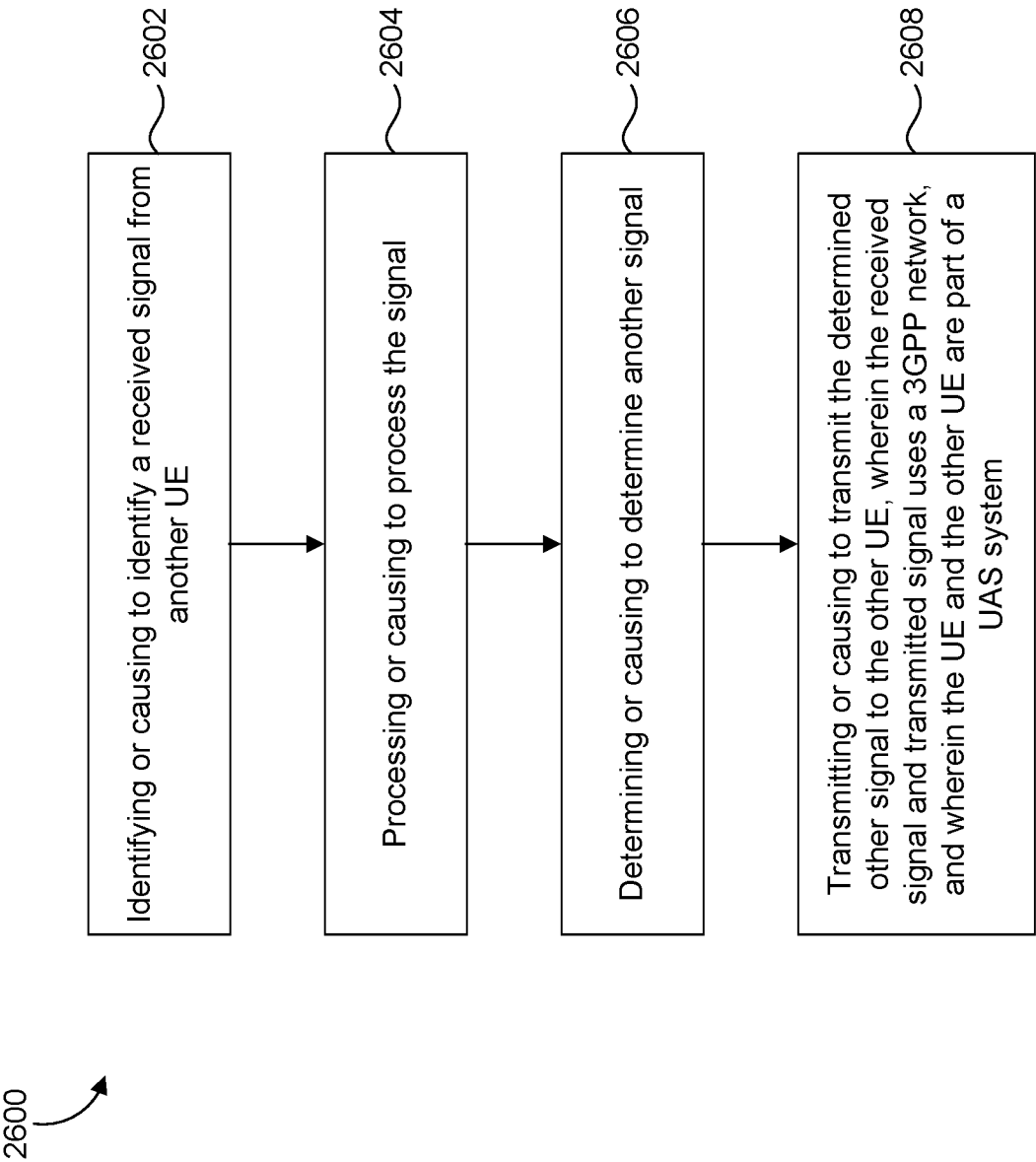


FIG. 26

2700

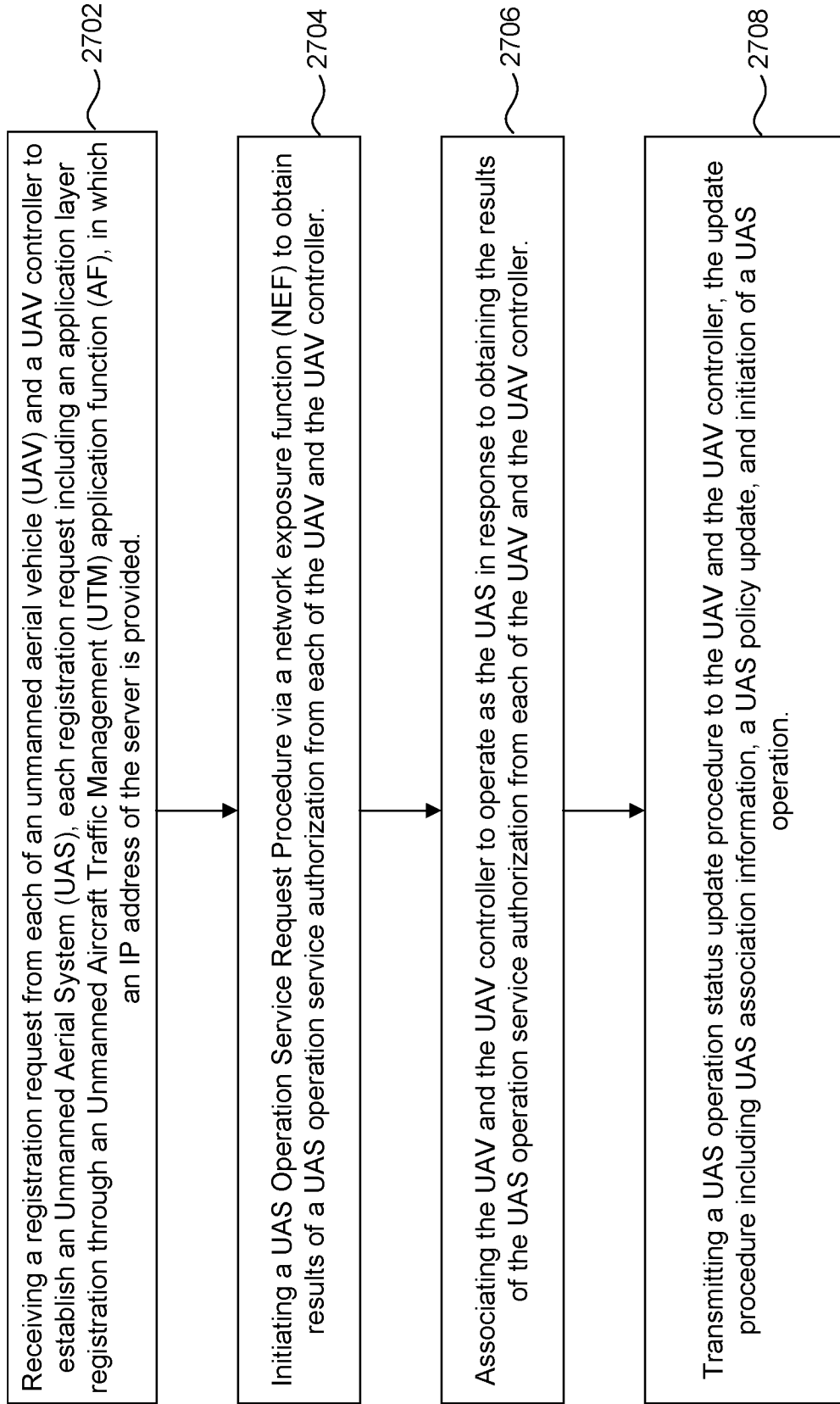


FIG. 27